REPORT

Study on the Feasibility of Epidemiological Studies on Health Effects of Mobile Telephone Base Stations – Final Report

Neubauer, G., Röösli, M., Feychting, M., Hamnerius, Y.,
Kheifets, L., Kuster, N., Ruiz, I., Schüz, J., Überbacher, R., Wiart, J.

Sponsored by
Swiss Research Foundation on Mobile Communication
Swiss Agency for the Environment, Forests and Landscape
Swiss Federal Office of Public Health

Workshop support by
EMF-NET

March 2005
Copy No. 1
ARC-IT—0124

seibersdorf research
Ein Unternehmen der Austrian Research Centers

List of distribution

Copy No. 1-2: Swiss Research Foundation on Mobile Communication
Copy No. 3-5: Swiss Federal Office of Public Health
Copy No. 6-7: Swiss Agency for the Environment, Forests and Landscape
Copy No. 8-9: EMF – NET
Copy No. 10: University Bern
Copy No. 11: Karolinska Institutet
Copy No. 12: University Mainz
Copy No. 13: ITIS
Copy No. 14: Chalmers University
Copy No. 15: France Telecom R&D
Copy No. 16: Prof. Kheifets
Copy No. 17: Neubauer
Copy No. 18: Lamedschwandner
Copy No. 19: Ruiz
Copy No. 20: Secretariat IT

ARC-IT-0124 March 2005

Study on the Feasibility of Epidemiological Studies on Health Effects of Mobile Telephone Base Stations – Final Report

FSM – Project No. A2003-9

Sponsored by
Swiss Research Foundation on Mobile Communication
Swiss Agency for the Environment, Forests and Landscape
Swiss Federal Office of Public Health

Workshop support by
EMF-NET

Neubauer, G.[1], Röösli, M.[2], Feychting, M.[3], Hamnerius, Y.[4], Kheifets, L.[5], Kuster, N.[6], Ruiz, I.[1], Schüz, J.[7], Überbacher, R.[1], Wiart, J.[8]

1) ARC Seibersdorf Research GmbH, Business Unit Mobile Communications Safety
2) University of Bern, Department of Social and Preventive Medicine, Switzerland
3) Karolinska Institutet, Institute of Environmental Medicine, Division of Epidemiology, Sweden
4) Chalmers University, Department of Electromagnetics, Sweden
5) 715 Gayley, Apt.315 Los Angeles, Ca 90025 USA
6) Foundation for Research on Information Technologies in Society, Switzerland
7) University of Mainz, Institute of Medical Biometry, Epidemiology and Informatics, Germany
8) France Telecom Division Research and Development, France

Authors:

Dr. Georg Neubauer
Business Unit Mobile Communications Safety, ARC Seibersdorf Research GmbH
A 2444 Seibersdorf , Austria

Dr. phil. Martin Röösli
Department of Social and Preventive Medicine, University of Bern
Finkenhubelweg 11
CH 3012, Bern, Switzerland

Dr. Maria Feychting
Institute of Environmental Medicine, Division of Epidemiology, Karolinska Institutet
Box 210
S 17177 Stockholm, Sweden

Prof. Dr. Yngve Hamnerius
Department of Electromagnetics, Chalmers University
Sven Hultins Gata, 2
S 41296 Göteborg, Sweden

Dr. Leeka Kheifets
715 Gayley, Apt.315 Los Angeles,
Ca 90025, USA

Prof. Dr. Niels Kuster
ITIS, Foundation for Research on Information Technologies in Society
Zeughausstrasse 43
CH 8004, Zurich, Switzerland

DI Ignacio Ruiz
Business Unit Mobile Communications Safety, ARC Seibersdorf Research GmbH
A 2444 Seibersdorf , Austria

Prof. Dr. Joachim Schüz
Institute of Medical Biometry, Epidemiology and Informatics, University of Mainz
Obere Zahlbacher Straße 69
D 55131 Mainz,
Deutschland

DI Richard Überbacher
Business Unit Mobile Communications Safety, ARC Seibersdorf Research GmbH
A 2444 Seibersdorf , Austria

Dr. Joe Wiart
France Telecom Division Research and Development
RESA/FACE/IOP
39-40 Issy les Moulineaux 92794, France

Content

1 Introduction

The introduction of mobile phones using the digital GSM 900 / DCS 1800 systems in the 1990s led to a wide use of this technology and subsequently to an increase in the environmental exposures to RF fields. Latest developments in mobile communications, e.g. UMTS, will intensify this process. Today more than 1.5 billion people are using mobile telephones world-wide, about 400 million people of them in Europe. The frequent use of mobile phones has necessitated an increased deployment of base stations. The number of base stations in a country depends on several factors including the number of network providers, the number of users and the topography. In Austria more than 18,000 GSM base stations are in operation, in Switzerland about 9,000, in Germany around 40,000. In France only 200 persons used GSM in 1992 but in 2004 there are now more than 40,000 base stations in operation. Base stations are often situated close to dwellings or houses and have become the focus of concerns of parts of the population in recent years. These concerns resulted in the demand for epidemiological studies on the potential health effects of the RF emissions of base stations. However, there exist several scientific problems, e.g. lack of validated and reliable exposure assessment methods.

The scientific community debated the usefulness of epidemiological studies to investigate health effects related to the RF fields from mobile base stations. Up to now only a few cross sectional surveys on possible effects of base stations have been performed. These surveys are not informative and sound large scale studies are lacking. The problems and shortcomings of epidemiological studies on base stations were discussed at some international workshops and conferences. Some claimed that base station epidemiological studies could not be done (e.g. Scientific comment from COST 281: Epidemiological studies on the health impact of mobile communication base stations). Several questions remained open, e.g. the adequate type of study design, the outcomes to be investigated, the adequate exposure metric and how to deal with the emissions from other RF sources.

The purpose of this international co-operative effort is to address the feasibility of future epidemiological studies on health effects or effects on well being from environmental RF sources by evaluating existing studies in this field and dosimetric concepts. Within this context, the contribution of bases stations as well as other sources of environmental RF exposures, e.g. from radio or TV transmitters, to a subject's total exposure has to be determined.

In the frame of this study dosimetric concepts used in studies already performed are presented and their strengths and shortcomings are analysed. In addition, existing data on the exposure next to base stations is analysed in respect of suitability for epidemiological studies. An overview on the specific problems arising while performing reliable exposure assessments next to base stations is given. Additionally, possible outcome measurements are evaluated with a focus on soft outcome measurements. Based on these analyses needs of future epidemiological studies are discussed and dosimetric concepts are developed.

2 Dosimetric approaches

This chapter is dedicated to give an overview on the methodologies applied in the past to assess RF exposure in the frame of epidemiological studies (chapters 2.4.1 to 2.4.3) and other RF exposure assessment campaigns and analyse their strengths and weaknesses, in particular in respect of their suitability for epidemiological studies. The methodologies are subdivided into residential exposure assessment concepts, occupational assessment concepts and concepts for mobile devices. Based on the available information the suitability of exposure metrics based on distance (chapter 2.4.5.1), on analytical calculations (chapter 2.4.5.2) and measurements (chapter 2.4.5.3) are analysed and requirements are derived.

Specific aspects of the in situ exposure assessment (under real life conditions) next to fixed RF transmitters, e.g. mobile communication base stations are analysed in chapter 2.1. The focus is set on field variations in time and space, meteorological parameters and the contributions from other sources. Finally an overview on existing assessment methodologies is given in chapter 2.2.

2.1 Specific aspects of the field distribution in the environment of base stations

The determination of the exposure next to mobile communication base stations under real life conditions needs to consider several aspects. The RF field distribution depends on several environmental factors, field levels are varying in space and time. Multipath propagation and fading effects lead to scenarios that are often not easy to reproduce leading to large uncertainty budgets. Considerable variations of the field levels in the GSM 900, DCS 1800, UMTS, Broadcasting and FM frequency range were found in restricted areas, e.g. the relation between the maximum field level and the average field level within one cubic meter was found to be typically between 2 and 5, the ratio between the maximum and minimum being much larger. One approach to describe exposure scenarios is to use laws of field distribution, e.g. Rayleigh, LogNormal, Rice. Within the examined areas it was not possible to find clear relations between field scenarios defined by distance, LOS or NLOS conditions (Line Of Sight, Non Line of Sight) and Indoor versus Outdoor conditions.

Preliminary results indicate that the meteorological conditions on the ground like water or snow may have an important impact on the propagation of reflected waves.

2.1.1 Variations in space

2.1.1.1 Introduction

The spatial variation of the field strength (fading), can be divided in two different types. The distinction is conditionally made by the cause of its origin (*Parsons, 2000)*, *Pätzold, 1999*) in *large-scale fading (also: long-term fading, shadowing*) and *small-scale fading (also: short-term fading, fast fading).*

Large scale fading is a phenomenon that happens in the range over 10 wavelengths of the propagating wave; whereas under 10 wavelengths we speak from small scale fading.

At first the field strength sways very quickly around the local mean average value. When the fluctuations happen within a wavelength the phenomenon is called *small scale fading*; and it is provoked by interference between the propagation waves, that arrive through different paths to the receiver.

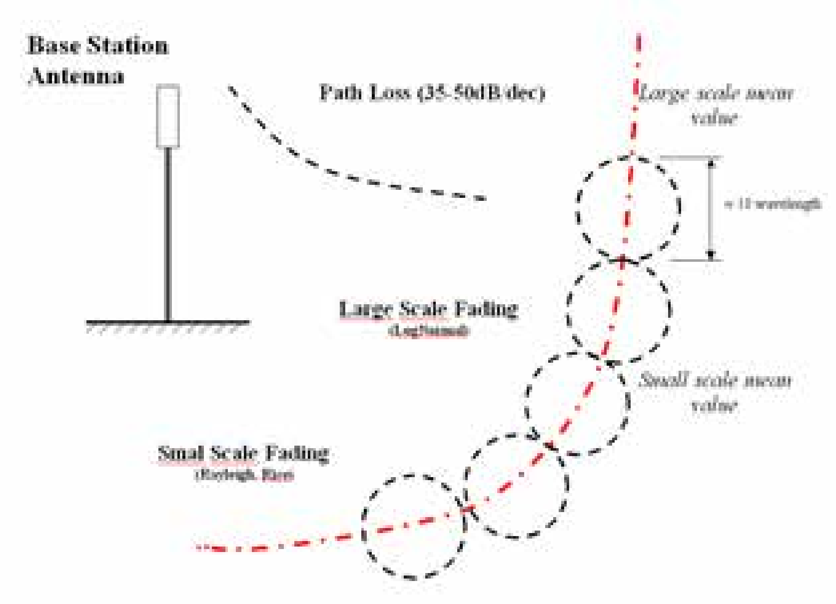


Figure 1: Different types of Fading (*Bonek und Molisch (2000)*)

If we obtain the mean average value over more than 10 wavelengths, it oscillates around a global mean average value. Shadowing effects are the reason for these fluctuations. If all these fluctuations are averaged by statistic methods, the received field strength will also be decreased monotonously with the distance to the base station. This is the case of *large scale fading*.

The large and small scale fading effects usually are described with statistical methods, which are explained in detail in the Annex.

2.1.1.2 Measurements on real sites

In the literature we can find a variety of different examples for measurements on sites with different exposure situations from base stations.
The comparison and the classification is due to different measurement concepts quiet difficult. As an example of different exposure situations we describe three typical situations, measured on the area on Seibersdorf. The examples demonstrate that it was not possible to define classes according to scenarios so far.

Example for no line of sight (NLOS)

As example for an exposure situation for NLOS, the following situation is presented. Given is a closed room without any windows, as depicted in Figure 2 and Figure 3, and at a distance within 100-150 meters from the GSM900 base station located on the roof top.

Figure 2: The room TOX7 (ARC Research-Austria)

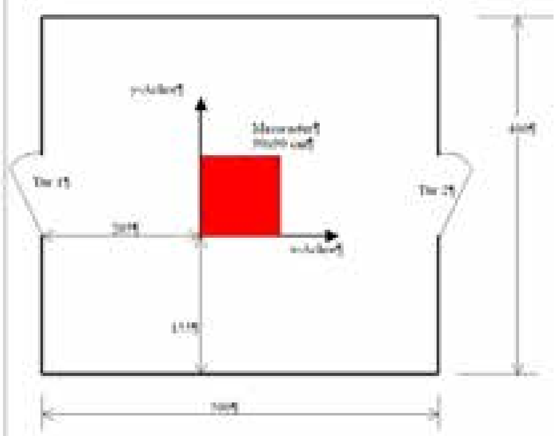


Figure 3: Measures of the room [cm]

The dimension of the side length of the examined field cube was 0.9 m with a grid of 0.15 m. The antenna used for the measurement was the PCD 8250 (ARC-Research) using the isotropic measurement procedure (ADD3d).

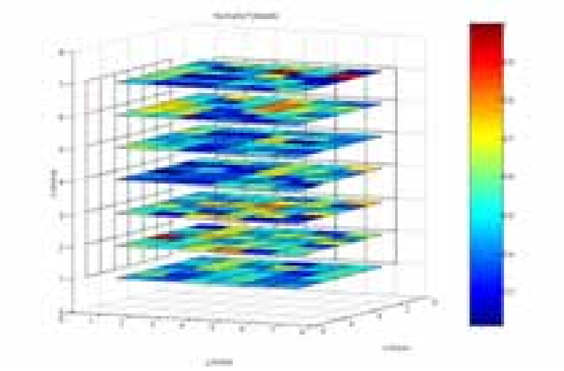


Figure 4: Field cube with normalized values

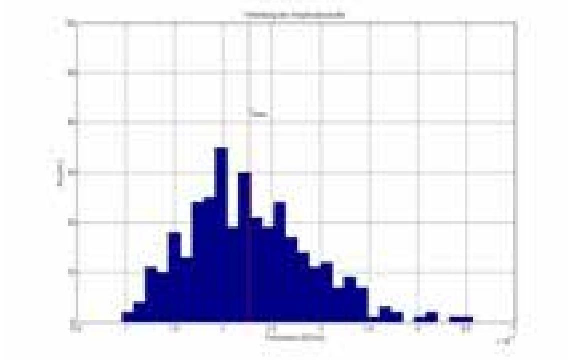


Figure 5: Discrete amplitude distribution of the field values (PDF)

Figure 5 fits good with an expected Rayleigh distribution, as discussed in chapter 7.2.1.2., the slower decreasing right part of the bell-shaped curve is typical.

Example for line of sight (LOS)

An example for typical line of sight is the room CC2-17 in Seibersdorf, as in Figure 6. It consists of a room with 4 windows and a door, as shown in Figure 7.

Figure 6: Room cc2-17 (Seibersdorf)

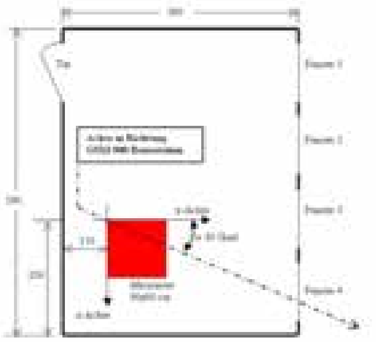


Figure 7: Room cc2-17, dimensions in cm

The field distribution in the measured cube with a side length of 90 cm length and a grid of 15 cm is shown in Figure 8.

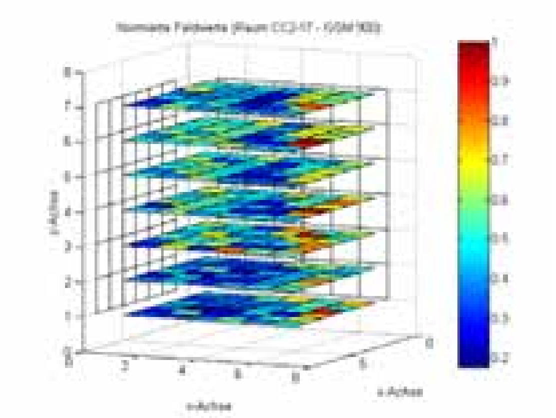


Figure 8: Field values

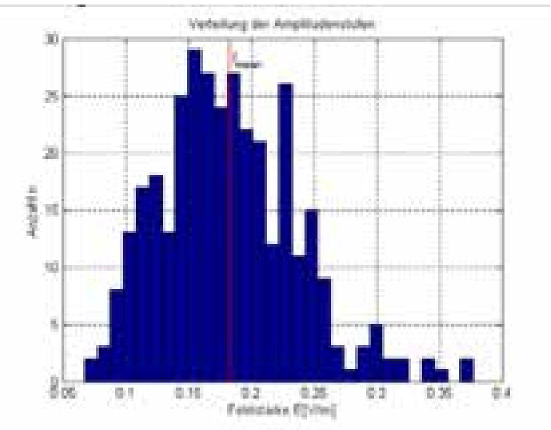


Figure 9: Discrete amplitude distribution

Figure 9 shows the discrete amplitude distribution. The theory predicts a Ricean distribution for direct line of sight, which can be applied to describe Figure 8. We see that the dominant path is not so clear to distinguish as in the theory. An important question is also the sample volume over we made the measurement: in our case it was a volume of a side length of around 3 wavelengths and 343 points because of the limited time for the whole measurements.

Example for mixed distributions

In the two previous examples we have found a description through elementary distributions. To bring an example that it is not always possible to find these distributions, we show the situation of Figure 10 and Figure 11.

Figure 10: The base station N751 (GSM900) on the rooftop

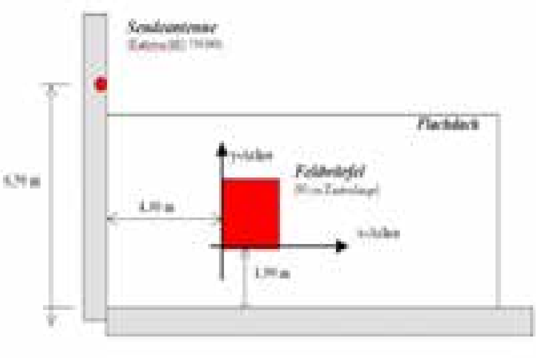


Figure 11: Dimensions of the rooftop [cm]

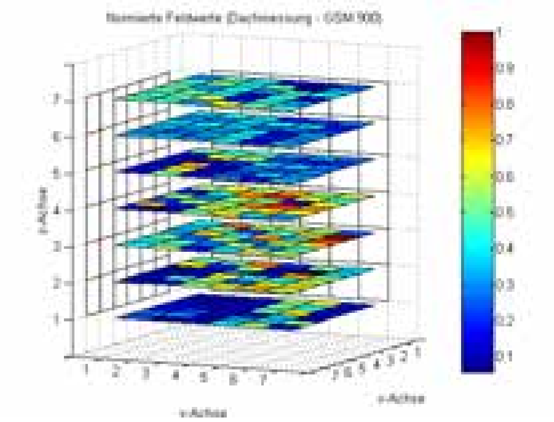


Figure 12: Field distribution in the measured cube

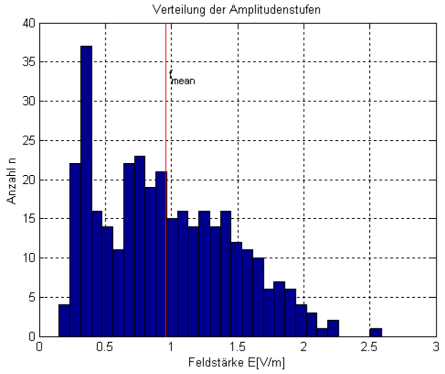


Figure 13: Amplitude distribution

Figure 12 shows the field normalized distribution over the measured cube. In Figure 13 we have now the situation that we don’t have only one single distribution, but it seems that we have 2 overlapping distributions.

To understand this phenomenon numerical simulations are very helpful. With a simplified model of the exposure situation and using field theoretical FDTD simulation tool the test shown in Figure 14 was done.

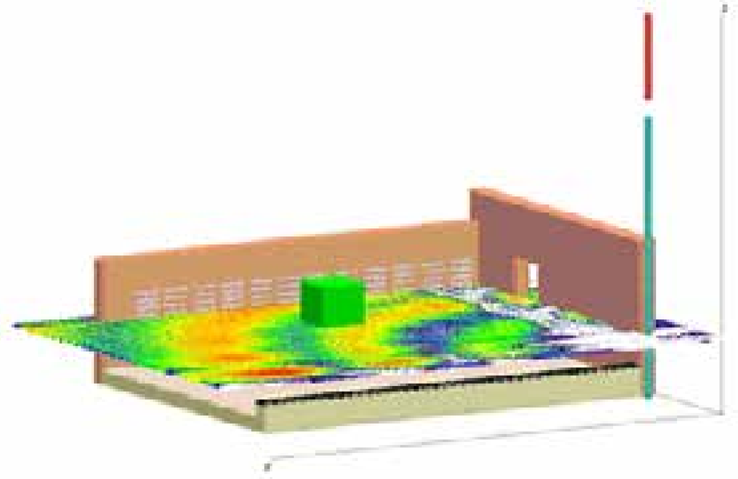


Figure 14: FDTD model for the simulation with field strength values for z=90 cm high

In the simulation it is easy to manipulate the geometries, being impossible under normal conditions. In the second simulation we have removed the roof (Figure 15, right).

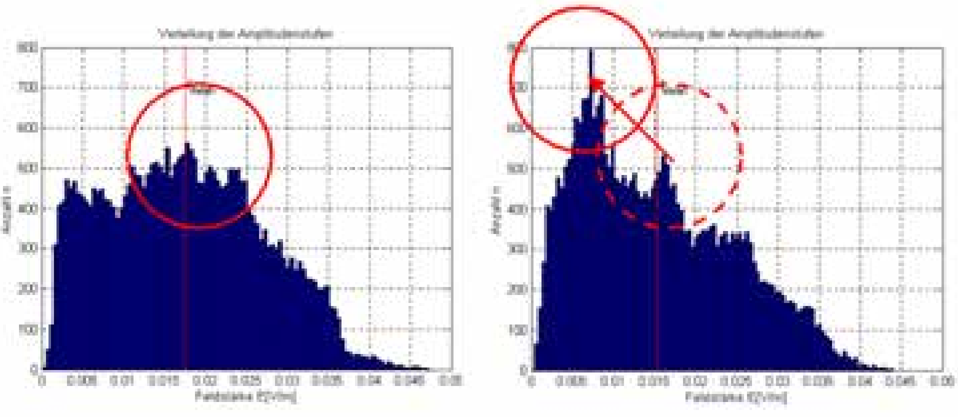


Figure 15: Moving of the amplitudes in the case of a removed roof top (right figure)

What we can see in these figures is the effect of the removed reflections that depend on the roof: the distribution in the left side has two big dominant peaks; without the roof and the reflections in the right figure we can describe all with a single distribution.

Because of fading variations, the measurement of the electric field in one point does not allow a repeatable exposure assessment (leads to very large uncertainty budgets). Therefore a few measurement points and an averaging scheme are of interest for in situ measurements. We cannot predict in practice the type of small-scale fading in function of the environment where the measurements are performed. It is therefore of interest to analyze the relation between the number of independent points and the mean uncertainty associated to the estimation of the average exposure. This analysis has been done by *Larcheveque et al. 2005*, the Figure 16 shows the respective results.

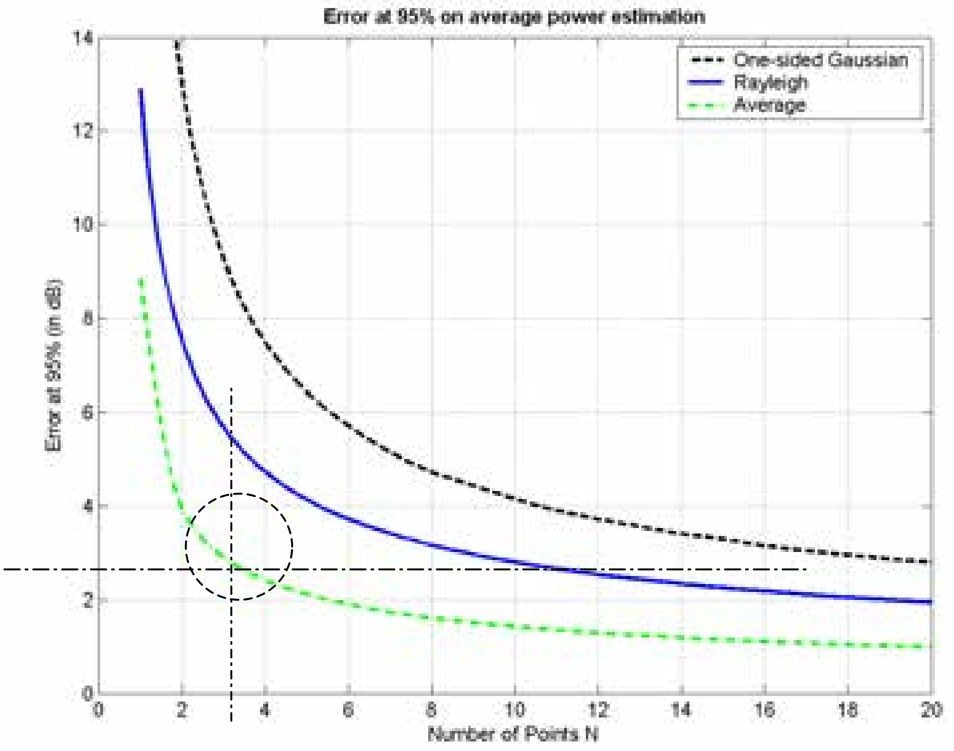


Figure 16: Error reduction due to averaging procedures for in situ measurements (Larcheveque et al. 2005)

2.1.2 Variation in time

The variation in time is a well investigated phenomenon, e.g. Figure 17. For the data transfer in mobile communications it is very important to have a reliable channel model in the time domain to estimate for example the bit error ratio in transmitted data.

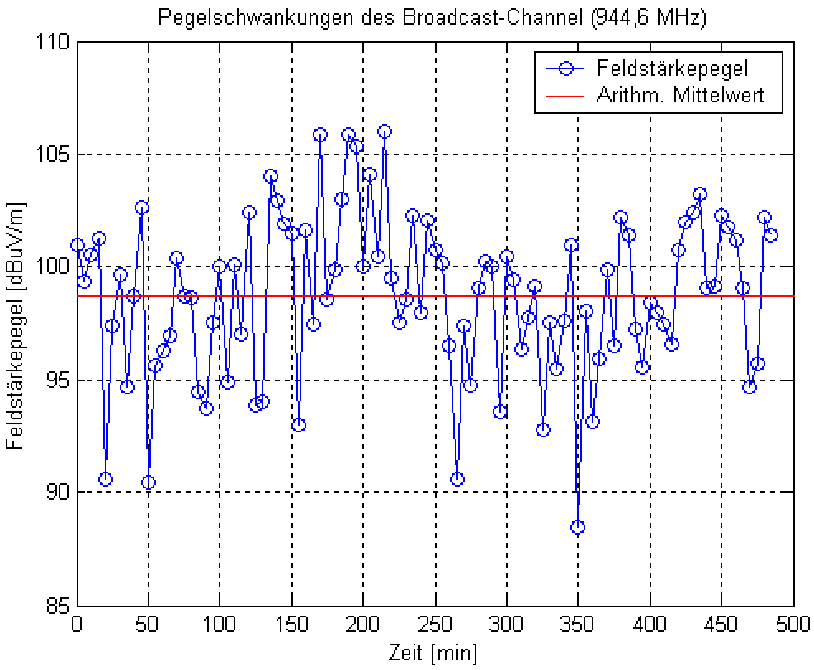


Figure 17: Changes of the signal level from the investigated BCCH from a GSM 900 Base Station, measured on 25.03.2002 in room CC2-17 in Seibersdorf.

In the Figure 17 the variation of a GSM signal along 8 hours is shown. The values changed between 88 dBμV/m and 106 dBμV/m, about 20 dB.

While in the short range from millisecond to second good models exist for the prediction, for longer terms in the range from hours and more, it is not any more possible to find describing models. Moving objects like trees moved through the wind, persons walking or cars moving can provoke under and overestimation of the field as a highly time variant object, leading in practice to new boundary conditions every moment.

Figure 18 shows a setup to investigate the time dependence of a mobile channel with a constant power (BCCH) from a GSM 900 base station operating at the frequency f = 946,6 MHz. The measurements were performed over a period of 1 week.

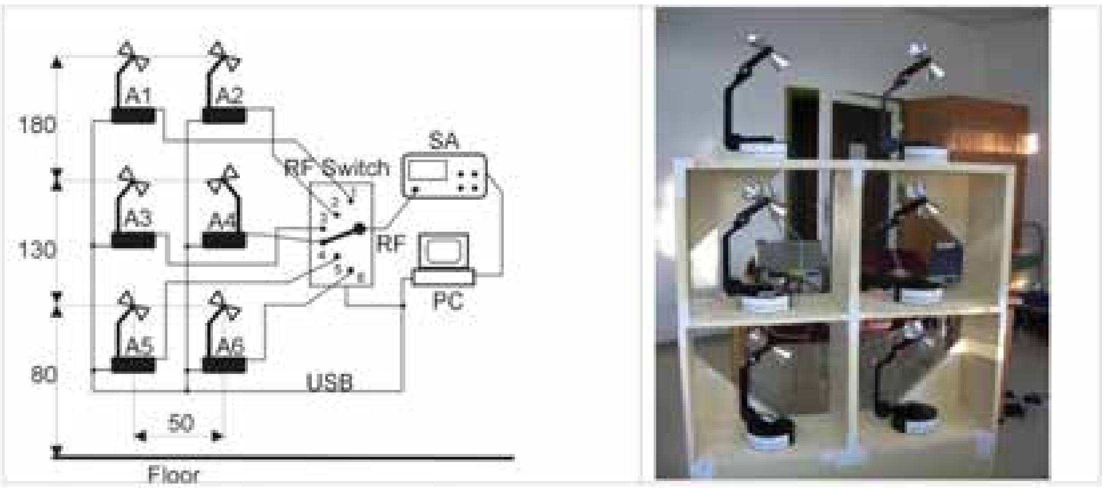


Figure 18: Schematic view from the measurement setup and picture from the realized

Transmitting and receiving antennas during the measurement period where fixed, the receiving antennas were in a closed room to avoid disturbance by walking persons in the near.

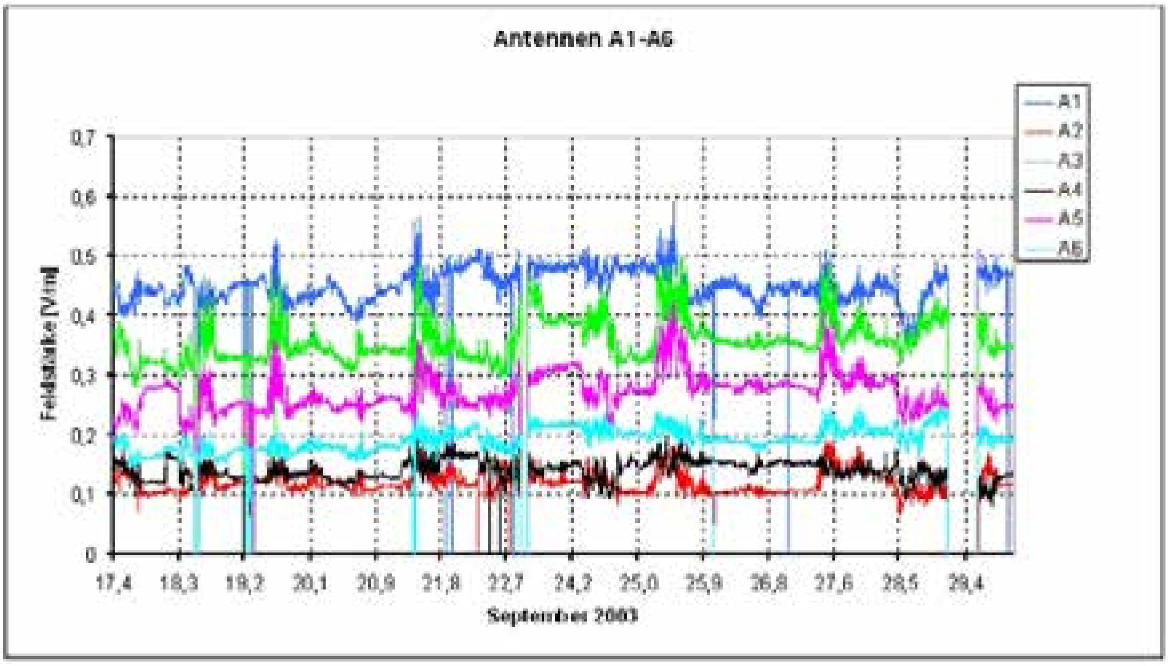


Figure 19: Variation in time from a BCCH from a GSM 900 base station (measurement cycle: 4.5 min, transmitted with constant power)

The short peaks with a field value of 0 V/m in Figure 19 are from short interruptions for maintenance of the measurement set-up. The variations of the received signal demonstrate very well the changes of the channel versus time mainly caused by moving objects, e.g. persons, cars, trees and changing meteorological conditions, e.g. rain or wet versus dry ground.

2.1.3 Meteorological parameters

Research about the impact of meteorological conditions on electromagnetic wave propagation has been carried out for a long time for *radar signals* and for higher frequencies but very little is known about the impact of meteorological conditions in the frequency range of mobile communication.

Figure 20: Measurement setup (*Olsson, 2004*)

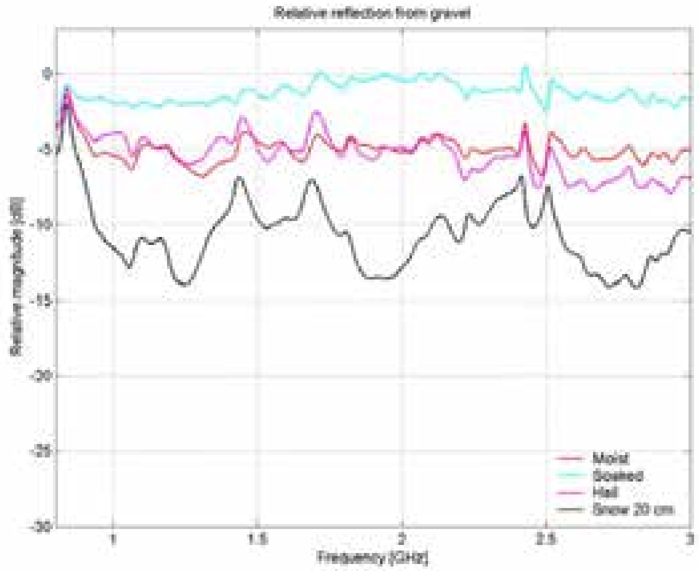
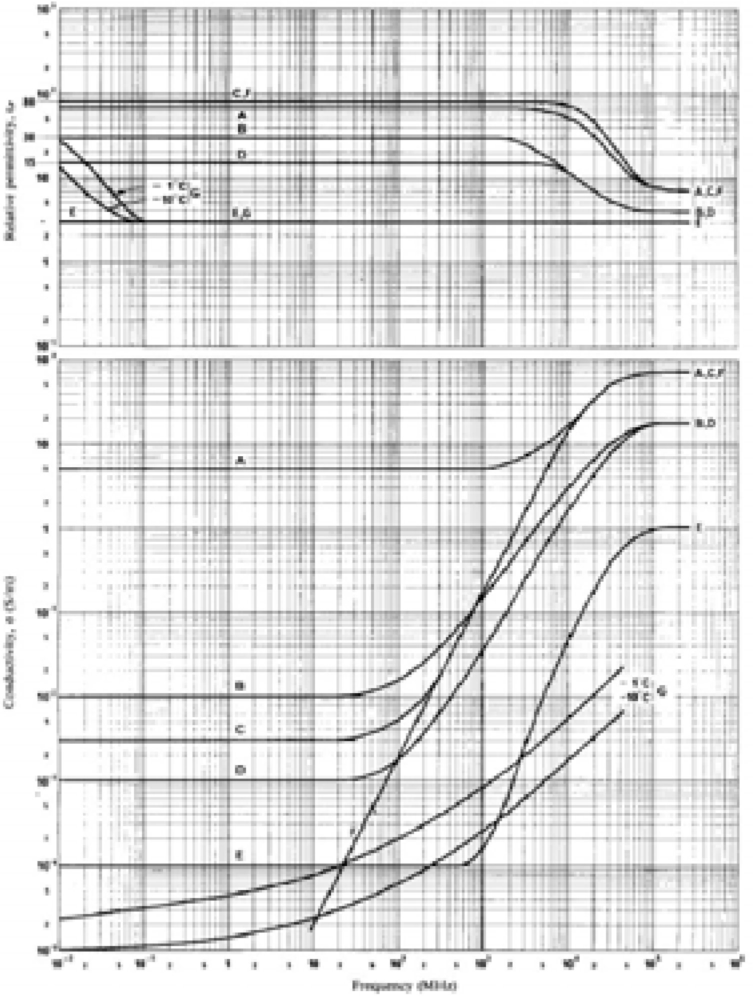


Figure 21: Example for a result for ground reflection (*Olsson, 2004*)

It is known that the electromagnetic field strength measured in the vicinity of base stations varies versus time, on reason for this effect are moving objects. However, other factors have to be considered, too.

One possible additional explanation is the changes in the field distribution arising due to different meteorological conditions. Meteorological impact on mobile communication has always been considered negligible and therefore not examined as careful as for higher frequency systems like radar and satellite communication where meteorological conditions have a large impact on the transmission (see Figure 21).

It is important to know how the transmission might change due to meteorological parameters to assess the electromagnetic exposure on humans due to mobile communication (see Figure 22).



A: Sea water (average salinity), 20 °C
B: Wet ground
C: Fresh water, 20 °C
D: Medium dry ground
E: Very dry ground
F: Pure water, 20 °C
G: Ice (fresh water, and seawater over 30 MHz

Figure 22: Relative permittivity and conductivity as a function of frequency (*ITUR, 2001*)

Results indicate that the impact of humidity and temperature on the field propagation in the frequency range of interest can be neglected (Figure 22). However, humidity, temperature and rain/snow coverage may affect the cables and antennas, and in that way change the transmission. The reflection from the ground and buildings varies considerably, depending on the meteorological conditions. Due to multi-path propagation there might be an impact on mobile communication transmission conditions; further investigations on this topic are urgently needed.

2.1.4 Contributions from other sources

A general problem of several exposure assessment approaches dedicated to determine the contribution from specific sources, e.g. a GSM base station, is the emissions from other RF sources. Looking at typical exposure scenarios being representative for the general population it is not a priori a correct approach to neglect contributions from other RF sources. Several investigations have shown that the contribution from an investigated RF source are quite often dominant, however this is not always the case and depends strongly on the selected location of the examination. *Bornkessel and Schubert, 2004* or *BAKOM, 2002* demonstrate very well that the contributions from other GSM stations can often be relevant and in some cases even dominant. Not only the exposure due to other base stations, but also of other fixed installed RF transmitters, e.g. broadcast or radar stations can lead to relevant contributions to the overall exposure (*Uddmar, 2002*, *Garn et al. 1998*, *Neubauer et al. 1998 and 1999*). A specific problem is the often temporary contributions from mobile sources, e.g. mobile phones.

Several epidemiological studies performed in the past used distance as a surrogate for the exposure. Apart from the limitations of such procedures in describing the exposure from the source under investigation in a reliable way, the contributions from other sources are usually no considered at all. This can lead to a considerable exposure misclassification. Procedures based on the use of broadband measurements equipment are suitable for epidemiological studies if one source is dominant or if other reliable procedures as analytical calculations are applied that make it possible to distinguish between the contributions from different sources. Analytical calculations or the use of crude surrogates like the distance to stations alone seems not be suitable to take the complex field distributions on one hand and the contribution from different sources on the other into account.

Reliable assessment procedures have to be able to distinguish between the contributions from different RF sources and in addition be able to estimate individual's exposure. Possible dosimetric approaches are the use frequency selective monitoring equipment to assess variations versus time and frequency selective equipment like dosimeters to assess individual's exposure.

2.2 Available methods and equipment

2.2.1 Numerical methods

The numerical methods can be divided in two main different types based on the used physical wave propagation model:

- Field theoretical methods (solving Maxwell's equations):
  - Finite elements (FEM)
  - Finite differences in time domain (FDTD)
  - Method of moments (MOM)
  - Finite integrals (FID)
  - Boundary element method (BEM)
  - Transmission line method (TLM)

- Optical methods (GTD/UTD):
  - Ray launching
  - Ray tracing

The big difference between optical based methods and field theoretical methods next to the physical background is the different requirement to the computer hardware.

Optical methods are used for scenarios where field theoretical methods are limited because of their computer requirements.

In the literature we can find also hybrid methods. These hybrid methods are a combination between field theoretical methods and optical methods and have the advantage to consume lower computer resources. For the investigation of small areas field theoretical methods are often used, e.g. FDTD, and for large areas optical method like ray tracing are often applied.

Actually on the market is a very big amount of different tools for simulating electromagnetic field distributions under different conditions. A good overview with over 200 products and a short description can be found on the internet address: http://www.emclab.umr.edu/csoft.html.

2.2.1.1 Field theoretical based methods

The calculation of electromagnetic fields in an analytic way is only possible in a reliable way for very simple geometries. Therefore, for more complicated scenarios the use of field theoretical methods in the discrete field room is recommended. The field room is subdivided in cells (e.g. the Yee cell in FDTD) and based on this, the mathematical Methods established are described in the next chapter.

All the field theoretical methods have in common, that for complex field problems because of the complex geometries in the field space, the resulting necessary discretisation requires lot of memory on the hardware (see Figure 23).

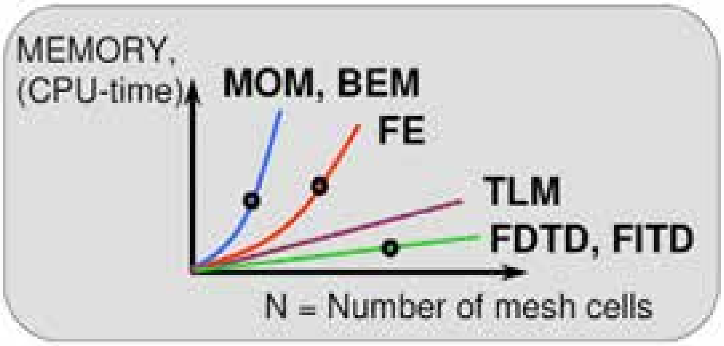


Figure 23: Requests to the computer hardware (source: www.cst.de)

Field theoretical methods are perfectly suitable for the calculation of complex heterogeneous structures (e.g. absorption ratio for the human body). The dimension of the calculated area is limited because of the required memory request.

A further subdivision of the field theoretical models can be made in explicit and implicit methods:

implicit algorithm:

$$\underline{A} \cdot \vec{x} = \vec{b} \tag{2.2.1}$$

with the solution

$$\vec{x} = \underline{A}^{-1} \cdot \vec{b} = \frac{\underline{A}^{\mathrm{adj}}}{\mathrm{Det}(\underline{A})} \cdot \vec{b} \tag{2.2.2}$$

explicit algorithm:

$$\vec{x}^{\,n+1} = \underline{M} \cdot \vec{x}^{\,n} \tag{2.2.3}$$

The big advantage from the explicit algorithm is, as shown in Figure 24, that there is no requirement to invert the matrix for the solution of the unknown.

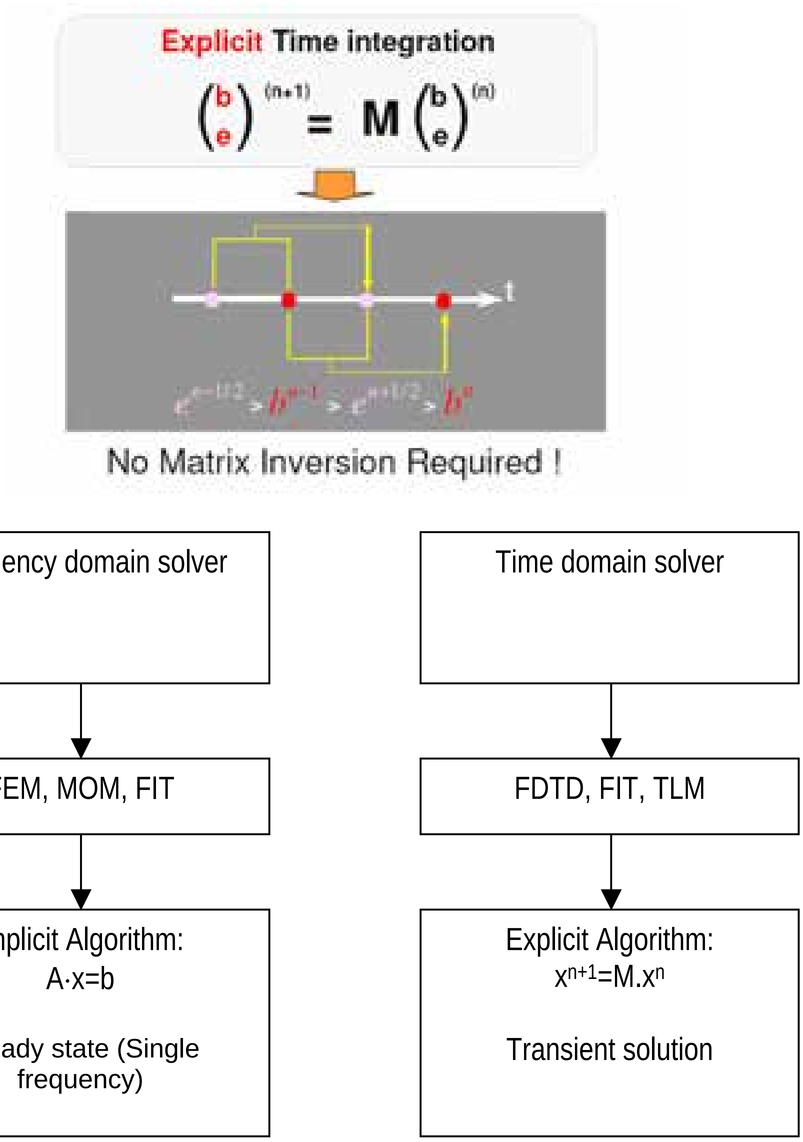


Figure 24: Comparison of simulation methods (source: www.cst.de)

The further discussion of the field theoretical methods exceeds the scope of this report, and we refer to the appropriate literature.

2.2.1.2 Optical based methods (GTD/UTD)

(Generalized Theory of Diffraction/Unified Theory of Diffraction)

Optical based methods are very important for the estimation of electromagnetic field distributions in the environment of base stations. In situations, where due the large dimensions of the field rooms and the resulting requirements to the computer hardware it is not anymore possible to use field theoretical methods like MoM, FEM or FDTD.

The physical background for the optical method is for the reflections and the refractions Fresnel's formula and for the geometric diffraction the geometrical theory of diffraction (GTD) and the unified theory of diffraction (UTD). The GTD/UTD model assumes that all existing waves are planar waves.
Also is presupposed that all objects are in the far field, and that all dimensions of the geometries are greater than 1 or 2 wavelengths. This theory does not consider any electric currents, so that the calculation of impedances is not possible.

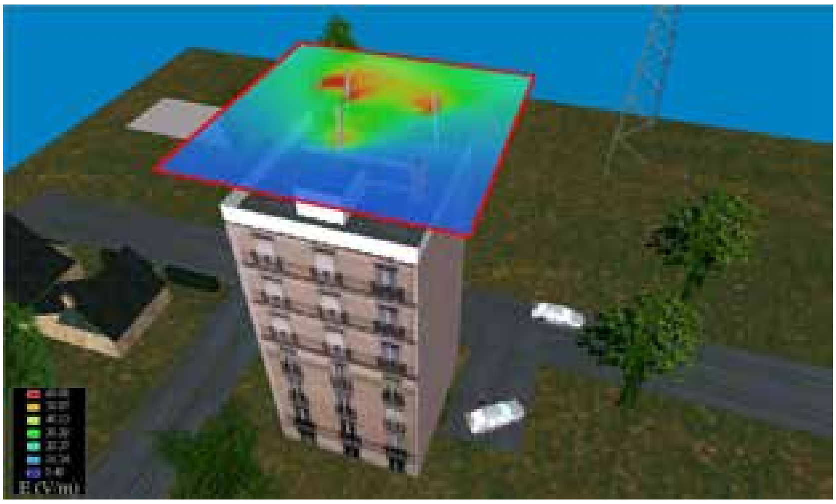


Figure 25: GSM base station on the roof top of a building (EMV Visual 1.2, ANTENNESSA France)

The advantage from the GTD/UTD method is that there are practically no limitations considering the dimension of the object and no dependence of the simulation duration from the frequency, like for example with FDD methods.
The main application for optical methods is the calculation of large scale field distributions like e.g. the planning of mobile radio networks.

2.2.1.3 Hybrid methods

In the literature one can find hybrid simulation techniques (*Rousseau et al.,1995*, *Lautru et al., 2000*, *Mochizuki et al. 2003*, *Bernardi et al., 2002*). Field theoretical methods where combined with each other or with optical methods (GTD/UTD) like MOM with GTD/UTD, FDTD with MOM and FDTD with GTD/UTD. The concept is shown in Figure 26.

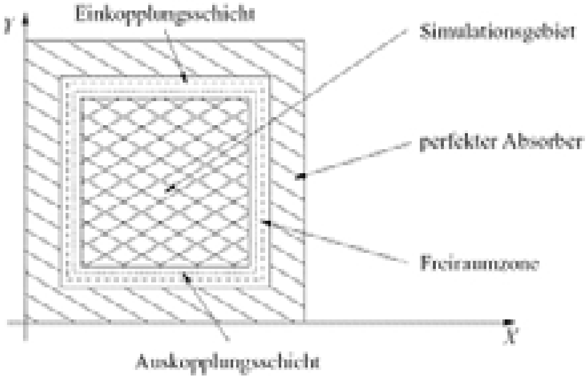


Figure 26: Inner and outer layer for coupling hybrid methods

The main principle is based on the idea that the large scale area is simulated with optical methods, and specific areas like the human body area are simulated using field theoretical based methods.

A commercially modular software package that combines FDTD with optical methods is available from Remcom Inc (http://www.remcom.com). It consists of the FDTD program *XFDTD* and the GTD/UTD based program *Wireless InSite*.
In the smaller region of interest the field distributions from antennas can be simulated using as example the FDTD tool (in Figure 27 depicted as the green cube) and the solution can be imported in the optical

tool *Wireless InSite*. There the radiated field pattern is used as a source of waves and by applying the GTD/UTD theory used to calculate the wave propagation for larger areas.

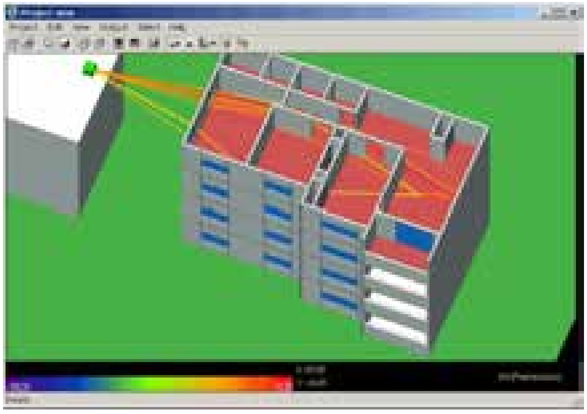


Figure 27: Propagation paths in a building; GSM 900 base station antenna on the opposite roof

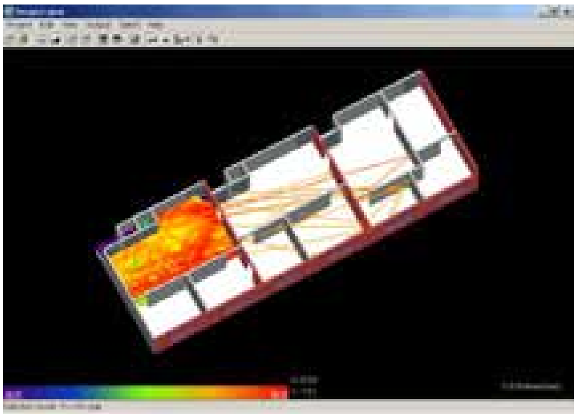


Figure 28: Wireless InSite (Remcom Inc); simulated indoor field distribution

The applied wave propagation model can be chosen from a list with 9 different wave propagation situations (Figure 28). The models can be adapted to different wave propagation scenarios like e.g. urban canyon or hilly terrain, and can be distinguished in respect of the precision of the results and the time needed for calculation. The most expensive model for the computation is the *full3d* solver that fits the field theoretical based methods.
The program takes into account reflections, transmissions, refractions and diffractions.

Another example for hybrid tool is FEKO matching MOM and GTD/UTD (www.feko.info).

2.2.2 Measurement Methods

2.2.2.1 Spot measurements

Measurements of radio frequency electromagnetic fields can be basically performed in two ways: broadband and frequency selective. The principal difference between both is that in the frame of broadband measurements the total contribution over a large frequency range is obtained without distinction of the contribution of different sources operating at different frequencies, which is actually obtained using frequency selective devices because they allow distinguishing between the specific contributions in the different frequency ranges. Broadband measurements are performed with probes and hand-held measuring instruments, while for frequency selective measurements spectrum analysers attached to antennas are used.
Owing to their sensitivity, the broadband devices are often used for compliance assessment. With a typical sensitivity of around 0.2 V/m such measurements can be carried out with enough accuracy. Spectrum analysers can detect signals being at least 8 to 10 orders of magnitude lower as the limits specified in the guidelines, standards or other documents. Spectrum analysers are well suited for detailed frequency selective measurements.

Location of the measurements

The location of a measurement must be selected in a way that the distance between the detector and any object is sufficient to avoid any impact on the antenna impedance and pattern. Field distortion due to the measuring engineer should also be avoided. The measurement location should always be selected in a way that it corresponds to a representative exposure scenario.

According to the draft standard EN 50400 field calculations and measurements can be used in the radiating near and far field to estimate the E and H-field or power density. In the reactive near-field, it is recommended to use specific absorption rate measurements. Following the GSM Measurement Recommendation from BUWAL, the location of the measurements should be done at a height between 50 and 175 cm above the floor (the EN 50400 states three heights, 110, 150 and 170 cm) with the antennas located 50 cm away from walls, ceilings, or furniture. In respect of broadband measures, the field will be assessed with accuracy if just the BCCH is active, but if one or more TCH (speech channels) are active the field strength will be overestimated.

Broadband measurements

For broadband measurements a probe, usually isotropic, and a field meter are used. The probe consists of a short-electric dipole (or loops) that detect the field. The corresponding current flows through a conductor wire (with high resistance) to the field meter. Probes can be distinguished whether they are only able to measure the fields in one direction or they are isotropic and measure the field components in the three orthogonal directions in space and calculate the magnitude of the resultant field strength, and thus facilitating the assessment procedure. On the field meter, the value obtained is shown as effective or peak value.

Figure 29: Portable device for broadband measurements composed of a probe and a field meter (MonIT, Portugal).

Obtaining a result is easy, convenient, and fast. However, minimum qualifications are needed to avoid false handling and subsequently false results. Due to the isotropic characteristic of the field probe, the unknown direction of the maximum field component and the polarization are typically not relevant. In such cases, the reading corresponds to the squared sum of the field components (*Haider et al., 2002*).

It is important to note that a typical broadband field probe is not designed to distinguish between emissions of different frequencies such as radio and TV broadcast stations, GSM mobile phones, or a base station. Therefore, the field probe provides no information as to whether the meter reading corresponds to e.g. base station's emissions or to some other signal within the probe's measurement range. In fact, the reading will correspond to the sum of several signals. A field probe can be sensitive even to out-of-band signals.

MAXHOLD function is also used for broadband measurements, but field meters with this function take some time to come to the steady state, and when the probe is moved the values can change too fast, producing sometimes overestimation of the real fields.

In broadband measurements calibration is decisive as well: the calibration factor of the probe is generally not constant over the entire frequency range and it is often only valid for sinusoidal signals.

Additionally, sensitivity of the devices is also rather poor with values of about 0.1 V/m.

For epidemiological studies the use of a broadband field probe is usually not recommended (an exception might be the use of probes with filter functions) because it does not capture the contribution of every source but the total of all the sources of exposure and because such probes are often not sensitive enough. A field probe might be used only when results are confirmed by additional frequency-selective measurements showing that the signal of interest is much stronger than the other signals at the measurement location (*Haider et al., 2002*).

Frequency selective measurements

For a frequency selective measurement the following components are required:

1. Frequency analyser or a receiver.
2. Receiver antenna (according to the type of measurements)
3. RF-cable to connect the antenna to the spectrum analyser.

The antenna receives the energy of the signals at the location of investigation, these signals are feed to the spectrum analyser through the RF-cable, and the analyser will display the voltage corresponding to the field strengths in the frequency range chosen (using a filter). A typical frequency range is from 9 kHz to 2.9 GHz. For measures in the surroundings of mobile communications base stations the range must at least cover the frequencies from 900 MHz to 2.3 GHz. The most suitable antennas for this purpose are dipole antennas with low directivity, like biconical antennas.
The set of antennas recommended in the *ECCREC 02(04)* are:

- Magnetic loop,
- Broadband dipole antenna or (encapsulated) log periodic antenna,
- Bi-conical antenna,
- Directional antenna, recommended when there is a main contribution and the secondary contributions are negligible),
- Selective Probe " 3 axis ".

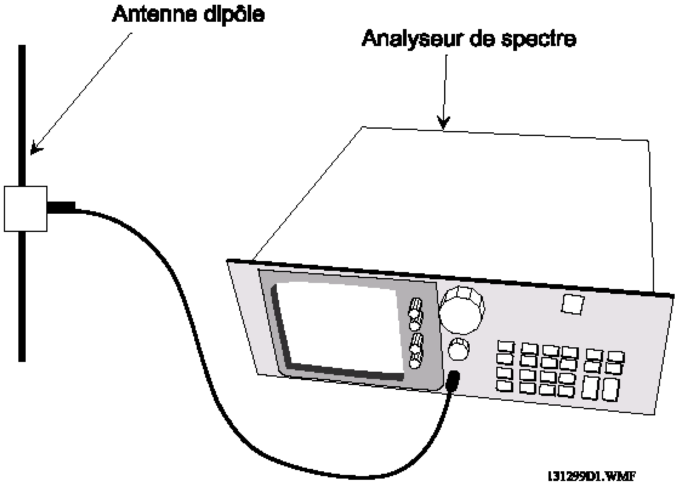


Figure 30: Elements of a frequency selective measurement

Because the purpose of the measurement is often to obtain the maximum value of the immission, the spectrum analyser might be set to MAXHOLD function so that every maximum value measured will substitute the formerly saved maximum.

Possible methods for field strength assessment are*:*

Directive Antenna Methods

Single Point with Directive Antenna
The measurement system consists of a directive antenna and the frequency selective receiver or spectrum analyser. Typical directive antennas are log. periodic or horn antennas. The measurements are typically done by orientation of the antenna toward the transmitter of interest. For in situ measurements this method becomes a time consuming job due to the small beam width of the antenna because the area of interest has to be analysed by manual search for each interesting frequency.

Sweeping Method
For cost effective verification of interesting areas this frequency selective measurement method relying on the determination of a so-called "maximum electric field strength value in a given space" can be used. In order to determine the maximum field strength in a given volume, the receiving antenna is moved in this volume using a receiver with the peak detector in its maximum hold function. Small directive antennas are often preferred instead of antennas with dipole like radiation characteristic to reduce the influence of the measurement engineer and the (moved) RF cable. The use of non isotropic measurement equipment leads to an enlarged uncertainty budget, overestimation as well as an underestimation of signals is possible, this method is still debated.

Isotropic Antenna Methods

Due to the fact that no high frequency antenna has an isotropic radiation characteristic by itself, one solution consists in the addition of the contributions of three measurements using an antenna with a dipole like radiation pattern and a rotator to position the antenna in three orthogonal orientations. The principle of three orthogonal measurements was already applied 1992 for field strength measurements of broadcast and TV stations. The Austrian Research Centre Seibersdorf developed small RF-antennas having a dipole like radiation pattern and established the so-called ADD3D method.

ADD3D Method (*Haider et al., 2002*)
The ADD3D method, uses a broadband omnidirectional antenna. The precision biconical antenna (PCD 8250) covers the frequency range of 80 MHz to 2.5 GHz continuously. The directional characteristic of this antenna is similar to that of an elementary dipole. Therefore, the effective field strength can be obtained from three voltage measurements with orthogonal orientation (e.g., x-, y-, and z-axis) of the antenna: Ux, Uy, and Uz [V] are measured. The field strengths are calculated in linear quantities:

$$Ei = Ui \cdot AF, i = \{x, y, z\} \tag{2.2-4}$$

The effective field strength E_{eff} [V/m] is calculated as follows:

$$Eeff = \sqrt{Ex^2 + Ey^2 + Ez^2} = \sqrt{Ux^2 + Uy^2 + Uz^2} \cdot AF, \tag{2.2-5}$$

where AF is the antenna factor in linear quantities [1/m]. All contributions (U, AF) and, therefore, E_{eff} are frequency dependent.

The measurements in three orthogonal directions are done with a single antenna (see Figure 31). Therefore, the only problem that remains is that the readings do not happen at the same time. To avoid measurement errors due to rapidly changing signals, sufficiently long measurement times must be chosen for each direction.

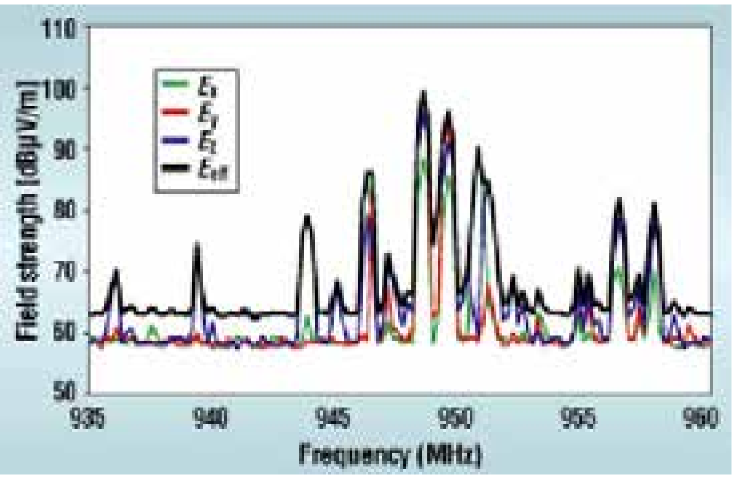


Figure 31: Three orthogonal E-field components obtained by multiplying the voltage readings with the antenna factor and the effective field strength Eeff according to Equation 4 in logarithmic quantities (20 log10(E)) as a function of frequency.

The measurement procedure is simple and time efficient because it is controlled by software. The power flux density can be calculated from the effective field strength with Equation $S = E^2_{eff}/377$. An operator positions the antenna in the three different orientations. For each orientation, the software sets the receiver bandwidth and the frequency range. It also stores the measured data. Measurements can be done in the frequency range of interest, and the appropriate limit values can be applied. As with the directive-antenna method, out-of-band signals play no role as long as the receiver is well designed.

With one set of measurements (three directions), the effective field strengths of all neighbouring base stations (operating at different frequencies) can be determined. By doing so, much time is saved when mapping the field distribution.

2.2.2.2 Dosimeters

Dosimeters allow determining the personal exposure due to electromagnetic fields versus time. It is crucial for the evaluation in respect of the electromagnetic fields from base stations and other sources to monitor in a way that allows distinguishing between the contributions from different application, e.g. mobile phones, GSM 900 base stations or broadcast stations. One system fulfilling such requirements was developed by *Antennessa* (www.antennessa.com). The sensitivity of the system is reaching 0,05 V/m, the minimum measuring cycle is 3 minutes long. A personal dosimeter is essential for characterization of the exposure in the general population, as it allows measurements being taken over a longer time period during all of a person's usual activities.

Figure 32: Example of a portable dosimeter (*Antenessa*, France)

Dealing with personal exposure in usual case where general public has access the frequency band of interest are FM (88 to 108 MHz), TV (174 to 223 MHz) & (470 to 830 MHz), GSM 900 [Tx(up) (875 to 915 MHz)] & Rx (935 to 960 MHz), GSM1800 [Tx (1710 to 1795 MHz)] & Rx (1805 to1880 MHz) and UMTS [Tx (1920 to 1980 MHz)] & Rx (2110 to 2170 MHz).

Frequency bands	*9 Fixed ranges*
Sensitivity	*0.05 V/m*
Dynamic	*40 dB up to 5 V/m*
Operating conditions	*-10 °C to 50 °C*
Samples	*Over 7000 samples*
Battery life	*> / days*
Dimensions	*193 x 95.6 x 69.4 mm*
Weight	*450 g*
Protection	*IP 43*
Power Supply	*230 V @ 50 Hz*

Figure 33: Specification of the portable dosimeter (*Antenessa*, France)

The measurements carried out in Europe have also shown that the results are very often below 1 Volt per meter and rarely above 5 V/m. Therefore a measurement tools having a dynamic limited to 40 dB with a measurement range of 0.05V/m to 5 V/m is able to record the exposure in a reliable way. In order to analyze the exposure over 1 or 2 days the system shall record each 3 minutes the exposure encountered in each frequency band of interest.

Dealing with the personal dosimetry isotropy is a key point. If the dosimeter is put on a desk or on a table the E field recorded shall be assessed with an acceptable isotropy.

Frequency band	Polarization	Signal	Isotropy
GSM 900 Tx	PV	TDMA	+/- 1.4 dB
	PH	TDMA	+/- 1.9 dB
GSM 900 Rx	PV	CW	+/- 0.7 dB
	PH	CW	+/- 1.4 dB
GSM 1800 Tx	PV	TDMA	+/- 1.4 dB
	PH	TDMA	+/- 1.4 dB
GSM 1800 Rx	PV	CW	+/- 1.4 dB
	PH	CW	+/- 1.4 dB
UMTS Tx	PV	CW	+/- 1.4 dB
	PH	CW	+/- 1.4 dB
UMTS Rx	PV	CW	+/- 1.4 dB
	PH	CW	+/- 1.4 dB

Figure 34: Isotropy of the portable dosimeter (Antenessa)

If the antenna is close to the body coupling occurs and than free space calibration is not adequate. In this case the person is moving and the field is coming through multi-path propagation. As a consequence an averaging over an adequate time window is able to provide an estimation of the exposure.

Another system that fulfils the requirement of frequency selectivity is named *FieldCop* and will be supplied by MIC6 (www.mic6.com) in close future. The system also operates in different frequency bands as shown in Figure 35.

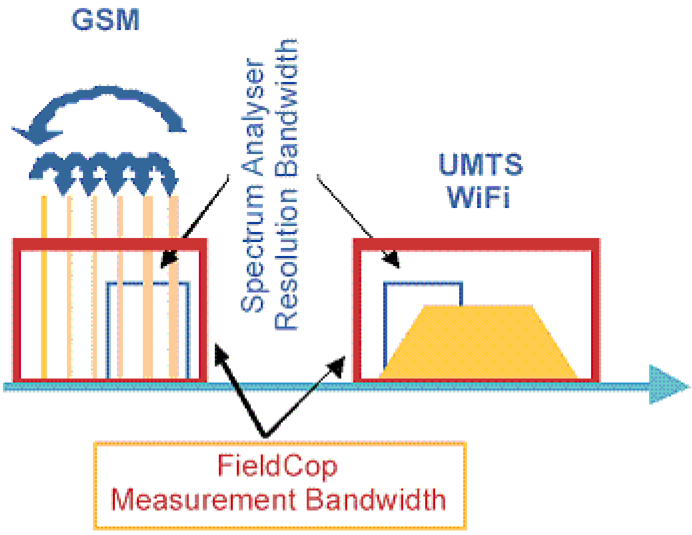


Figure 35: FieldCop (MIC6)-Distinction between different frequency bands (NARDA)

The disadvantage of the use of larger bandwidths is the fact that the distinction between specific sources operating in the same band is not possible.

An example for a stationary, broadband dosimeter from *NARDA* (www.nardamicrowave.com) is shown in Figure 36. The power supply is provided by a solar panel. A measurement data transfer trough GSM link is implemented and permits the control of the dosimeter trough remote enquiry.

Figure 36: Stationary dosimeter Type 2600 from NARDA (www.nardamicrowave.com)

The measurement range can be selected by connecting different probes, as depicted in the Table 1.

Probe*		
E-field probe Type 330	500 kHz to 3 GHz	0.3 V/m to 300 V/m
E-field probe Type 309	1 MHz to 18 GHz	0.8 V/m to 800 V/m
H-field probe Type 305	20 Hz to 3 kHz	10 nT to 40 µT

* Other probes available on request

Table 1: Probes for the NARDA area monitoring system 2600 system (NARDA)

Rohde & Schwarz (http://www.rsd.de/) has also developed a portable spectrum analyzer, called R&S RFEX, which along with an isotropic probe (which performs measurement of the field strength independently of the polarisation and the incident angle of the signal) and a notebook computer, provided with the software system *R&S RFEX* for the analysis and evaluation of the signals measured, can conform an adequate monitoring or dosimeter system.

The RFEX can measure in the frequency range from 100 MHz to 6 GHz (depending on the model) either the total immission in a location or the contribution of every individual source present in an environment (a determined band, a transmit channel or frequency). This device permits mobile and stationary, short or long-time measurements (from minutes to days), which, along with its portability, makes it adequate for dosimetry or monitoring. The level measurement uncertainty is lower than 1.5 dB, typically 0.5 dB.

Figure 37: The Handheld Spectrum Analyser R&S FSH (Rohde und Schwarz)

2.2.2.3 Monitoring Systems

Monitoring systems allow monitoring continuously the whole frequency range (monitoring mode) for all types of signals in the frequency range of interest. For monitoring methods again isotropic systems are necessary, but also additional functionality of these systems is needed. Caused by their permanent operation data base functionality for data processing is recommended. The systems have to be fail safe (e.g. if the analyzer is sending not valid data or some devices have a total error) under certain conditions weather given, air-conditioned and the systems should be able to work together in a network with other stations. It becomes essential to send an alarm to a central unit if some results were exceeding the general expected signal floor or any limits. The system has to store such events in detail (field strength, frequency, bandwidth and time) whereas for the other time period sliding average values of the selected field strength will be adequate to avoid exorbitant data volume.

As can be seen in Chapters 2.4.4 and 7.1.4.6 some organizations perform control of the exposure with permanent monitoring systems where the levels of exposure obtained are compared with international or national guidelines. These systems consist of an isotropic probe that captures all the contributions within a specific frequency range. The data obtained in the monitoring station are sent to a central station where they are processed and displayed in graphics.

While such systems are usually broadband devices, more sophisticated ones have also been developed like the Field Nose Complete: a frequency selective and isotropic measurement system designed for short- and long-term EMF measurements as well as for monitoring and scientific studies, created in ARC Seibersdorf.

The Field Nose is based in the Add3D system (described in Chapter 2.2.2.1) and works according to the dot screening method. As can be seen in Figure 38 it consists of a spectrum analyser, a precision conical dipole antenna with positioning unit that allows measurements in three orthogonal antenna orientations, a power supply unit and a measurement controller. The antenna covers a frequency range from 80 MHz up to 2.5 GHz and is designed for a dipole-like radiation pattern. The software allows the definition of measurement setups as well as data evaluation and visualisation of results.

In a few words it works as follows: the antenna is positioned sequentially in three orthogonal orientations by the positioning unit. The software calculates the equivalent isotropic field strength from three measured values with the Add3D algorithm which guarantees optimum isotropic characteristics.

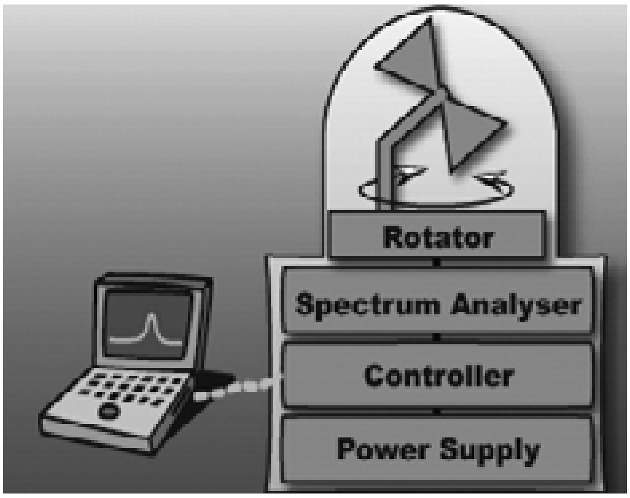


Figure 38: Schematic of the Field Nose Complete setup

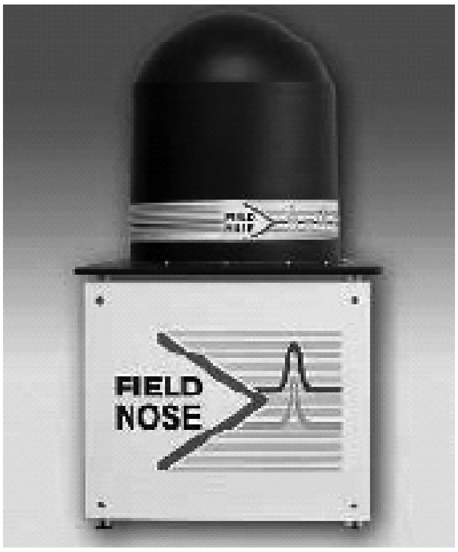


Figure 39: Field Nose Prototype

The measurements described in Chapter 2.1.2 **Variation in Time** were performed with the Field Nose system and the environment and the results of the measurements are shown in Figure 18 and Figure 19.

2.3 Range of exposure obtained in measurement campaigns

2.3.1 GSM

In the German “Messreihen” performed by the RegTP (see Chapters 2.4.4 and 7.1.4) maximal and minimal values obtained in GSM 900 and 1800 bands (given without distinction of the two bands) were, respectively, 140 mW/m² (7.27 V/m) obtained in the IMST1 and 0.000073 mW/m² (0.00524 V/m), obtained in the IMST3. These values are the extremes from the total three series (IMST 1, 2 and 3). In a similar way, the search for compliance with guidelines about radiation performed in Liechtenstein (Amt für Kommunikation, *Wuschek, 2001*) obtained values between 110 and 0.00106 mW/m² (6.44 and 0.02 V/m) for the GSM band.

In the results of the measurements performed by the BIPT (Belgian Institute for Postal services and Telecommunications) next to GSM stations, values are also given in a similar way, as can be seen in Table 2:

Spectral power density (mW/m²)		Electric field (V/m)		Scenario
max	min	max	min	
27.35		3.21		rural indoor, 30 m
14.86		2.37		semi-urban, indoor, 150 m
618.91		15.27		urban, indoor, 1 m
1030.78		19.71		rural, outdoor, 7 m
674.19		15.94		semi-urban, outdoor, 6 m
290.99		10.47		urban, outdoor, 50 m
	0.007		0.051	rural indoor,
	0.001		0.018	semi-urban, indoor, 60 m
	0.034		0.114	urban, indoor, 40 m
	0.014		0.073	rural, outdoor, 500 m
	0.037		0.119	semi-urban, outdoor, 50 m
	0.026		0.1	urban, outdoor,

Table 2: Maximal and minimal values according to the different investigated scenarios (indoor, outdoor, rural or urban) obtained in the GSM measurements of the BIPT, Belgium.

The values are given for in- and outdoor and rural, semi-urban and urban scenarios at different distances from the base station.

The “Campagne de Mesures” performed in France (see also chapter 2.1.4) provides summarized results of the immission for certain locations. Although, in rural environments the mean value obtained for a single frequency in the GSM 900 band was 0.0049 mW/m² (0.13 V/m), some extreme cases with relative high exposures are reported. For instance, in an apartment in an urban environment a maximal value of 16.8 mW/m² (2.52 V/m) was obtained for the entire GSM 1800 band, while for the GSM 900 band the maximum was 1.62 mW/m² (0.78 V/m).

A similar measurement project is that performed by Umwelt-Steiermark *(Kurt et al., 2003)* which obtained a maximal level for GSM 900 of 1.25 mW/m² (0.69 V/m) and 3.52 mW/m² (1.15 V/m) for GSM 1800, respectively. In the frame of the measurements performed by ARCS in Graz (2004) and Vorarlberg (2003) values are also given separately for the upper and lower band. In the case of the campaign of Vorarlberg, the values are 21.31 mW/m² (2.83 V/m) in the lower band and 3.72 (1.19 V/m) in the upper.

In the case of Graz, values are given both for the entire GSM 900 or 1800 band and for every separate GSM channel. By making a summation of all the channels of the GSM band, the maximum values obtained were 0.16 mW/m² (0.25 V/m) for the GSM 900 band and 1.44 mW/m² (0.74 V/m) for the GSM 1800 band. The minimum values were 0.0037 mW/m² (0.037 V/m) in the GSM 900, and 0.008 (0.055 V/m) in the GSM 1800 band.

The measurements of *Neubauer (2003)* provide a comparison between values obtained considering one band measurements and the total immission over the entire GSM band. While for a single frequency the values ranged from 13.43 mW/m² (2.25 V/m) to 0.00000016 mW/m² (0.00024 V/m), , the maximal and minimal values varied from 47.64 mW/m² (4.24 V/m) to 0.0012 mW/m² (0.021 V/m) for the entire GSM downlink bands. Furthermore, when indoor and outdoor measurements were taken into account, the differences were remarkable. In indoor locations they ranged from 9.275 mW/m² (1.87 V/m) to 0.0000262 mW/m² (0.0031 V/m), the span in outdoor measurements was 13.43 mW/m² (2.25 V/m) to 0.000076 mW/m² (0.0053 V/m).

2.3.2 UMTS

For UMTS the values found for comparison are scarce. The results of the Graz measurements of ARCS ranged between 0.21 mW/m² (0.28 V/m) to 0.0032 mW/m² (0.035 V/m) considering the entire UMTS band, and those in Vorarlberg reached a maximum of 1.42 mW/m² (0.73 V/m) and a minimum of 0.0037 (0.037 V/m). In the frame of the last mentioned measurement campaign only one channel was operating (in a single location there were two operators providing service, but the total immission only reached 1.12 mW/m² (0.65 V/m)).

Other measurement campaigns and projects that were dedicated to measure UMTS signals were the Umwelt Steiermark project, which obtained a maximal value of 0.001 mW/m² (0.019 V/m) or the report of the AUC in Denmark which measured values as high as 0.1 W/m² (0.19 V/m) at a distance of 25 m from the base station.
Finally, *Danestig,2004* measured in different locations around UMTS base stations obtaining a maximum of 22.93 mW/m² (2.94 V/m) at a distance of 20 m, and 1.16 mW/m² (0.66 V/m) at a distance of 40 m (all values from single UMTS channels). Although these measurements were done in operating environments (not public frequented places) they help to give us an idea of the order of magnitude of the exposure due to UMTS signals.

2.3.3 RF Broadcast transmissions

Regarding FM broadcast transmissions, ARCS measured values for the entire band between 2.03 mW/m² (0.88 V/m) and 0.038 mW/m² (0.1189 V/m). Considering single channel measurements the maximum power density obtained in the measurements performed by ARCS was 0.029 mW/m² (0.11 V/m). *Danestig, 2004* measured a maximum of 4.01 mW/m² (1.23 V/m) at a single frequency, as well.
The values obtained in the Liechtenstein series for FM broadcast towers ranged between 0.01 and 0.84 V/m (0.00026 and 1.87 mW/m²).
ARCS measured also in other bands, like Analogue and Digital TV (DVB-T). The measurements of analogue TV showed a maximal power density of 0.2209 and a minimal value of 0.001 mW/m² (0.29 and 0.019 V/m). The results obtained with digital TV were considerably higher ranging from 34.58 mW/m² to 0.0028 mW/m² (3.61 – 0.033 V/m).

In the “Campagne the Mesures” in France radio and analogue TV transmissions were checked, too. For extreme exposure cases values obtained for FM radio were between 3.36 and 7.76 V/m (29.945 and 159.73 mW/m²) in an urban scenario (25 m away from receiver). In the same location, the electric field strength was in the range 0.42 to 0.71 V/m (0.46 and 1.33 V/m) for TV transmissions. In all cases the entire bands’ immissions were considered.

2.3.4 DECT

The electric field strength from a DECT base station in the near region was between 0.5 and 3.0 V/m; at a distance of 2 meters we are below 0.1 V/m, as stated by the Bayerisches Landesamt für Arbeitsschutz The maximal power for a transmitted signal in DECT is 250 mW (24 dBm).
Examples for measured field values for performance analysis of DECT systems are 40 dBμV/m to 105 dBμV/m (*Döttling et al., 1997*) and 95 to 117 dBμV/m (*Kolosowski et al., 2001*) Usually in the literature we find values for the received power in [dBm] and from this the calculated path loss in [dB], being more descriptive to describe the propagation characteristics compared to field strengths given in V/m.

In an expert’s report performed in the University of Bremen (*Uni Bremen, 2001*) to measure the radiation from WLAN devices, measurements of other technologies present in the environment were also measured to provide a comparison with the levels of WLAN power densities. Of special interest for our considerations are the test performed with measurements at different distances from a DECT-Telephone, which are shown in Table below as power density and exposure quotient of the level of the 26.BimSchV regulation (9.5 W/m² in the DECT band):

Distance Probe – DECT-Telephone	Power density (W/m²)	% of the 26. BimSchV.
0.40 m	0,17	1,8%
0.60 m	0,13	1,4%
1.70 m	0,02	0,2%
3.00 m	0,011	0,1%

Table 3: Results of the measurements performed by the University of Bremen (Uni Bremen, 2001).

2.3.5 TETRA

The TETRA system is a cellular digital communications system operating in Europe in the 380-400 and 410-430 MHz band. The operating radius is about 15 km in rural area and the typical transmitted power from a TETRA base station is 25 W ERP. Neither in the IEEE journals (www.ieee.org) nor in the other literature we found papers on investigations about the field distributions regarding this technology.

2.3.6 WLAN

According to the standard 802.11g (frequency: 2.4 - 2.4835 GHz, 54 Mbit/sec) a WLAN (Wireless Local Area Network) router has a maximal transmitting power of 100 mW ERP consisting of a pulsed radio frequency electromagnetic field.

Regarding measurements of exposure arising from this technology, only a note in the measurement report of the Bayerisches Landesamt für Arbeitsschutz is given, that affirms that measured field strengths are higher than 0,3 V/m if it is necessary to move closer than 30 cm to the transmitting antenna; outside from this zone no relevant field strengths were detectable by the measurement devices.

The ÖKO-Test Magazine (*Eddelbüttel, 2002*) measured in four cities of Germany the power density in different spots close to public WLAN 802.11b facilities. The results showed a great spread of the power densities measured, ranging from some µW/m² to 23 mW/m². The specialist of the ÖKO-Test concludes that the exposure of WLAN reduces rapidly with distance from the source and that at a distance of about one metre from the WLAN-Card the immission ranges from 15 to 20 mW/m². A summary of the evaluation is given in Table 4.

TEST WLAN-Hotspots	Aachen, Marktplatz ein.	Münster, Geologic Museum, Flur EG	Münster, Castle Cellar	Münster, Castle Cellar	München, Airport Hall D, Northern Section	Göttingen, Laws Library
Situation of the antenna	In a window 8m high	Round-radiancy Antenne	Round-radiancy - antenna	Round-radiancy antenna	2 Sectors-Antennas	Round-radiancy antennas
Distance to the antenna (m)	10	4	15	5	2	1
Characteristics of the measurement spot	-	Corridor below room omni directional antenna, solid ceiling	-	-	Sum of both antennas	Sum of both antennas
Radiation Strength in µW/m²	0.007	0.005	0.320	1.3	4.2	23

Table 4: Summary of the measurements performed by the ÖKO-Test Magazine (Edelbüttel, 2002)

In the expert's report of the University of Bremen, WLAN immission measurements in the frequency band 2.4 – 2.485 GHz were also carried out. The most remarkable test was the measurement of the power density at different distances from the WLAN Network-card of a Notebook. The results and the exposure quotient of the German guideline (10.0 W/m²) are displayed in Table 5, and a picture of a measurement is shown in Figure 40:

Figure 40: Scenario of a measurement at a distance of 20 cm from the notebook

Distance Probe – WLAN-Card	Maximum (mW/m²)	% of the 26. BImSchV.
1.50 m	1,58	0,016%
0.80 m	1,26	0,013%
0.60 m	3,15	0,032%
0.35 m	3,97	0,040%
0.10 m	49,96	0,500%
0.20 m	99,69	0,997%
0.20 m	158,00	1,580%

Table 5: Results of the measurements of WLAN

Measurements were also performed around WLAN access points and are summarized in Table 6 :

Uni Bremen WLAN Access Points locations	Characteristics	Power density [mW/m2]
Room 122	Height 1,20 m Height 1,70 m Height 2,00 m	0.79 2.5 1.99
Room 4200	Distance 3,80 m Distance 2,50 m	0.53 0.67
Cafeteria	Balcony	0.008

Table 6: Results of the measurements performed by the University of Bremen (*Uni Bremen, 2001*).

Comparison with the emissions of other technologies (GSM, DECT, Radio and TV) showed that WLAN immissions were dominant when measured close to the access points.

2.3.7 Bluetooth

Bluetooth operates at a frequency of 2.45 GHz with mean transmitted power from 10 mW to 100 mW. The situation is similar as with WLAN, electric fields over 0.3 V/m were only found closer then 30 cm to the antenna, while outside from this area no relevant exposures was detectable.

2.3.8 Comparison of the exposure from GSM phones and GSM base stations

The comparison of the magnitude of exposure from GSM phones and GSM base stations depends strongly on several assumptions, e.g. the duration of mobile phone use per day, the power control conditions, and typical traffic status. The most reasonable assumption for different user profiles has not been determined yet. Thus, two comparisons of handset and base station exposure resulted in divergent results:

1. *Dale and Wiart, 2004* made a comparison of the exposure between mobile phones and base stations at 900, 1800 and 2100 MHz. They found out, that at the moment of maximum exposure, the mobile telephone exposure is greater than the base station exposure. For day averaged exposure the local exposure due to mobiles and base stations is usually in the same order of magnitude. The situation differs for the whole body, exposure averaged over a day: based on the assumptions used, base station exposure was getting larger than mobile phone exposure.

2. An estimation of the authors of the exposure due to GSM phones compared to exposure due to GSM base stations indicated that an exposure of 1 V/m of the central nervous system from a base station for 24 hours corresponds to an exposure of one second from a typical mobile phone. Looking at whole body exposure the relation would be about 24 hours to 3 minutes.
Considering exposure of bystanders (the mobile phone is 1 m away from the person) the ratio is changing: Estimation of the exposure of the bystander due to GSM phones compared to exposure due to GSM base stations indicated that an exposure of 1 V/m of the central nervous system from a base station for 24 hours corresponds to an exposure of 14 minutes from a typical mobile phone. Looking at whole body exposure the relation would be about 24 hours to 1hour.

2.3.9 Exposure summary

It has to be pointed out that the available data gives almost no information on personal exposure of the population. In addition, the fact that most times different measurement protocols were used and the selection protocols for the assessment positions differed makes the data not really comparable. The information given can only be seen as a first attempt, harmonized selection and assessment protocols are needed to give reliable information.

The range of exposure of the general population due to GSM downlink signals can be estimated to be between some tens of mW/m² (in the case of Germany they levels reach one hundred and in the measurements in Belgium even 1 W/m², although these values are extremely high compared to all other values) and a few µW/m² (in many measurement projects the values obtained did not reach even the minimum sensitivity of the devices used for the measurements). For UMTS the measurements are scarce and due to the rather limited expansion of this technology (till date) not too many channels are operated due to the low traffic. Values slightly over 1 mW/m² have been measured, while minimum levels are also a few µW/m².
For RF broadcasting systems (FM radio or Analogue TV) the maximum values measured were below 10 mW/m², and we can include the measurements of the new digital TV technology (DVB-T) in Austria, where exposures between 34.5 mW/m² and 0.0028 mW/m² were registered.
Regarding other technologies a very limited number of measurements have been performed and an estimation of the exposure is not meaningful.
No information on the distribution of personal exposure in the population is available (either total or due to a particular source).

2.4 Existing exposure assessment concepts

2.4.1 Residential exposure assessment concepts

Concerning residential exposure, most of the available studies have focused on radio frequency transmitters such as TV and radio transmitters. More recently a few studies have focused on base stations from cellular telephony systems.

Only a very limited number of epidemiological studies on health effects due to the emissions of fixed radio transmitters based on measurements to estimate exposure are available (*Altpeter et al., 2000, Navarro et al., 2001* and *Hutter et al., 2002*). The exposure assessment is in all cases based on spot measurements and does not take variations in time into account. In the frame of two of these studies, *Altpeter et al., 2000, Navarro et al., 2001*, the exposure was at least partially estimated by using broadband probes making distinctions between the contributions from different sources almost impossible, though in the last one an effort was made to demonstrate that the dominating source was the one coming from the base station under study. *Hutter et al., 2002* used frequency selective equipment for the exposure assessment. Finally, the assessment is always limited to restricted areas, e.g. sleeping rooms. So far, use of spot measurements as exposure measure has not been validated. Thus, it is not clear whether reliable conclusions on personal exposure during the whole period of investigation can be drawn.

Most of the studies on residential exposure used distance as surrogate for the exposure. It has been shown in several investigations (e.g. *Bornkessel and Schubert, 2004*) that distance is not a reliable proxy for exposure in typical in situ conditions with field variations in time and space and multisource exposure. The antenna characteristics, topography and objects like buildings can also have an important impact on the field propagation. The study of *Maskarinec et al., 1994* went a step forward obtaining the distance with the help of a geographical software package, and in (*Santini et al., 2001a, 2001b and 2002)* exposure was estimated by the subjects themselves (reporting distance to the antenna, position of the antenna, or time lived in the vicinity of the base station), which adds another source of misclassification of the exposure.

A few studies (*Hocking et al., 1996, McKenzie et al., 1998, Hallberg and Johansson, 2002*) are based on calculations of the exposure due to fixed installed transmitters and are partially superior to the studies using distance alone as surrogate.

Overall, the available epidemiological studies on fixed installed RF transmitters have many dosimetric limitations. Most important, lack of validation studies makes it impossible to draw any reliable conclusions on personal exposure.

2.4.2 Occupational exposure assessment concepts

Around 20 epidemiological studies on occupational RF exposure were identified, information on historical exposure was often not available. Nine studies on occupational exposure relied on measurements for the exposure assessment. In five cases only broadband devices were used, one study implemented frequency selective equipment and in one case both frequency selective and broadband equipment was used. In almost all cases the exposure assessment was restricted to spot measurements or short periods of time up to 6 minutes, only in one case an estimation of the whole day exposure was made. One study gave neither specific information on the type of equipment used nor on the duration of the assessment period. The type of sources ranged from plastic sealers and police radar devices to fixed installed transmission antennas, e.g. TV and UHF antennas.

The other studies used different approaches, e.g. job exposure matrices, expert opinions and personal interviews. The concepts applied are partially quite suitable to assess exposure in the close vicinity of devices emitting RF electromagnetic fields, but they seem not to be applicable for the exposure assessment of the general population in respect of the exposure due to fixed installed RF transmitters.

Classification by a job title alone can be considered as a very crude surrogate as it does not necessarily reflect the subjects' main work areas or job activities, e.g. electrical engineers often work in an office and are then only exposed to background levels like other office workers. With this approach, subjects with the same job title are all classified as exposed or unexposed, which leads to a huge potential of exposure misclassification. An improvement is the classification of job profiles, which is usually done by expert rating. This enables researchers to take into account not only the occupation of persons, but also the job history to assess cumulative exposure or to consider potential confounders. An advanced approach is to establish a job exposure matrix (JEM). By means of systematic measurement campaigns the typical exposure of different occupations or work areas is assessed. In the frame of an epidemiological study each person is assigned to an exposure value from a job exposure matrix according to his occupation, work area or job activity.

In 11 studies out of 12 found on occupational exposure due to RF sources classification was based on job titles, in one case (*Grayson, 1996*) a job exposure matrix was used. In the frame of 7 out of 11 studies expert ratings were used to estimate exposure. In most cases information on the job title was obtained by means of a census, company records or hospitalisation records. Detailed information can be found in the annex.

2.4.3 Exposure assessment concepts for mobile devices

In the past several studies on different health endpoints and mobile phone use were performed. All of these studies have some limitations in respect of the exposure assessment. Due to the fact that the information on exposure is most times based on questionnaires, recall bias cannot be ruled out, exposure misclassification is often very likely (see chapter 4.2). In some cases billing records are used: in such cases recall bias is not a problem, however it cannot be excluded that other persons used the phone. None of the studies gives good information on individual levels of exposure as only information on the duration of exposure has been collected. The individual dose of exposure remains unknown. Another problem is the unknown latency or induction time period between exposure to mobile phones and incidence of diseases like cancer. If an association would exist it might be related to the lateral use of mobile phones and SAR distribution. However, if the information of mobile phone use laterality is collected retrospectively in case-control studies recall bias is likely to be a problem. Several studies mainly focused on analogue phones, however nowadays most people are using digital phones. One approach would be the use of dosimetric mobile phones in the future giving information on individual's exposure versus time.

No finished epidemiological studies on potential health effects based on measurement as metrics were found. It needs to be mentioned, however, that within the framework of an ongoing large multinational case-control study on causes of brain cancer (Interphone), measurements are performed to validate exposure metrics based on questionnaire information. Software-modified mobile telephones (SMP) will be used in 13 countries to evaluate to what extent the average output power of the mobile phones is related to patterns of mobile phone use. Measurements with phantom heads are used to identify the areas in the brain where the most energy is absorbed. These are improvements compared to previous studies on this topic, as illustrated in the next chapter.

In the reports described here, the surrogates for the exposure are most times based on questionnaires, information was obtained from interviews (*Hansson-Mild et al.,1998, Chia et al.,2000, Muscat et al., 2000, Stang et al.,2001, Inskip et al.,2001, Hardell et al.,1999, 2002a, 2002b and 2003, Warren et al., 2003, Christensen et al.,2004, Lönn et al.,2004*) or in a few cases from subscribers lists provided by telecommunication companies (*Rothman et al.,1996, Dreyer et al.,1999, Auvinen et al.,2002, Johansen et al., 2001, 2002*), no other methods were found. The fact that no measurements were used to assess exposure can be considered as shortcoming, however the Interphone study uses a superior approach.

Studies which assess exposure by questionnaires obtain data directly from subjects via direct interviews (personal or by telephone) or indirectly by written forms sent to the participants. The subjects are asked about common usage of the devices, like duration, number of calls, laterality (when diseases are specific to the side of use) and sometimes also about the model of mobile phone, the technology (when analogue phones where considered), usage of hands-free devices or exposure to other sources. The subjectivity of the respondents can be considered as important potential source of misclassification.

When subscriber lists (billing records) are used as surrogate, similar data as those obtained by questionnaires or interviews is collected, without having the problem with the subjectivity of respondents. However, many providers only account for outgoing calls and do not know to what extend subscribers of mobile phone are users and what part of the users is also a subscriber (phone use not only by the owner but also by other persons, a relative or employees who might share a phone with the subscriber). As this kind of exposure misclassification is independent of case-control status, one should rather expect a bias towards a null effect (see chapter 4.2).

2.4.4 Large Scale Studies for exposure assessment of the population next to base stations – available information

In many countries in the European Union are present ongoing initiatives dedicated to assess the exposure from GSM and other telecommunication system stations and provide information for the public. In some countries audits are performed to assess the correct installation of the stations, and in some others measurement campaigns are ongoing or already finished. Other types of investigations are measurements on demand in conflictive locations (sensitive places, like hospitals or schools) or scientific investigations to study the non- ionizing radiation.

The most common efforts are projects based on spot measurements to assess the people's exposure to electromagnetic field comparing the levels of radiation obtained with national or international guidelines. In the annex some of them are presented.

2.4.5 Discussion of existing methodologies

2.4.5.1 Exposure estimation based on distance

Studies dedicated to investigate associations between fixed installed transmitters, e.g. TV or broadcast transmitters and different endpoints often used distance from a transmitter as a surrogate. The surrogate distance does not take into account the contributions from other RF sources, e.g. mobile phones, this situation is similar to the ELF range to a certain extend. However, the situation is even worse in the RF frequency range. Due to the fact that multipath propagation, reflection, attenuation, antenna pattern lead to very heterogeneous field patterns, distance alone is not well correlated with exposure (e.g. *Danestig,2004*).

In the years 1997 to 2000 64 frequency selective measurements were performed in the vicinity of different GSM base stations distributed all over Austria, in all cases the power density of the strongest channel of the respective base station was recorded. Figure 41 demonstrates very well that the distance alone is not an adequate surrogate to assess exposure, e.g. at distances of about 70 m the power densities vary by about a factor of 1400.

It is not unusual that the power density is lower at positions located closer to fixed radio transmitters compared to other locations being farer away. One reason for such situations can be the shadowing effect arising from buildings or other objects or the specific radiation pattern of the transmitting antennas. Epidemiological studies using such approaches, e.g. *Dolk et al.,1997a* and *Dolk et al.,1997b* suffer from these shortcomings and the outcome of such studies might be seen as indication for possible effects, but the results have to be interpreted with caution.

It was demonstrated that the distance and power density from base stations are not well correlated (*Schüz and Mann, 2000, Mann et al.,2000*, *Neubauer,2003, Bornkessel and Schubert,2004, Röösli et al.,2002a,* see also figures 41 and 62*).* Despite of the advantage of such a surrogate due to its practicability in large studies it turned out that neither lateral nor radial distance alone is suited to be used as reliable exposure estimate. This is caused e.g. by the way power is radiated from base stations and the fact that the directivity of the antennas leads to higher and lower exposed areas. To take such parameters into account there is need to consider antenna parameters and some environmental factors.

2.4.5.2 Analytical calculations

Another approach is the use of analytical calculations based on plane wave exposure assumptions (see formula 2.4.11). By taking several parameters as gain of the antennas, input power, side lobes, down tilt and height of the antennas into account it is possible to get a more reliable exposure estimate sometimes suited for rather uncomplicated exposure scenarios, e.g. mast on the countryside without objects in the vicinity. *Hocking et al.,1996* used such an approach, spot measurements showed in this particular study that the measured field levels were about five times below the calculated ones. It has to be taken into account that multipath propagation and shadowing effects due to objects like buildings or trees were not taken into account and it is not unlikely that this could be the reason for the deviations found between measured and calculated fields. In general measured fields tend to be below those calculated by means of simple analytical formulas. However, it can never be completely excluded that calculations could lead to underestimations, too.

The use of plane wave assumptions is superior to the use of distance alone, but it has also several limitations. A comparison between measurements performed in Austria should illustrate such problems.

$$S = \frac{G.P}{4.\pi.r^2} \tag{2.4.1}$$

S = Power density (W/m²)
G = Gain
P = Power (W)
r = Distance (m)

Within an Austrian study 64 frequency selective measurements were performed at different locations in the vicinity of different base stations. In addition the distance between the respective base station and the location of the measurement was determined. The respective measured power densities allocated to single broadcast channels are given in Figure 41 versus the distance to the base station (points C representing the measured power densities).

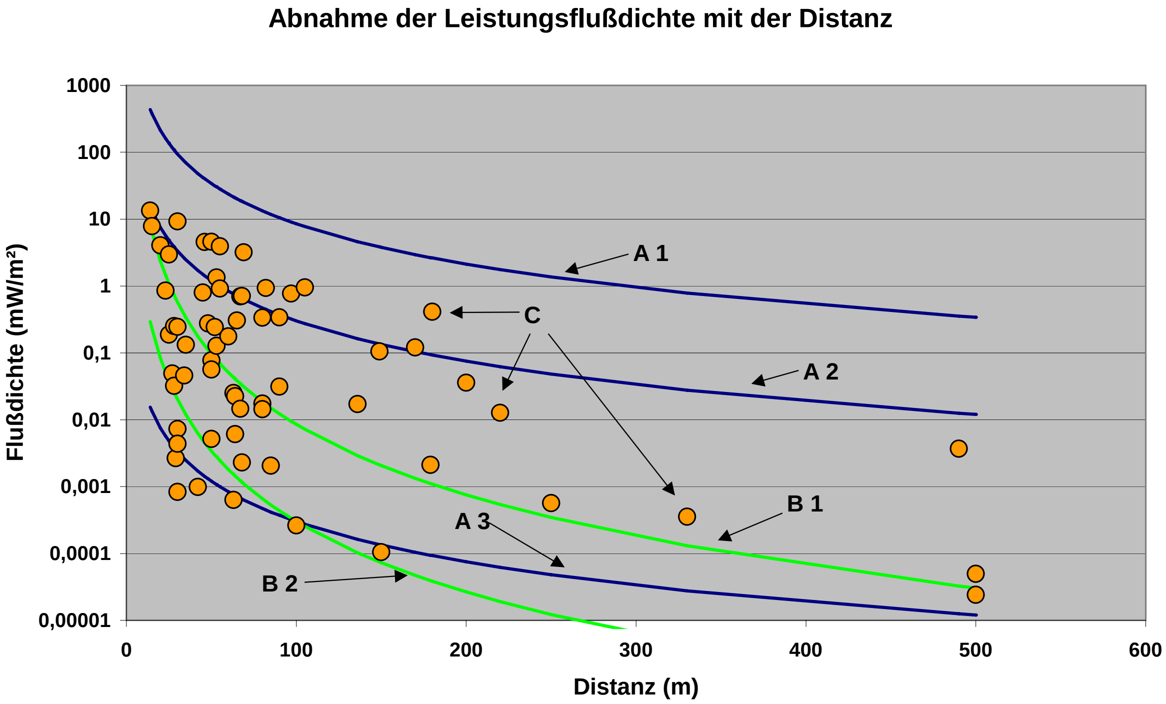


Figure 41: Relation between power density allocated to the broadcast channels of GSM base stations and the distance from the base station (*Neubauer, 2003*)

From Figure 41 it is visible that the power densities measured next to different base stations at almost the same distance vary by close to 4 orders of magnitude, e.g. single measurements were performed at a distance of 68 and 69 m in the vicinity of the antennas of two different base stations. In one case the maximum power density in the GSM band was 3.2 mW/m², in the other case 0.002 mW/m². This means that the two power densities measured in the vicinity of different base stations at almost the same distance varied by a factor of about 1,400. *Mann et al.,2000* found even variations up to almost 4 orders of magnitude, the study of *Bornkessel and Schubert,2004* is also well in line with these results.

There are multiple reasons for such large variations: different types of emitting antennas with different antenna patterns, differences in the input power from base station to base station and variations in orientations and also downlink. Of course the location of the measurement position in respect of the orientation of transmitting antennas of a base station is crucial. Looking at sector base station antennas the exposure in the direction of the main beam is of course much larger compared to the other directions.

Under certain circumstances the impact of buildings cannot be neglected: reflections can occur on several parts, in particular at metallic parts and can lead to interference scenarios with the incoming wave and there to heterogeneous field distributions (e.g. *Danestig,2004*). Different types of materials might absorb electromagnetic fields in the frequency band of interest and can therefore lead to a reduction of the exposure. The higher the number of buildings, trees and other objects like vehicles, the more complicated becomes the field distribution. The simple formula describing the decrease of the power density with the square of the distance from the emitter under plane wave conditions can only be used for rough estimations under such complicated conditions.

In the area A in Figure 41 (range between the curves A1 and A2) the decrease of the power density under far conditions is shown for typical base stations, formula 2.4.11 was applied for the calculations. The upper curve A1 was calculated by using an input power of 12 Watt and a gain 19.5 dBi, the lower curve is based on 6 Watt and 8 dBi. These data correspond to the typical range of input power per channel and gain of base stations in Austria at the time of investigations. The area between the curves corresponds therefore to the power densities that might be expected in the main beam of base station antennas per channel, operated with an input power between 6 and 12 Watt having a gain between 8 to 19.5 dBi assuming ideal propagation conditions.

The comparison of the measured values C with the calculated ones (area A), shows that the measured values are usually smaller than the calculated ones. In 15 out of 64 cases (23 %) the measured values lay in the area between curve A1 and A2, the measured values are up to a factor of 1000 smaller compared to curve A2.

One of the main reasons for this finding might be the fact, that many measurements were not performed in the area of the main beam. Apart from that reflections and attenuation were not taken into account by the simple calculation model. In a few cases it might be possible that the input power and/or the gain could have been below the range used for the determination of the area A.

An additional requirement is therefore to take horizontal and vertical side attenuations of the respective transmitting antenna into account to determine the power density outside the main lobe. The narrow side lobes of the antenna pattern might lead to considerable changes of the exposure due to small changes of the location of the exposure assessment in lateral as well as radial direction. Therefore outside of the main beam measurements are in particular better suited for exposure assessment compared to analytical methods. Curve A3 shows the decrease of the power density with distance for the same input power and gain as curve A2 taking an additional side attenuation of 30 dB into account. It can be seen that almost all measured values lay in the area between curve A1 and A3. This shows that in many cases the measured values in Austria will not lie outside this range, but does allow particular conclusions on specific exposure values.

Ramsdale and Wiener,1999 propose to use of formula 2.4.12 for the estimation of the exposure due to base stations in rural or hilly areas. This analytical approach is based on a decrease of the power density with an exponent of -3.5 of the distance.

$$S = \frac{G \cdot P}{4.\pi.r^{3,5}} \qquad (2.4.2)$$

S	Power density (W/m²)
G	Gain
P	Power (W)
r	Distance (m)

Area B in Figure 41 shows the decrease of the power density according to formula 2.4.2 using the same set of data as for area A.

In 20 out 64 cases the measured values can be found in area B. This means that the majority of the measurements performed in Austria in the vicinity of base stations are larger compared to the values calculated according to the approach proposed by *Ramsdale and Wiener,1999*. This suggested method for exposure estimation seems not to be in line with the exposure conditions found within this measurement campaign in Austria.

One additional important problem is also the fact that the technical setting of the base stations can vary versus time. Several factors like channel number, number of channels used, input power, down tilt, and antenna type can be changed due to adaptation of the mobile communication network. Calculated data are therefore always historical data and actual exposure might differ significantly due to such reasons.

Variations versus time and variation in space due to shadowing, fading effects, attenuation etc. cannot be taken into account by using simplified analytical approaches (see also Chapter 2.1). This has to be taken into account while interpreting the results of analytical calculations.

2.4.5.3 Measurements

In general measurements have the advantage that they capture the contributions from all sources in the frequency range of the device.

Two cross sectional studies on possible health outcomes were performed in the vicinity of base stations. *Hutter et al., 2002* used frequency selective spot measurements to investigate a possible relation between subjective symptoms and the exposure from base station, *Navarro et al.,2002* took broadband meters to investigate similar outcomes. The broadband approach does not give the opportunity to distinguish between the contributions from different sources, it is therefore usually not possible to establish a link between the exposure from a base station or another specific electromagnetic source and health relevant outcomes as long as no additional methodological approaches like analytical calculations are used to be able to differentiate between the contribution from the investigated type of source and other relevant contributions from other types of sources. It is a better approach to use frequency selective equipment; however spot measurements do often neither take variations in space nor in time into account. Multiple measurements can give some information on the field variations in space.
The question remains open how representative spot measurements are for personal exposure.

In the frame of several measurement campaigns often intended to gain information on the exposure of the general public different technical approaches were used, e.g. *Bornkessel and Schubert,2004*, *Danestig,2004*, *Neubauer,2003*, *Neubauer et al.,2001*. The fact that different assessment protocols were used makes a direct comparison of the results often questionable. In most of the cases spot measurements were performed. Broadband measurements are in general not suitable to give information on the immissions arising from a specific source and are therefore not adequate to be used for the exposure assessment in the frame of epidemiological studies on specific RF sources. The use of frequency selective equipment allows distinguishing between the contributions from different sources and is therefore better suited. Additional measures are necessary to deal with variations in time. Two approaches seem to be suitable to assess RF exposure in situ: monitoring and the use of dosimeters.

In the ELF range it was demonstrated that there is no correlation between long time measurements of 24 or 48 hours and spot measurements (*Schüz and Mann,2000*), however it is unknown if this also true in the RF range. Of course also monitoring over periods of 1 or 2 days cannot take long term variations into account.

3 Epidemiological Analysis

3.1 Existing epidemiological studies on RF sources and health

The objective of this chapter is to give an overview on existing epidemiological studies in the radio frequency field. It is aimed to differentiate between the various study types. An epidemiological study is per definition a study on a human population which attempts to link human health effects (e.g. cancer) to a cause (e.g. exposure to a specific chemical). Epidemiological studies include observational studies as well as intervention studies. Human experiments in laboratories or clinical trials do not belong to the classical definition of epidemiology, however, these designs are also discussed in the report because they play an important role in this research area. There are different epidemiological study types, including hybrid designs. Overlapping and hybrid studies are therefore discussed in those chapters where they are considered most appropriate. For each study type a short introduction/definition is given (summarized from 'modern epidemiology'*(Rothman and Greenland, 1998))* and a number of examples in the radio frequency range are referenced. These references are not intended to be complete, but are used to clarify which study types have been used to investigate different health outcomes. The objective of this overview is to show possible study designs in the radio frequency range for different outcomes. Moreover advantages and disadvantages for each study design will be discussed. It has to be emphasized that the chapter did not aim to consider evidence of possible associations between health effects and exposure to radio frequency and microwave electromagnetic fields. That can be found in a number of published review articles *(e.g. (Breckenkamp et al., 2003; Cook et al., 2002; Elwood, 1999; Elwood, 2003; Goldsmith, 1995; Goldsmith, 1997; Heath, Jr., 1996; Hyland, 2000; Jahn, 2000; Repacholi, 1998; Röösli et al., 2003c; Rothman, 2000; Warman et al., 2003*)). However, we do systematically review epidemiological studies on base stations

3.1.1 Experimental studies

In an experiment, those who are exposed to the agent are exposed only because the investigator has assigned the exposure to the subject. Because the goals of the study rather than the subject's needs determine the exposure assignment, ethical constraints limit the circumstances in which experiments are feasible. It is obvious that an exposure to radio frequency fields during the experiment must not jeopardize the health status of the study participants to the best of our knowledge.

3.1.1.1 Clinical trials

A clinical trial is an experiment with patients as subjects. It exists in a research area investigating therapeutic applications of RF fields. Because this aspect is not relevant with respect to adverse effects from mobile phone base stations we do not focus on these studies here.

3.1.1.2 Laboratory studies / Human experimental studies

Introduction

In principle laboratory studies are not considered as an own study type. Often experimental studies are classified in clinical trials and field studies *(e.g. (Rothman and Greenland, 1998)).* In the context of RF field studies we consider it appropriate to distinguish between laboratory and field trials. Both types of studies are dealing with healthy subjects. In laboratory studies exposure is applied in the laboratory whereas field trials are 'real life' situations.

In a laboratory study exposure can be either applied in a cross-over design or in a parallel group design. The advantage of a cross-over design compared to a parallel group design is that between subject variability can be ignored as each subject is compared with her or himself. Thus, a smaller sample size is sufficient. However, carry over effects can occur, meaning that an exposure effects last into the unexposed period. In a parallel group design, an exposed group is compared with an unexposed group. Thus, study results can be confounded by different group characteristics. Major characteristics of laboratory studies are randomisation and blinding (see also Strengths), which often cannot be achieved in field trials and are usually not possible in observational studies.

Outcomes studied

Due to ethical restrictions laboratory studies have focused on physiological effects; adverse health effects cannot be investigated in laboratory studies for obvious reasons.

A number of studies investigated changes in the electroencephalogram (EEG). Roughly these studies can be divided into studies either investigating spontaneous EEG when study subjects were awake *(e.g. (Hietanen et al., 2000; Lebedeva et al., 2000; Reiser et al., 1995)),* studies on spontaneous EEG during sleep *(e.g. (Borbely et al., 1999; Huber et al., 2000; Huber et al., 2002; Lebedeva et al., 2001; Mann and Röschke, 1996; Röschke and Mann, 1997; Wagner et al., 1998; Wagner et al., 2000))* or studies investigating evoked potentials *(e.g. (Arai et al., 2003; Bak et al., 2003; Croft et al., 2002; Eulitz et al., 1998; Freude et al., 1998; Freude et al., 2000; Hamblin et al., 2004; Hladky et al., 1999; Jech et al., 2001; Krause et al., 2000; Krause et al., 2004; Ozturan et al., 2002; Urban et al., 1998)).* Evoked potentials could be either visual or acoustic.

In most of these studies on EEG a GSM 900 exposure was applied. However, the exposure setting differed greatly. Specific absorption rate (SAR) during exposure was stated from 0.06 W/kg onwards until 2 W/kg, whereas most studies applied a level around 1 W/kg. Exposure duration was often in the order of 30 to 60 minutes, however, during sleep it was longer. In a few studies intermittent exposure was applied. Some studies applied the exposure previous to EEG recording.

Laboratory studies have also focused on cognitive functions, partly concurrently investigating EEG *(Curcio G. et al., 2004; Edelstyn and Oldershaw, 2002; Freude et al., 1998; Haarala et al., 2003b; Jech et al., 2001; Koivisto et al., 2000b; Koivisto et al., 2000a; Krause et al., 2000; Krause et al., 2004; Lass et al., 2002; Preece et al., 1999; Zwamborn A.P.M. et al., 2003).* Most of those studies applied a GSM 900 exposure from a mobile phone handset during a period of 30 to 60 minutes.

With respect to possible effects from base stations the so called Dutch TNO study is most relevant because they applied an UMTS or GSM signal from a base station under far field condition *(Zwamborn A.P.M. et al., 2003).*

Additionally, perception of field status as well as subjective symptoms or effect on the well being has been investigated in a number of studies *(Hietanen et al., 2002; Koivisto et al., 2001; Radon and Maschke, 1998; Tahvanainen et al., 2004; Zwamborn A.P.M. et al., 2003).*

Further investigated endpoints in laboratory studies were cerebral blood flow in the head *(Haarala et al., 2003a; Huber et al., 2002)* or ear *(Monfrecola G. et al., 2003),* and effect on the circulatory system (pulse rate, blood pressure, etc) during exposure to a mobile phone handset *(Braune et al., 1998; Braune et al., 2002; Hietanen et al., 2002; Huber et al., 2003; Mann et al., 1998; Tahvanainen et al., 2004).*

A few studies focussed on effect of the hormone system such as melatonin, cortisol, growth hormones, etc.*(Bortkiewicz et al., 2002; Braune et al., 2002; de Seze et al., 1998; Jarupat et al., 2003; Mann and Röschke, 1996; Radon et al., 2001).* A laboratory study on the immune system investigated effects on neopterin and salivary immunoglobulin A (sIgA) *(Radon et al., 2001).*

Strengths

The advantage of laboratory study is that exposure can be applied under controlled conditions. The gold standard for laboratory studies is to be double blind and randomised. In cross-over studies exposure

sequences should be counterbalanced and possible carry over effects should also be avoided by sufficient length of the wash out period and additionally taken into account in the data analysis.
In particular, using a cross-over design allows application of various exposure conditions in order to get information about possible relevant exposure settings such as exposure level, exposure duration, frequency, modulation etc. Other exposure sources both in the electromagnetic field range and further environmental factors can be eliminated. Thus, bias and confounding can be controlled to a large extent. It is possible to perform sensitive physiological measurements using sophisticated instruments which are operated by experts. Such physiological measurements may be useful in order to elucidate a biological mechanism.

Weaknesses

The main disadvantage of laboratory studies is the fact that only the investigations of short term exposures are feasible. It is not possible to expose study subject over a period of several weeks. Thus, it is not feasible to examine effects occurring only after long exposure duration or effects occurring after short exposures but with a long latency until the effect is apparent. Due to ethical constraints only physiological effects but not health effects can be studied. Thus, the question about the health relevance of the studied outcomes will inevitably arise. Due to logistic reasons only a relatively small sample size can be investigated in the laboratory and thus only large effects can be detected. Also, sensitive subgroups, should they exist, is likely to be missed. Possibly recruiting of study participants creates a selection bias, as not everybody would agree to take part in such a study. Thus, the generalisability of the results may be hampered.
Another issue is that physiological measurements possibly are too sensitive and too unspecific. Investigating a large number of sensitive parameters is expected to result in false positive findings.
Further it has to be considered that the unfamiliar laboratory environment may create some distress and may cover subtle physiological effects or effects on well-being.

3.1.1.3 Field trials

Introduction

A field trial is defined as a study on persons exposed to RF outside the laboratory. We distinguish between two different kinds of exposure settings in such studies. One possibility is that an experimental set up is placed outside of the laboratory, e.g. at the participants home or work place. This type we call artificial experimental field trial. The second possibility is that an existing exposure source (e.g. transmitter) that can be turned on and off is studied, or if a study is made in a population where new sources are built (e.g. base stations). However, this may also be considered an observational study. We call this a “natural” experimental field trial. In an artificial experimental field trial one needs to expose people that would otherwise have been unexposed, and therefore the same ethical constraints exist as discussed above for the laboratory studies. In a natural experimental field trial this issues is limited to questions about data privacy etc.
In most cases a field study is longitudinal and prospective. In a longitudinal design a panel of subjects is observed during a given time. Each individual can be compared with him or herself. This leads to more sensitivity due to lower data variability and allows a better control of bias/confounding. However, training problems can arise, when subjects have to answer the same questions on several occasions. Cross-sectional or retrospective field studies are also conceivable. For instance comparing different populations where new base stations are being built and taken into operation immediately, and some where new base stations are built but not taken into operation immediately. If data are available retrospective studies would allow analyses of longer latency periods when comparing disease rate after setting up a new source. However, it is obvious that bias/confounding from longer-term secular trends and changes in competing risks would become more problematic with increasing time span.

Mainly in natural experimental studies (e.g. residents of a transmitter) study subjects are not exposed to the same amount of radiation. This would allow analyses of dose response relations.

Outcomes studied

There are not many field studies available. Effects of a permanent shut down of a short wave transmitter on sleep quality and salivary melatonin level has been studied *(Altpeter et al., 1995).* The effect of setting up a new base station on sleep quality was investigated in a pilot study *(Röösli et al., 2003b).*
A possible association between daily use of mobile phone and the excretion of the melatonin metabolite 6-hydroxymelatonin sulfate (6-OHMS) was investigated based on urine samples from 3 days *(Burch et al., 2002).*

Strengths

The advantage of field trials is that people are investigated in a 'real life' exposure situation. Thus, the exposure circumstances are directly relevant for the public, at least in the field trial from type 'natural experiment'. Compared to an unknown laboratory situation, the familiar real life situation is expected to lead to a more sensitive symptom reporting. This may be particularly relevant for all symptoms of well being which are characterized by an unclear and subjective diagnosis (e.g. headache, sleep disturbances, etc.) More sensitive symptom reporting may offer the possibility to study subtle effects. Field trials allow studies of longer exposure periods than a laboratory study could reasonably achieve. As the effort for participating in the study is generally lower than in a laboratory study, participation bias may be lower, guaranteeing a study group which is more representative of the general population.
Larger samples can be investigated than in the laboratory which results in more power. If individuals are compared with themselves, effect of bias and confounding on the study result can be reduced.

Weaknesses

Blinding study participants from exposure status is the most difficult part in field studies. Emissions from base stations or broadcast transmitters can be easily detected using corresponding communication devices. Thus, study participants could use measurement devices to measure exposure levels. Thus, even artificial signals, which are not used for communication, can be detected. This problem becomes particularly important when study participants are neighbours and communicate with each other as it may often be the case in natural experimental field studies. In this case knowledge of exposure status may disperse rapidly.
Due to logistic reasons only simple physiological measurements can be performed at participants' homes.
Only diseases with a relatively short latency can be studied in field trials. Analysis of rare diseases or diseases with a long latency may be difficult as bias and confounding are complicated to exclude over a longer time period.

3.1.2 Non experimental studies (observational studies)

3.1.2.1 Cohort studies

Introduction

In the classic cohort study, the investigator defines a group of people that are free of disease and that differ according to the extent of their exposure to RF field. Cohort studies could be prospective or retrospective. In prospective studies exposure measurement are performed before occurrence of disease. (The prospective/retrospective distinction is sometimes used to refer to the timing of subject identification. If so, retrospective means that subjects are identified today and the study follow up period started in the past.) Prospective cohort studies are often considered as the gold standard in order to investigate causal effects. However, retrospective cohort studies are often more convenient, in particular for diseases with a long latency or induction period. It is crucial in a retrospective study that collection of the exposure and confounder information is made independently of the disease. The difficulty in retrospective cohort studies is to elicit historical exposure. Historical high-quality and complete databases on exposure are needed to construct valid exposure metrics for retrospective cohort studies. Cohort studies are not very efficient for rare diseases, because for such diseases a large study sample is needed to serve enough cases. Thus, cohort studies on rare disease are mostly based on registry information where it is not necessary to personally contact every study participants. The price of doing a large cohort study is often a less sophisticated (and hence cruder) exposure assessment. In prospective cohort studies collection of exposure and confounder information can be systematically planned. Thus, in small cohorts where it is feasible to contact individuals directly, high data quality can be obtained. However, such studies are feasible only for relatively frequent diseases.

Proportional mortality studies are often referred to as cohort studies. A proportional mortality study includes only dead subjects. Such data are often easily available and can be linked to registry information to collect exposure and confounder data. The proportion of dead exposed subjects assigned to one ore more specific cause of death is compared with the proportion of dead unexposed subjects to the index causes (or the general population).

Outcomes studied

Prospective cohort studies on RF field exposure have not been performed so far.

Retrospective cohort studies have focussed on cancer from occupational exposure. For instance brain tumour risk of Motorola employees *(Morgan et al., 2000),* testicular cancer from radar guns in police officers *(Davis and Mostofi, 1993; Salvatore, 1993; Volkers, 1992),* delivery outcome of physiotherapists exposed to diathermy devices *(Guberan et al., 1994; Kallen et al., 1982; Lerman et al., 2001)* or semen quality and hormone levels among radiofrequency heater operators *(Grajewski et al., 2000).*

Overall and cancer mortality, or incidence have been investigated in amateur radio operators *(Milham, Jr., 1988a; Milham, Jr., 1988b),* plastic-ware workers *(Lagorio et al., 1997),* military persons *(Szmigielski, 1996)* other occupational exposures *(Cano and Pollan, 2001)* and mobile phone users *(Dreyer et al., 1999; Johansen et al., 2001; Rothman et al., 1996).* Cutaneous melanoma has been investigated with respect to occupational exposure *(Perez-Gomez et al., 2004).*

Strengths

The main advantage of prospective cohort studies is the fact that collection of exposure and confounder information can be done prior to disease onset. Thus, possible bias is reduced (or can be adequately treated) to a large extent. However, budget restriction may limit the design, especially in studies of rare outcomes. In retrospective studies data quality is determined by availability.

An advantage of a cohort study is the fact that several diseases can be studied simultaneously. Outcomes can even be added during the conduct of the study, if there is scientific evidence that the particular outcome has to be investigated.

Additionally, the incidences of the disease of interest can be calculated. Thus, risk can be expressed in absolute numbers which may be useful in many circumstances.

Weaknesses

Cohort studies are not very efficient for rare diseases. In order to investigate rare diseases a large study population is needed. Thus, often there is a trade off between study size and quality of information on exposure and possible confounding factors which can be obtained. Thus, a high quality cohort study is generally quite expensive. Large cohorts are usually based on data from registries where data availability is limited in terms of the study goal. Prospective cohort studies are time consuming, whereas retrospective exposure assessment is limited due to data availability, and often very crude assessments of the exposure must be used which may hamper the ability to detect modestly increased risks.

The main problem in a proportional mortality study is that exposure that you study may increase mortality overall, and if you only include dead subjects, an increased mortality of for example brain tumours can be hidden by an increased mortality of other causes such as heart disease, stroke, etc. In contrast a cause can increase the index cause of death or can prevent from other causes of death resulting in a relative increase of the index cause of death.

3.1.2.2 Case-control studies

Introduction

Case-control studies are best understood by defining a source population, which represents a real or hypothetical study population in which a cohort study might have been conducted. In a case-control study, the cases are identified and their exposure status is determined. A control group is randomly selected from the same source population and their extent of exposure is compared with the cases. Thus, the difference between the cohort design and the case-control design is that in a cohort study exposure information is collected for the whole study base, while in the case-control study exposure information is only collected from a sample. That makes case control studies more efficient for rare diseases. A prospective case ascertainment in case-control studies means that incident cases are ascertained prospectively starting from the beginning of the study. A retrospective case ascertainment, e.g. based on data from population-based cancer registries, is based on cases that were diagnosed during a particular time interval in the past. Retrospective case ascertainment is a problem in interview-based studies examining fatal diseases, since many of the cases may have deceased.

Outcomes studied

Case control studies were mainly used to investigate possible associations between different types of cancer and exposure to sources in the microwave or radio frequency range. A few case control studies investigated brain tumour risk of mobile phone users *(Auvinen et al., 2002; Collatz Christensen et al., 2004; Hardell et al., 1999;; Hardell et al., 2002a; Inskip et al., 2001; Muscat et al., 2000; Muscat et al., 2002),* of military persons *(Grayson, 1996).* Testicular cancer has been investigated in association with use of radar guns *(Hayes et al., 1990).* Risk of uveal melanoma has been studied in association to occupational exposure and use mobile phones *(Stang et al., 2001).* Outcome delivery in physiotherapists using diathermy has been studied in case control studies *(Larsen, 1991; Taskinen et al., 1990)* as well as parental occupational exposures and the incidence of neuroblastoma in offspring *(De Roos et al., 2001).* Childhood leukaemia and exposure to broadcast transmitter, *(Maskarinec et al., 1994)* and adult leukaemia due to occupational exposure has been studied *(Fabbro-Peray et al., 2001).*

Strengths

Case control studies are more efficient than cohort studies, in particular for rare diseases. The smaller study group allows collection of more detailed exposure information for the same cost. Besides that the same strengths as for cohort studies hold, as long as the control group truly is a representative sample of the population that have generated the cases.

Weaknesses

The main disadvantage of case control studies is that additional bias may occur compared to cohort studies due to an inappropriate selection of the control group or low participation rates. It is often difficult to prove whether such bias occurred or not. In addition, exposure assessment is often limited because it usually has to be done retrospectively. Even the use of measurement instruments is critical in case-control studies, because it needs to be shown that today's measured values are representative for the etiologically relevant time period. A crucial point in case control studies is to assure that information is collected independent of disease status. This goal may be jeopardized by the fact that cases are more motivated to think about past exposure than controls, which may introduce differential exposure misclassification, i.e. recall bias.

3.1.2.3 Cross-sectional studies

Introduction

In a cross-sectional study disease prevalence and exposure status are measured at the same point in time. Thus, drawing of any conclusions in terms of causal associations is strongly limited and is usually based on the assumption that present exposure is correlated to historical exposure. Moreover, it is often difficult to take into account other factors possibly confounding the study result. In cross-sectional studies the population studied can be either a (representative) sample from the general population (survey) or various groups of people differing in terms of the extent of exposure (e.g. occupational groups).

Cluster studies can be of cross-sectional or ecological design. Cluster studies investigate the occurrence of a disease at a given place (in the vicinity of an exposure source of interest) with the occurrence of disease in a control region. There are numerous problems related to that type of study which is discussed below.

Outcomes studied

Two studies investigated unspecific health symptoms and residential proximity of living close to mobile phone base stations using a cross sectional design *(Navarro E.A. et al., 2003; Santini R. et al., 2003a; Santini R. et al., 2003b; Santini et al., 2001a; Santini et al., 2001b).* A number of studies focussed on unspecific health symptoms in mobile phone users *(Chia et al., 2000; Hocking, 1998; Oftedal et al., 2000; Sandstrom et al., 2001; Santini et al., 2001b).*

A few studies investigated parameters of the immune system such as number of leucocyte and lymphocyte cells or monoclonal antibodies and antigens with respect to proximity of living place to a broad cast transmitter *(Boscolo et al., 2001; Del Signore et al., 2000)* or with respect to occupation exposure to diathermy devices *(Tuschl et al., 1999).*

Levels of hormones such as melatonin were studied in different occupational exposed groups *(Dasdag et al., 1999; Grajewski et al., 2000; Vangelova et al., 2002).*

Effects on the circulatory system from broadcast transmitters (pulse rate, blood pressure, etc) were studied in different occupationally exposed groups *(Bortkiewicz et al., 1996; Bortkiewicz et al., 1997).*

Neurophysiological examination, 24 h electrocardiogram and unspecific symptoms of ill health such as headache, fatigue, etc has been investigated in radio frequency plastic sealer operators and compared with controls *(Wilen et al., 2004).* Human attention has been compared in user of mobile phones compared to non users *(Lee et al., 2001).*

Chromosomal aberrations in peripheral blood lymphocytes from people occupationally exposed to radio frequency radiation have been studied *(Fucic et al., 1992; Garson et al., 1991; Lalic et al., 2001; Maes et al., 1995).*

Strengths

Cross sectional studies are often relatively cheap and can be performed relatively easily in terms of organisational complexity. In some circumstances routinely collected data may be adequate to do a cross-sectional study. In principle long and short term effects can be addressed. For instance comparing cancer prevalence with electromagnetic field measurements at home addresses implicitly effect of a long term exposure assuming that the measured value is representative for the past. In contrast occurrence of headache on a given day with respect to use of mobile phone on that specific day would address short term effects.

Weaknesses

Causal associations cannot be directly studied in cross sectional studies as disease and exposure information are collected at the same time. Conclusions are usually drawn based on assumptions which cannot be proven. For instance that present exposure is representative for previous exposure.

It may be difficult to separate cause and effect. Disease status may influence the exposure status. For example mobile phones are less useful if one is bedridden. Also possible confounding factors may be influenced by disease status.

One problem in cross-sectional surveys is the fact that cases with a long duration of the disease are over represented and those with a short duration have a little likelihood to be included in a cross-sectional survey. This is important when studying an agent which does not alter the risk of disease but the duration of illness. Let's assume that RF field would cause a faster tumour progression resulting in premature death of exposed cases. Thus, exposed cancer cases would be less likely to be included in a cross-sectional survey than not exposed cases. Therefore, one would find more cancer cases which are not exposed than exposed.

Additional problems occur in cluster studies. First of all, there is a problem of a priori cluster, i.e. that an eye-catching number of cases has been observed in a relatively small area and has been ascribed to a potential hazard source. An ensuing investigation might conclude that indeed significantly more cases had been occurred than expected. However, it remains unclear whether this is by chance and would not have been observed around other hazard sources from the same type. In this situation there is often a post hoc or no hypothesis. Another issue is that boundaries in time and space of clusters are often drawn arbitrarily. In particular boundary shrinkage of cluster is a problem. One case of a rare disease in a very small population is always more than expected.

3.1.2.4 Ecologic studies

Introduction

In ecologic studies the exposure information is not obtained on an individual level, but rather for groups of people. The groups may be classes in a school, factories, cities, counties or nations. They may differ with respect to average exposure status in the group. Ecologic studies are often studies on available data on health and exposure that are combined. They may be hypothesis generating but cannot be used for hypothesis testing. Ecological studies based on prevalence are of a cross-sectional design. Studies based on incidence take into account the time dimension. If so, some of the problems in cross sectional studies can be avoided.

Outcomes studied

A few ecologic studies investigated a possible association between leukaemia incidence in children and/or adults and proximity of living place to broad cast transmitter *(Cooper et al., 2001; Dolk et al., 1997b; Dolk et al., 1997a; Hocking et al., 1996; Michelozzi et al., 2002; Selvin et al., 1992).* One study compared spatial and temporal correlations between melanoma incidence and frequency modulated broadcast transmitter density *(Hallberg and Johansson, 2002).* Two studies focussed on time trends in brain tumour incidence in order to compare with the increasing use of mobile phones within the last two decades *(Cook et al., 2003; Lonn et al., 2004).*

Strengths

In ecologic studies usually routinely collected data are used. Thus, data are easily available and cheap analyses can be performed. Many hypotheses can be generated.

Weaknesses

The main problem is the ecological fallacy: the bias that may occur because an association observed between variables at an aggregate level does not necessarily represent an association that exists at an individual level. In addition, different groups of people differ not only with respect to exposure status but also other factors possibly confounding the exposure disease association of interest. Information about possible confounders are only available on group level but not on an individual level. This limits the possibility of controlling confounding factors to a large extent. Imagine, a comparison of two regions differ in exposure prevalence and disease incidence, with a higher incidence in the region with the higher exposure prevalence. Then it cannot be concluded that the excess of cases is attributable to exposure because it is not known if the cases were really those individuals that were exposed.

Another issue is data quality. There may exist spatial (or temporal) variability in the data quality. Thus, differences in the prevalence/incidence of a disease across regions (or over time) may be not a result of different exposure status but different methods used to collect data. Conclusions in terms of causal associations cannot be drawn. Difficulties of cluster studies which can be of ecologic design are discussed in chapter 3.1.2.3 (Weaknesses).

3.2 Existing epidemiological and human experimental studies on base station exposure: a critical systematic review

3.2.1 Selection of relevant studies

A systematic search in the online database Pubmed (*http://www.ncbi.nlm.nih.gov/PubMed/*) using the MESH[1] search strategy yielded one epidemiological study on adverse effects from base stations.[2] It was the survey study from Santini and colleagues *(Santini et al., 2000).* Performing a conventional search strategy using the ambiguous term “base station” combined with “health” results in 44 hits[3], thereof only the French survey addressed health risk from mobile phone base station. The other studies were either comments, reviews or dealing with exposure aspects or with different kinds of base stations (not used for communication).

However, we are aware of additional approaches undertaken to investigate possible health risks from mobile phone base station exposure. Recently a Spanish survey has been published (Navarro E.A. et al., 2003). Another cross-sectional survey from Austria has been presented at the Workshop in Rhodes 2002 *(Hutter H. et al., 2002).*

A pilot field study on sleep quality in a cohort of 24 residents during the process of setting up a new mobile phone base station was presented at the EBEA conference in Budapest 2003 *(Röösli et al., 2003a).*

Another study investigated immediate effects of UMTS and GSM exposure under far field conditions (similar to that from base stations) on cognitive functions and well being in a randomised double blind manner *(Zwamborn A.P.M. et al., 2003).* All of these studies will be discussed here.

3.2.2 Study results

3.2.2.1 Cross-sectional surveys on base station exposure

Three cross-sectional surveys on health effects of mobile phone base stations have been performed. All of them focussed of unspecific symptoms of ill health. Symptoms were collected based on self administered questionnaire filled in by the study participants. Exposure assessment was based on self estimated distance to the base station or spot measurements. In the following the results of the three studies are discussed in more detail:

In a French survey 530 individuals (270 men and 260 women) filled in a questionnaire on 18 unspecific symptoms of ill health *(Santini R. et al., 2003a; Santini R. et al., 2003b; Santini et al., 2000; Santini et al., 2001a; Santini et al., 2002).* Study subjects were enrolled through information given by press, radio, and web sites, about the existence of a study on people living near cellular phone base stations. Symptom frequency was asked on a 4 level scale (never, sometimes, often, and very often). Questions were asked about fatigue, irritability, headaches, nausea, loss of appetite, sleep disturbances, depressive tendencies, feeling of discomfort, difficulties in concentration, memory loss, skin problems visual disturbances, hearing disturbances, dizziness, movement difficulties, and cardiovascular

---

[1] MeSH is National Library of Medicines controlled vocabulary used for indexing articles for MEDLINE/PubMed. MeSH terminology provides a consistent way to retrieve information that may use different terminology for the same concepts (http://www.nlm.nih.gov/mesh/meshhome.html).

[2] The exact search term was: "Radiation, Nonionizing/adverse effects"[MeSH] AND base station AND epidemiology, performed on 21 April 2004

[3] the exact search term was “base-station* AND health”

problems. Frequency of symptoms was cross tabled with self estimated distance of the residence from a base station (<10 m, 10-50 m, 50-100 m, 100-200 m, 200-300 m, >300 m). Frequency of the complaints experienced in relation to responses with 0 (=never), were analysed by means of chi-square test with Yates correction taking the group of people living at least 300 m from the next base station as reference group. Each symptom was statistically significantly more frequent than in the reference group in at least one exposure category. Most evidence was found for fatigue, headaches, and sleep disturbances.

A similar survey was performed in la Nora using the same method and a Spanish language adaptation of the French questionnaire *(Navarro E.A. et al., 2003).* 101 questionnaires were analysed. This was more than 5% of all inhabitants of La Nora. The authors state that 70 percent of the distributed questionnaires were returned, but they do not describe how and based on what criteria questionnaires were distributed. Spot measurements in the bedroom of each participant have been performed. However, apparently exposure assessment was based on self estimated distance to the base station. 47 individuals living closer than 150 m to a base station were considered as exposed (mean field levels 0.65 V/m) the remaining lived more than 250 m from a base station (average field level 0.2 V/m). It is not discussed why no individuals were living between 150 and 250 meters from a base station, which would have been expected if the participants is a random sample of the population. Most of the symptoms were statistically significantly[4] more frequently observed in the exposed group (irritability, headache, nausea, appetite loss, discomfort, sleep disturbance, depression, difficulty in concentration, dizziness).

An Austrian cross-sectional survey has focussed on subjective symptoms and complaints, sleep quality and cognitive performance in people living in urban and rural areas for more than one year in proximity to one of ten selected base stations *(Hutter H. et al., 2002).* Eligible subjects were living in the direction of the main beam of the antennae with a maximum distance of 200m. 365 individuals were randomly selected from the telephone directory (Vienna) or by random walk (Carinthia). Participation rate is not published. They answered questionnaires and performed reaction time tests on a laptop after an introduction of the study assistant. After completion dates were arranged for the visit of a technician to measure exposure to EMFs. Measurements were performed in sleeping rooms. Field measurements yielded field values in the high frequency range from 0.01 to 0.75 V/m, 70 percent of exposure was estimated to be from mobile phone base stations. An analysis of covariance (ANCOVA) did not reveal a significant exposure effect on cognitive performance and perceptual speed. After controlling for concerns about base station a sleep quality score which was accumulated from questions about sleep length, problems falling and staying asleep, recovery during sleep and number of symptoms of insufficient sleep was not related to exposure. Unspecific symptoms of ill health were divided into three categories exhaustion, digestive and cardiovascular symptoms. A significant exposure effect was observed in the latter but not in the first two types.

3.2.2.2 Field study on sleep quality

A pilot study in the vicinity of a future base station site during the process of setting up the station was performed in Switzerland *(Röösli et al., 2003a).* It was aimed to test whether psychological effects (due to the building of a station) and physical effect (due to radiation) can be investigated with such a study design. Study participants were recruited from areas that were expected to be most heavily exposed: main radiation beam, maximum distance 500 m. From 76 eligible households 37 individuals agreed to participate and 33 individuals finished the study. They filled in sleep diary during 6 weeks and gave first void urine every Wednesday morning to determine cortisol levels. In one participant an actiwatch device was tested to record activity during the night. Only the period during which the station started to transmit could be examined due to logistical problems. Exposure levels were almost identical after transmission started because the radiated power was set much lower than allowed. Thus, data were not meaningful with respect to change in the exposure levels. However, it was concluded that sleeping diary data were useful for such analysis. Compliance of randomly selected individuals was good and the data reflected

---

[4] data apparently analysed based on t-test using numerous values of symptom reporting (0-3).

external influences on sleep such as caffeine/alcohol intake, day of week and therefore should provide sensitive outcome data for this type of study. Actigraph data provided additional information whereas urinary cortisol levels appear to be less useful for short term analyses.

3.2.2.3 Laboratory study

Only one laboratory study focussed on far field exposure similar to exposure from mobile phone base stations *(Zwamborn A.P.M. et al., 2003).* In a randomised, counterbalanced order, placebo, GSM 900, GSM 1800 and UMTS signal exposure were applied to a group of 36 individuals perceiving themselves as EMF hypersensitive and a group of 36 individuals not stating problems with EMF exposure, respectively. Exposure level was 1 V/m at maximum. Possible effects on well-being and cognitive performance were addressed. Well-being was evaluated based on a 23 item questionnaire. Each of the questions had to be answered on a 4 step scale from having symptoms ‘not at all’ to ‘extremely, could not have been worse’ (corresponding to the values 0 to 3). During exposure study subjects performed a reaction time test, memory comparison test, visual selective test and dual tasking test. In both groups significant effects on well-being was associated with UMTS exposure but not GSM exposure. In the sensitive group mean well-being score was 7.5 after placebo exposure and 10.8 after UMTS exposure. In the reference group the respective values were 2.4 (placebo) and 3.1 (UMTS). Cognitive performance was not consistently associated with exposure, for both UMTS and GSM.

3.2.3 Discussion

In all three cross-sectional surveys significant associations between well-being and exposure from mobile phone base station were observed. The main problems in these surveys are the potential for bias, especially selection bias, and self-reporting of the outcome in combination with the exposure assessment methods used. Self-reported distance to the base station was used as exposure proxy in the French and Spanish surveys. It has been shown that distance is not correlated to measured field levels *(Röösli et al., 2002a; Schüz and Mann, 2000).* Thus, it is unlikely to be a useful proxy for actual exposure. It is also possible that the outcome (lack of well being) may have influenced the estimation of the distance to the base station. In addition, measured levels in the Spanish and Austrian survey were very low. Thus, it has to be expected that use of mobile phones and other sources in the high frequency range may play an important role and leading to further misclassification of exposure. None of those surveys did take such sources into account. For instances people living far away from mobile phone base stations may be more exposed when using a mobile phone than people living close to a base station due to power control of the handset *(Lönn et al., 2004).* None of those surveys did take into account use of mobile phone in their analyses on a rough level at least.

Another big problem is selection of study participants in cross-sectional surveys. In the French and Spanish survey this procedure is not well described, however is likely to be biased. The study was communicated in the media as a mobile phone base station study. This is expected to result in a highly selective and biased study collective. It is obvious that people ascribing their symptoms to base station exposure must live close to a base station. Additional including a few persons not directly exposed with less health problems would result in the observed associations. The Austrian survey used a more appropriate procedure by collecting a population sample. Moreover, exposure assessment was based on field measurements.

Additionally, unsuitable statistical analyses was done in the French and Spanish survey (no adjusting for confounding, multiple testing, violation of the normal approximation, etc). Beside the study specific weaknesses it has to be considered that the design of cross-sectional survey do not allow any conclusions in terms of causal associations (see chapter 3.1.2.2). Thus, overall it is not possible to draw any conclusions from those cross-sectional surveys. The observed associations may primarily reflect the concerns of the population.

The design of the field study described above has the advantage that each person is compared with himself before and after exposure. Thus, potential for bias and confounding is reduced compared to cross-sectional surveys and data variability is reduced to within subject variability of study participants. For instances, it can be expected that exposure to other sources than base station remains more or less stable (or varying randomly, respectively). Thus, misclassification of exposure due to other sources is reduced. However, the exposure setting is crucial in this type of study. Appropriate sites are rare and transmission apparently starts at a low level, because of the dense net which already exists and to avoid interference problems with neighbour cells. Thus, it is difficult to generate considerable exposure differences. Moreover, blinding of study participants is crucial to reach.

The laboratory study described above was randomised and double blind, obviously the most superior study design of all base station studies. The observed significant alteration of the well-being was not expected on the low UMTS exposure level. Though the observed effect was relatively small, it was statistically significant. The association is unlikely to be caused by confounding or bias because of the randomisation and controlled exposure situation which is part of the experimental study design. Nevertheless it cannot be ruled out finding from chance or some kind of artefact (e.g. that exposure status was somehow perceivable, audible). Therefore, these results need to be replicated before any conclusions can be drawn.

Overall conclusion is that base station studies to date are uninformative and much can be done to improve.

3.2.4 Ongoing studies

We are aware of a few ongoing studies which are presented in brief.

3.2.4.1 Deutsches Mobilfunk Forschungsprogramm

(Source: www.deutsches-mobilfunk-forschungsprogramm.de)

The German Mobile Radio Research Program is being developed by the Federal Environment Ministry (BMU) and the Federal Office of Radiation Protection (BfS) between 2002 and 2006. The project is financed by the BMU and the Mobile Services providers (with 17 Mio. Euros) and performed and coordinated by the BfS.

The project encloses four areas of research: Biology, Dosimetry, Epidemiology and Risk Communication, all directed towards the most widespread communication systems, GSM and UMTS.

The goal is to provide evidence of relevant biological mechanisms and the effects that these technologies provoke in health as long as an improvement of the available knowledge to date.

Other aims are the study of the causes of “electro sensitivity” and it is also stated that the results of this research can be widely used for the Telecommunication technologies on its whole to be used in future systems.

The emphases of the program are:

1. Mechanisms of action of the RF fields,
2. Effects in humans and animals,
3. Ascertainment of the exposure,
4. Risk communication.

Also of interest in this project is the internet portal (www.emf-forschungsprogramm.de) created by the BfS to include the description of the project, overview of the purposes, progress reports, final reports and short information brochures and abstracts (in German and in English). The website will also include the evaluation and description of other international projects about these topics.

Regarding biology, 22 projects are being performed. A project that studies the relations between breast cancer and exposure to HF-EMF (main focus UMTS and mixed exposures) is in planning stage.

In the field of dosimetry, interesting approaches dealing with base station's exposure are a project to evaluate (performing a "state of the art" literature research) the measurement techniques and devices to assess the exposure to base stations, and analysing the characteristics of the immissions from RF fields; and other project whose goal is the development and test of a system of RF-dosimetry for a cross sectional study about health risks and RF stations.

Among the planned projects the accurate classification of population into groups of exposure and the assessment of exposure round radio and TV broadcasting installations are also included.

In the field of epidemiology, a feasibility study of a cohort study of workers highly exposed to RF EMFs is already finished. 30 groups were primarily identified as highly exposed, and then tested according to certain criteria (exposure conditions and characteristics of the cohort). After the evaluation three potential cohorts were chosen (RF-resistance welders, technicians of medium- short wave facilities and radio amateurs) and a proposal for the study was made. However, the conclusion was not to perform a cohort study about high exposed workers, but to perform a cohort study of mobile phone users in the general population. The exposure is lower, but the health risks of mobile communications could be assessed, given, nonetheless, big cohorts due to the low exposure.

Assigned and planned epidemiological projects are: an extension of the international INTERPHONE project which investigates RF-exposure and the incidence of tumours in the head and neck zones; a cross-sectional study about assessment and evaluation of health risks due to base stations; two studies regarding child's health (cancer and exposure from big transmitters and health effects and mobile communications), and two studies regarding mobile phone users (a feasibility study for a prospective cohort study about incidence and mortality from cancer and neurodegenerative diseases, and a case-control study of functional disturbances, especially headaches) among others.

Finally, some projects about risk communications are also being developed to inform the public about the probable risks of the new mobile technologies.

The nationwide cross-sectional study will be described in more detail. The study is currently conducted to investigate health complaints in people living in the vicinity of mobile phone base stations. The study population consists of subjects in approximately 30,000 households that were randomly selected from all over Germany. The questionnaire of the cross-sectional study comprises questions on different aspects of health (particularly on health complaints that people attributed to electromagnetic fields in previous studies or anecdotal reports) and on characteristics of the residence and is one part of a large health panel questionnaire. The coordinates of the address of all participants will be linked to coordinates of the nearest mobile phone base station antenna. In this study, an attempt is also being made to calculate exposure from mobile phone base stations based on vertical and horizontal distance between residence and antenna and a variety of antenna characteristics like emitted power or downtilt. Depending on the validity of this newly developed metric (a validation study involving measurements is under way), this surrogate exposure will be used as either an exposure measure or a tool to select subjects stratified according to an expected exposure for a second study phase, in which a subsample will be further investigated by prolonged face-to-face interviews and more accurate exposure metrics (either measurements or more complex calculation methods).

3.2.4.2 MHTR, Mobile Telecommunications and Health Research

(Source www.mthr.org.uk)

In May 2000, the Stewart Report called for the establishment of a substantial independent research programme to help fill gaps in scientific knowledge about mobile phones and health.

This was accepted by the UK Government and mobile phone operators. In February 2002, a three-year £7.4 million independent health research program, the Link Mobile Telecommunications and Health Research Programme (MTHR), was announced. Mobile phone companies are funding 50% of the project, but will have no other involvement.

Regarding Epidemiology, the program will take the recommendations of the Stewart Report for further studies, which included:

- Large case control studies of brain cancer, acoustic neuroma, salivary gland cancer, and leukaemia.
- That in addition to already on going cohort studies, a large cohort study of long term mobile phone users be undertaken in the UK, which focuses particularly on people who started use in the 1980s and that, given the considerable design difficulties and potential costs entailed, a pilot study should be undertaken before a full scale investigation.
- Double blind trials be undertaken to assess the relation of mobile phone use to symptoms such as headache that have been reported by users, and that a cross sectional survey of symptoms be conducted in relation to mobile phone use in the UK.
- They propose that further epidemiological studies should be undertaken to clarify the relation of mobile phone use to the risk of motor vehicle accidents, and in particular whether the risk differs between hand held and hands free phones, and whether the risk of hands free use exceeds that of other forms of driver distraction, notably conversation with passengers.
- Finally, they say there is a need for a significant research program to be initiated so that the impact of mobile phone technologies on well being in its broadest sense is properly addressed and understood through epidemiological or other approaches.

Projects regarding base station exposure, funded by the MTHR are:

1. *UK Case-Control Study of Adult Brain Tumours.* A population based case-control study, conducted by identifying newly diagnosed patients with brain tumours from four areas in England and Scotland. The patients (with permission) help the study by giving details of their past use of mobile phones, other information about their past occupations and medical histories and also donate a blood sample.
2. *Case-Control Study of Cancer Incidence in Early Childhood and Proximity to Mobile Phone Base Stations.* In a case-control study in the UK the incidence of early childhood leukaemias/lymphomas and other cancers within 500 m of mobile phone base stations will be investigated. Cases comprise children in England and Wales aged 0-4 years, who were diagnosed between January 1st 1999 and December 31st 2001. In addition, a sub-study of children aged 0-2 years will be undertaken in order to minimise possible effects of migration. The postcoded national cancer registry will be used to identify cases (ca. 1700 cancer cases), the postcoded national birth dataset to identify controls, and the national “Sitefinder” database (augmented by data from the mobile phone operators) to provide data on base station locations and characteristics. Controls (one per case) will be matched on birth date and gender. Two proxies for exposure will be analysed for each case and control: distance from the nearest mobile phone transmitter and modelled power density. Power density is being modelled using a purposely-designed GIS-based propagation model. This uses data on the operating characteristics of each mobile phone transmitter (location, antenna height, antenna tilt, power output, gain), together with information on the surrounding topography (height, slope) to estimate the power density field within a radius of 500 metres. Power density is modelled as a log-normal Gaussian function of distance, centred on the point of intersection of the main beam with the ground surface. Summation of the power density fields for all transmitters at the place of residence of each case and control provides a measure of exposure. The model is being calibrated by detailed monitoring around a selection of isolated rural mobile phone masts. Once calibrated, the model will be validated through detailed monitoring at ca. 200 locations, stratified in terms of land cover (urban, rural), topography (hilly, flat) and exposure level (low to high). Field data will provide estimates of uncertainty in the exposure estimates (e.g. due to effects of

other emission sources and modelling error), which will be incorporated into the statistical analysis. Data on power density fields around FM masts are available from modelling undertaken by the companies. Data on other potential sources are not available. A range of proxies will therefore be used to take account of these, including location of (and distance from) major point sources such as airports, TV masts, and road density and population density as proxies for mobile sources (e.g. police or taxi networks). In addition, data on land cover will be incorporated into the statistical analysis, to take account of reflection and absorption by buildings and vegetation. Logistic regression techniques will used to analyse associations between health outcome and both distance from mobile phone mast and modelled power density, with control for potential confounders such as population mixing, rurality, other exposures). (taken from *Beale (2004)*).

3. *The International EMF Dosimetry Project.* The project was initiated at a NATO Advanced Research Workshop on RF Dosimetry in Slovenia in 1998. The mission of the project is to promote and develop high quality EMF dosimetry for the assessment of human exposure and for in vitro and in vivo experimental systems. The intention is to create an internationally-accepted Dosimetry Handbook which will be a living and substantially on-line document with integrated software tools and guides for dosimetry measurement and calculation.
4. *Measurement of the Power Density of Radio Waves in the Vicinity of Microcell and Picocell Base Stations.* Radio wave strengths will be measured near microcell and picocell base stations at twenty sites with a range of different base station designs and site characteristics in order to assess typical exposure levels. Spot measurements will be made using a spectrum analyzer and broadband antennas over a wide range of frequencies, chosen to encompass other environmental radio transmitters as well as base stations. A structured series of measurements will be made to produce a detailed profile of the radio wave strengths at ground level at a subset of the sites. The measurements will be interpreted by comparing them with the reference level advised by ICNIRP for exposure of the general public and also by comparing them with previously published measurements from larger (macrocell) base stations.

3.3 Evaluation of RF-studies performed so far

We identified 5 study types which are relevant in the area of adverse health effects from electromagnetic field exposure in the radio and microwave frequency range. There are different health outcomes investigated so far: EEG, blood pressure, cognitive performance, hormone secretion, well being[5], cancer, mortality, etc.

With respect to study design consideration, we group these outcomes based on two criteria. First of all, the time scale of effect manifestation plays an important role. Effects can either manifest immediately or within hours (immediate effects), within days to several weeks or few months (short term effects), or within one or several years (long term effects). Second, effects were classified as either being physiological effects, effects on well-being, or a third group of chronic disease with clearly defined diagnostic criteria (e.g. cancer, reproductive outcomes, etc.) or mortality. In contrast to the latter, effects on well-being are less standardized in diagnosis. They are often self diagnosed and thus more subjective. They are referred to as soft outcomes (see chapter 4.1.2). Physiological effects can be objectively measured. However, the normal physiological range is usually very wide and changes within that are difficult to interpret with respect to health relevance.

Time of effect manifestation as well as kind of diagnosis/measurement is directly related to the study design. A given study design may be appropriate for short term effect but not for long term effect or maybe appropriate for physiological changes but not for rare diseases.

Thus, for further discussion, we classify the following health outcomes:

- Immediate physiological effects (e.g. EEG, blood pressure, cognitive performance, hormone secretion, parameter of the immune system, etc).
- Short term physiological effects.
- Long term physiological effects.
- Immediate effects on the well being (such as headache, sleep quality, etc.).
- Short term effects on well being.
- Long term effects on well being.
- Long term chronic diseases (e.g. brain tumour, leukaemia, neurodegenerative diseases).
- Long term reproduction outcomes.
- Long term mortality.

In principle time period of effect manifestation cannot be addressed in cross-sectional studies. Nevertheless from a given study it can be derived what kind of effect manifestation a researcher inherently assumes. For instance in a study on cancer incidence in association with field levels at home, long term effects are addressed. That means the current exposure levels are considered to be representative for the past exposure at home (proxy). In contrast, if asking a sample of people about the occurrence of headache and the use of mobile phone on the respective day assumes a short term or immediate effect, respectively. In this context the cross-sectional base station studies on well-being are assumed both, short and long term effects.

Table 7 gives an overview on the health outcomes which has been investigated with a certain study design so far.

---

[5] well-being is related to the phenomena of electromagnetic hypersensitivity (EHS). EHS refers to people who report health problems that they believe are related to exposure to electromagnetic fields. In this context, most often non specific symptoms, such as sleep disorders, headache, etc. are reported. Objective criteria classifying these subjects as hypersensitive have not been established.

	Laboratory	Field	Cohort	Case-control	Cross-sectional[1)]	Ecologic
Immediate physiological effects						
Short term physiological effects						
Long term physiological effects						
Immediate effects on the well being						
Short term effects on well being						
Long term effects on well being						
Long term chronic diseases						
Short-long term reproduction outcomes						
Long term all cause mortality						

Table 7: Overview about health outcomes with respect to study type. indicates that studies have been done in the radio frequency range, indicates base station studies.
[1)] Time dimension in cross-sectional studies cannot be defined clearly as outcome and exposure measurements are performed at the same time point (see text). Thus, we determined time scale based on the underlying assumption.

Table 8 summarizes methodological strengths and weaknesses of each study type. This is a **general** and **simplified** discussion and refers to the potential of each study type. Obviously, study specific strengths and weaknesses depend on what has actually been done.

Exposure determination can be done most accurately in the laboratory and to some extent in a field study. In observational studies exposure determination is usually more complicated.

Control of bias is most effective done by study design. Thus, laboratory studies, which can be fully planned, allows control of bias to a large extent. In cohort studies bias can be controlled to a lower degree. Further reduced is control of bias in case-control studies; and lowest possibilities to control bias is present in cross-sectional and ecologic studies.

Control of confounding depends primary on the available information. Thus, a prospective study design allows collection of relevant information whereas retrospective studies are mostly restricted to available information (routinely collected data, interviews or questionnaires) (Laboratory studies and field trials can be considered as prospective study in a broader sense.)

Transferability of results to the general population is given in observational studies of the general human population under everyday exposure condition and is more difficult for laboratory studies. The power of a study depends primary on the sample size, the variability and prevalence of the exposure, and the incidence of the studied outcome.

With respect to effect manifestation laboratory studies are most appropriate for immediate effects, whereas cohort and case-control studies are necessary for long term effects.

	Laboratory	Field	Cohort	Case-control	Cross-sectional	Ecologic
Exposure misclassification	+	~	-	-	-	-
Contr. Of selection bias	+	~	~	~	-	-
Contr. Of confounding	+	+	~	~	~	-
Transferability of results	-	+	+	+	~	~
Power	-	~	+	+	+	+
Immediate effects	+	~	~	-	+	-
Short term effects	~	+	+	~	~	-
Long term effects	-	~	+	+	-	-

Table 8: Overview on methodological strengths (+) and weaknesses (-) of various study design (~ means medium)

4 Criteria for an appropriate epidemiological base station study

The aim of this chapter is to clarify the most important aspects which are relevant to judge feasibility of epidemiological base station studies. First, the most important concepts with respect to outcome measurements are discussed (chapter 4.1). Secondly, the most important exposure assessment concepts in epidemiological studies are introduced (chapter 4.2) and are discussed with respect to base station exposure (chapter 4.3). Later some aspects in study design concerning confounding and bias are presented in chapter 4.4 and criteria for a useful study are clarified from an epidemiological perspective (chapter 4.5). Finally requirements and suggestions for future metrics are made from a technical view point (4.6 and 4.7).

4.1 Health outcomes in base station studies

4.1.1 Type of health outcomes

With respect to methodological consideration in base station studies the following three types of possible outcome measurements are conceivable:

- Chronic diseases: cancer, neurodegenerative diseases, cardiovascular diseases, etc. Chronic diseases with clearly defined diagnostic criteria may be considered as most serious for health. They are rare and have generally a long latency[6] (at least in the low dose range). This also includes mortality studies.
- Physiological measurements: blood pressure, electroencephalogram, hormone levels, etc. Such parameters can be objectively measured. Physiological measurements can be an important part of the puzzle to evaluate hypothesized biological mechanisms. However, without such a context, the health relevance is often unknown, at least for immediate effects. Effect manifestation can be immediate, short-term or even long-term.
- Soft health outcomes: well-being related outcomes such as headache, dizziness, sleep disorders, etc.
  Well-being is subjectively rated, possibly combined with objective measurements. Well-being is health relevant. Effect manifestation can be immediate to long term.

These three types of health outcomes have different implications for study design considerations. Within this report we focus on soft health outcomes.

4.1.2 Soft health outcomes

4.1.2.1 Definition

‘Soft’ outcomes are a term which is widely used in health research, though a clear definition does not exist. Often soft outcomes are seen as the contrast to hard outcomes, which can be accurately determined, are quantifiable and do not depend on subjective impression by the affected subjects themselves. In principle, hard outcomes can be accurately reproduced by independent evaluators. In contrast soft outcomes are considered more subjective and may vary within and between observers.

---

[6] Actually, we refer in this context not only to latency but also induction period. The induction period is time until a disease occurs. It varies for different exposures (initiatior or promotor) and also for different diseases. The latency is the time from the point when the disease has occurred but is not yet diagnosed. This varies between diseases, but can also be affected by the expsoure.

Additionally, they may be time-dependent and their perception may vary within short time intervals. Thus, accurate reproduction is may be difficult to obtain and generally the assessment of soft outcomes are made with less confidence. Quality of life (QOL) scales are often referred as a typical soft outcome. Obviously rating of mood and well being belongs to the category of soft outcomes. However, the boundary between soft and hard outcomes is not always sharp. Diagnosis of soft outcomes such as headache, nervousness, sleep disorders, etc are generally based on subjective rating (questionnaires). However, using standardized questionnaires or appropriate physiological measurements does allow a certain amount of objectivity for the diagnosis of soft outcomes. In contrast the diagnosis of diseases (hard outcome) is not always that clear as one tends to assume as every diagnosis involves some judgement. Moreover, diagnostic procedures and classification of diseases may be different across studies and may change over time. Likewise, physiological measurements (hard outcomes) are not always easily reproducible and accurate. Several diagnoses may be placed between a soft and a hard outcome: e.g. tinnitus. In Table 9 soft and hard outcomes are compared.

Soft outcomes	Hard outcomes
Subjective	can be accurately determined
quantifiable only on arbitrary scales	are quantifiable
may vary within and between observers	should not depend on subjective impressions
crucial reproducibility	are accurately reproducible
often more relevant with respect to clinical status	may not be relevant to desired outcomes (physiological measurements)
tend to evoke less confidence	not always as accurate as one assumes
Examples: headache, nervousness, sleep disorders, etc.	Examples: death, cancer, reproductive outcomes, EEG, pulse rate, etc.

Table 9: Comparison between hard and soft outcomes.

4.1.2.2 Rationale

Why do we focus on soft outcomes in this report? Soft outcomes are included in the health definition of the WHO: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[7] Despite the WHO health definition it is sometimes argued that unspecific symptoms of ill health are less relevant than chronic diseases such as cancer, etc. However, life quality measurements in persons with unspecific symptoms of ill health often yielded lower scores than in persons with hard outcomes *(Diener E. and Diener C., 1996).*

The WHO stated in the research agenda on health effects from radio frequency fields in the epidemiology part the following:[8]

- Studies on the effects of RF sources other than mobile telephones (e.g. fixed sources) to affect sleep and other "soft" outcomes or chronic diseases should be addressed with epidemiology studies. In particular, possible effects from long-term, whole-body exposures at environmental levels need to be addressed. Furthermore, WHO has received hundreds of emails and letters requesting that the study of a population around base stations should be designed and conducted.

---

[7] Preamble to the Constitution of the World Health Organization as adopted by the International Health Conference, New York, 19-22 June, 1946; signed on 22 July 1946 by the representatives of 61 States (Official Records of the World Health Organization, no. 2, p. 100) and entered into force on 7 April 1948.

[8] http://www.who.int/peh-emf/research/rf03/en/index1.html

Several surveys of electromagnetic hypersensitive individuals revealed that they are most concerned about unspecific symptoms of ill health (soft outcomes). For instance about 400 electromagnetic hypersensitive (EHS) individuals in Switzerland ascribed 47 different symptoms to electromagnetic field exposure (see Figure 42). Most of these symptoms were unspecific. Most prominent were sleep disorders, headache, nervousness, fatigue and concentration difficulties which were ascribed to exposure from mobile phone base station in most cases.

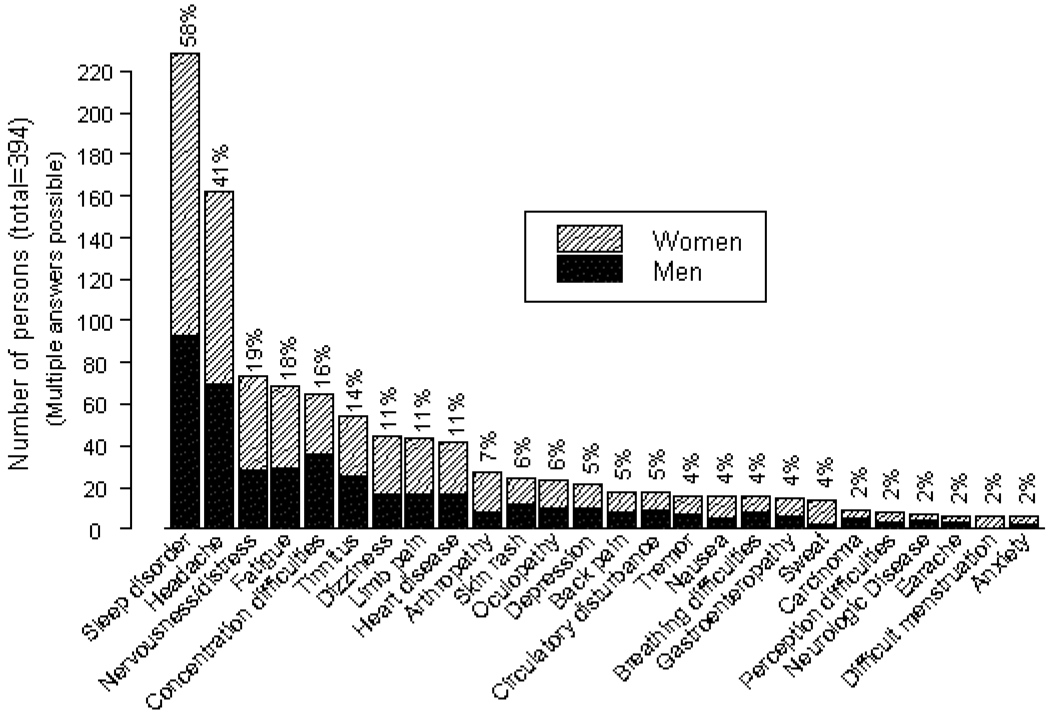


Figure 42: Symptoms ascribed to electromagnetic field exposure in a collective of EHS individuals (from (Röösli et al., 2004))

4.1.2.3 Electromagnetic hypersensitivity

In the context of exposure to electromagnetic fields the phenomena electromagnetic hypersensitivity (EHS) is widely discussed. There are people who claim to be hypersensitive to electromagnetic field exposure. Such patients suffer generally from unspecific symptoms of ill health such as headaches, sleep disorders, skin rash, dizziness, etc (soft outcomes). Estimates of the prevalence of people suffering from electromagnetic hypersensitivity (EHS) have varied. It is difficult or even impossible to correctly estimate the prevalence of EHS, simply because there are no established diagnostic criteria, and the definition of the disease is largely based on each individual's own beliefs and attribution of various symptoms to different sources of electromagnetic field exposure. Therefore, assessments of the prevalence will entirely depend on the methods used to identify cases, and the types of questions asked in each specific survey. While some earlier studies have assessed that a maximum one percent of the general population is afflicted, *(Bergqvist U, 1997; Silny, 1999)* a population survey in Stockholm reported that 1.5 percent of the population identified themselves as suffering from EHS *(Hillert et al., 2002).* In a survey in California 3.2% (95%-CI: 2.8%-3.7%) of the population reported hypersensitivity to exposure to EMF *(Levallois et al., 2002).* A similar result came out in a recent study which used an experimental procedure to determine EHS *(Leitgeb and Schrottner, 2003).* Though many acute health effects have been cited, the results of controlled experimental studies have been contradictory *(Flodin et al., 2000; Hietanen et al., 2002; Mueller et al., 2002; Oftedal et al., 1995; Radon and Maschke, 1998;*

Rea et al., 1991; Stenberg et al., 1995). Thus, a direct causal link between exposure to electric or magnetic fields below recommended reference levels and self-reported symptoms has not been established to date. There is no specific symptom profile or validated diagnostic criteria to diagnose EHS *(Levallois et al., 2002).* Apart from a pure EMF phenomenon, other causes of EHS, such as distress, neuroticism, psychiatric morbidity and an influence of the public debate have been considered *(David et al., 2002; Frick et al., 2002; Lonne-Rahm et al., 2000).*

4.1.2.4 Criteria for Development and Selection of Outcomes

In order to do a rigorous study about possible adverse effects of exposure from mobile phone base stations the outcome has to fulfil certain criteria. Obviously investigating chronic disease such as cancer or reproductive outcomes in association to exposure is justified and will not be further discussed. However, the criteria are more crucial with respect to well being (soft outcome) and physiological measurements (hard outcomes), see also table 10.

- Comprehensive (content validity): the outcome includes appropriate components of health. This criteria is well fulfilled if one addresses well-being. Well-being is part of the health definition and directly related to human life quality. However, it is more crucial when focusing on physiological measurements. The relation to health status is often not given or not known at least. E.g. pupil modification due to different light conditions is a physiological effect but not related to a health. Content validity of physiological measurements is given when they are pieces of a puzzle to clarify the biological pathway, which is aimed to be studied.
- Credibility (face validity): the outcome appears sensible and interpretable at face value. Thus, it is a measure of the extent to which the items of a test or procedure appear superficially to sample what is to be measured. This criteria is clearly fulfilled for hard outcomes. With respect to soft outcomes credibility depends on the instrument and has to be evaluated in each setting separately.
- Accuracy (content validity): the outcome consistently reflects true clinical status of patients. It is concerned with sample-population representativeness (in contrast to face validity which can be estimated individually). Physiological measurements are often useful to determine the clinical status. However, due to large natural variability often not sufficient. On the one hand well being may be considered as a true clinical status itself. If so, content validity is given. On the other hand, impaired well-being can not be medically explained in many circumstances and is often not correlated to clinical status. In that view content validity is questionable.
- Sensitivity to change (discriminant validity): the outcome detects smallest clinically important difference. One would expect that clinically important changes can be detected using appropriate physiological measurements. With respect to well-being, it depends on the used instrument and the setting whether the outcome is discriminant valid or not.
- Biological sense (construct validity): matches hypothesized expectations when compared (with other indirect measures). This holds for physiological measurements if the researcher performs such measurement on the background of a biological model. Effects on well-being are often not based on a biological model as a biological mechanism is not known under the current knowledge in many cases. In that view this criteria is arguable.
- Minimizing bias: ability to effectively measure an outcome (or a component of it), readiness, reliance or self-reform and recall.

Criteria	Chronic disease	Well-being	Physiological measurements
Comprehensive	-	-	**+**
Credibility	-	- **+**	-
Accuracy	-	- +	- **+**
Sensitivity	-	- **+**	-
Biological sense	(-)	**+**	(-)

Table 10: Criteria for development and selection of study outcomes. + means that the criteria is fulfilled; - + means that the criteria may be fulfilled or not, depending on the actual instrument which is used; - means an unfulfilled criteria.

4.1.2.5 Measuring soft outcomes

The goal of this chapter is to present an overview of methods which might be used to measure soft outcomes. Soft outcomes have been investigated in clinical research as well as in the area of environmental epidemiology in association with other environmental factors such as noise, weather, etc.

The review of the huge methodological literature has shown that there does not exist a well accepted gold standard for each type of symptoms. Rather, depending on the specific aim of the study different instruments has been applied. For instance, interested in the short term effect of a specific exposure after 30 minutes on well-being requires a different diagnostic instrument than evaluating the association of socioeconomic status and well-being in a given area.

Thus, we think it is not possible to be comprehensive and to give specific advice for the choice of instruments. Rather we introduce the most important concepts and instruments for selected outcomes which are the most relevant in the context of this project.

Some general aspects of such measurements are in the following introduced based on a review by Michel *(Michel G., 2004).*

GENERAL ASPECTS OF SYMPTOMS QUESTIONNAIRE METHODS

One has to be aware that symptom reporting questionnaires are used in various fields to assess how many or what kind of physical complaints an individual suffers from. It is a measure commonly used in psychology, sociology or medicine. In psychological studies, it is used as part of the assessment of well-being. In sociology, it can be used to assess the general health in certain neighbourhoods in a city. And in a physician’s general practice, the reporting of a patient’s symptoms is essential to diagnose an illness. However, even if symptom reporting is often understood as a valid measure it is not a perfect correlate of the underlying organic state. In contrast, often symptom reporting is not correlated at all with underlying clinical state. Symptom reporting is influenced by many factors. Different factors have a major influence on whether and how many symptoms are reported, and theses factors should be taken into account in studies using any kind of symptom reporting measures. In the following a few of such well-known factors are briefly introduced:

- gender: in most studies with many different kinds of samples and methodologies, women report numerous, more intense, and more frequent somatic symptoms than men. Possible explanations are biological differences, higher level of neuroticism and more body focused attention of women compared to men, different socialization and/or social expectations, and more stressful experiences, trauma and abuse.
- personality: by exploring what characterizes extreme over-reporters of somatic symptoms it was hypothesized that these individuals are especially high in what can be summarized as neuroticism. Neuroticism is defined by a tendency to experience negative and distressing emotions, anxiety and fear, but also hostility or depression. Besides neuroticism other personal characteristics may play a role such extraversion, optimism, self-efficacy etc.
- emotion: increased symptom reporting is correlated with negative emotions; in particular unpleasant emotions, depression and alexithymia (“no words for feeling”). In many cases

symptom experiences change more slowly over time than mood ratings. Thus, mood measured at any point in time may be a net result of several influencing factors, including somatic symptoms.

- cognitive factors: symptom reporting is influenced considerably by cognitive beliefs or preconceptions, selective attention to bodily events, schemata, attributions or coping. The fact that negative expectation of becoming sick can indeed yield in sickness is referred to the nocebo phenomenon. Selective attention: typically, someone is constantly observing his or her body for possible changes, he or she will find something sooner or later, which can be interpreted as an illness symptom.
- Attribution: a feeling of dizziness may be experienced as first signs of poisoning if it is attributed to a liquid an individual has been in contact which during work. On the other hand it will not be reported as a somatic complaint if attributed to a fast run up the stairs.

Symptom questionnaire methods are generally part of a study on soft outcomes. However, in many cases physiological measurements (i.e. hard outcomes) can also be used in such studies which have their focus on unspecific symptoms of ill health.

Therefore, in the following discussion we classify subjective measurements using a questionnaire and objective methods based on physiological measurements. Note that a well evaluated and standardized questionnaire may be considered to a substantial extent as an objective measure.

SLEEP QUALITY

Insomnia is classified as either being primary or secondary. Primary insomnia occurs when it is the sole complaint of a patient. Secondary insomnia can be caused by medical conditions, drugs, environmental factors, emotional conditions or psychiatric disorders. Insomnia is categorized by its duration. Transient insomnia lasts for a few days, short-term insomnia for no more than three weeks, and chronic insomnia is characterized by at least three affected nights a week for one month or longer. In general, people with insomnia experience an inability to fall asleep despite being tired, a light, fitful sleep that leaves one fatigued upon awakening or waking up too early.

Impaired sleep quality is quite prevalent in the general population.

Objective methods

To investigate properly the characteristics of sleep, human subjects are made to sleep connected to a polysomnograph. This non-invasive test simultaneously collects data relating to several variables, such as the bio-electric activity of the brain (electroencephalogram (EEG)), eye movements (electro-oculogram (EOG)) and muscle tone (electromyogram (EMG)). According to the accepted standard procedure for sleep scoring, these signals are analysed to extract patterns that allow the identification of the subjects' sleep stages and waking states. Traditionally, polysomnographic recordings are visually scored by well-trained personnel. This evaluation is time-consuming and prone to subjectivism. Thus, computerised systems are increasingly used. Computerized scoring is more reproducible. However, that does not automatically imply more accuracy. Several different systems are available with a wide range of quality.

Other signals, such as body movements, provide context information that is useful for discarding artefacts. For body movements many systems are available. A simple device is the actigraph which is worn like a watch on the wrist. Due to its simple handling, it is well suited for field studies; for instance in a field study on the effect of extremely low frequency fields on the sleep behaviour *(Tworoger et al., 2004).* Actigraphy is also used in laboratory studies. Other systems for movement recording have been developed for specific needs. For instance in a field study on sleep quality at the participants home, sleepers' movement has been recorded using sensors placed at each of the four bedposts *(Mueller et al., 2002).*

Subjective methods

Subjective methods of sleep measurements include diaries and sleep scales. Many versions of self administered diaries are available. During a given period individuals fill in the diary daily (evening and/or morning). Relevant information regarding sleep behaviour is: bedtime, wake up during night, wake up time, etc. as well as quality related issues. The latter can be measured on ordinal scales or on visual analogue scales (a continuous scale represented with a line having polar items at each end). Moreover, possible factors influencing sleep behaviour may be noted such as caffeine and alcohol consumption, drug use, etc.

Sleep scales are used to rate the usual sleep behaviour and may provide evidence for the presence or absence of sleep problems. Additionally they are used to measure sleep behaviour before and after an intervention. The reference time interval is variable and ranges from a few days to an indefinite period (referred to as general pattern). Often, scales can be divided in various subscales to provide information about the kind of sleep problem (falling asleep, early wakening, stress or anxiety related sleep problems, etc.). Some validated sleep scales are:

Livingston's Sleep Scale, Pittsburgh Sleep Quality Index, Verran and Snyder-Halpern (VSH) Sleep Scale, Medical Outcomes Study- Sleep Scale (MOS-S), Epworth Sleep Scale, Parkinson's Disease Sleep Scale (PDSS).

Conclusion

Practising physicians know that a large number of individuals complain about sleep disorders, even though objective methods do not find indications of a problem. Typically, such persons claim not to have slept during the whole night, however EEG measurements reveal several hours of sleep. The reason for the discrepancy is still unclear. In the practice one would not disregard the subjective complainants. This phenomenon has to be taken into account when designing a study on a possible association between sleep quality and exposure in the radio frequency range.

HEADACHE

Headaches occur in many varieties, all of which have symptoms that may vary slightly from one another. Primary headaches (including migraines, cluster headaches and tension-type of headaches) are a result of neurochemical changes within the nervous system. Secondary headaches result from underlying causes, such as post-traumatic injuries, brain tumours, changes in intracranial pressure, infections, drugs, etc.

Headache is quite prevalent in the general population and is one of the most frequent complaints of mobile phone users. Headache has been less frequently attributed to mobile phone base station exposure.

Objective measurement methods

An objective diagnosis instrument for headache does not exist. In most cases when the symptoms are exceptionally strong or frequent, further diagnostic tools are applied to determine an underlying cause such as a brain neoplasms. For instance ultrasonography is a technique in which high-frequency sound waves are bounced off internal organs and the echo pattern is converted into a 2 dimensional picture of the structures beneath the transducer (*Young and Silberstein, 1992*).

Subjective methods

Diagnosis of headache is based mainly on questionnaires. The design of a questionnaire may be:

- diagnostic purpose
- quantifying pain
- change in pain due to an intervention or an external factor
- determination of prevalence in a population sample

- questionnaire for specific types of headache
- …

See the following references for examples:

- Hunter M. 1983.The Headache Scale: a new approach to the assessment of headache pain based on pain descriptions. *Pain.* 16:361–373.
- Melzack R. 1975. The McGill Pain Questionnaire: major properties and scoring methods. *Pain.* 1:277–299.
- Jahanshahi M, Hunter M, Philips C. 1986. The headache scale - an examination of its reliability and validity. Headache 26 (2): 76-82 FEB
- Sjaastad O, Fredriksen TA, Petersen HC, Bakketeig LS. 2002. Grading of headache intensity. A proposal. J Headache Pain 3:117–127
- Kosinski M, Bayliss MS, Bjorner JB, Ware JE Jr, Garber WH, Batenhorst A, Cady R, Dahlof CG, Dowson A, Tepper S. 2003. A six-item short-form survey for measuring headache impact: the HIT-6. Qual Life Res. 12(8):963-74.
- Stewart WF, Lipton RB, Whyte J, Dowson A, Kolodner K, Liberman JN, Sawyer J.Neurology. 1999. An international study to assess reliability of the Migraine Disability Assessment (MIDAS) score. 22;53(5):988-94.
- Special issue on headache measuring: Quality of life Research, Dec. 2003

The choice of headache scale or questionnaire suitable for base station studies depends on the study purpose. A study focussed on long term exposure effects would apply a scale which measures occurrence of headaches over a longer time period. Moreover, it would probably be of interest to differentiate between different types of headache and extent of pain. In contrast a study investigating immediate effects after a change in the exposure levels will focus on the present symptoms and will be designed to be sensitive to slight changes in symptoms.

WELL-BEING

Well-being may be considered as a general health status, such as the net sum of all symptoms. Thus, well-being may be impaired due to any symptom. The extent of impairment is dependent on the gravity of the symptom as well as a function of the time course. Generally, occurrence of a new symptom affects well-being the most. After a while one gets used (adapted) to it. (Of course this differs between individuals and specific symptoms.)

In addition well-being may be connected to the phenomena electromagnetic hypersensitivity. EHS is mostly understood as the occurrence of individually different symptoms. Thus, focusing on well-being would capture all aspects of EHS, whereas focusing one single symptom would not.

Subjective methods

Mainly in pharmaceutical research, drug side effects on well-being are taken into account. For that purpose diaries are used, where study participants can fill in noticeable events. Such non standardized methods may not be suitable for a systematic analysis of the data, however may give a clue for a wide variety of non expected side effects. A more standardized questionnaire asks about a number of dimensions in the context of well-being: mood, headache, sleep quality, exhaustion, digestive and cardiovascular symptoms, etc.

Questionnaires on well-being or quality of life are useful for evaluation of unspecific health effects, however they are not designed for a certain specific symptom. Usually there is only a limited number of questions on a specific symptom. Thus, an item by item analysis reduces the power to find an effect. Moreover, such questionnaires are not designed and standardized for that kind of problem. Using a questionnaire from another language requires a careful translation, preferably also a back translation. Different cultural backgrounds should be taken into account.

Objective methods

Using physiological measurements to assess well-being is rarely possible or suitable. As stated before, rating of well-being is rarely correlated to clinical status. Thus, physiological measurements may be primarily useful in within subject's analyses. An increase in certain parameters (e.g. hormones) compared to the individual average may indicate an altered well-being (e.g. increase in stress).

4.1.2.6 Further unspecific health symptoms

So far, from population complaints a distinct symptom pattern with regard to base station (or EMF in general) exposure can not be discerned. Rather, the symptoms mentioned are quite heterogeneous. From that point of view, use of a broad questionnaire asking about various unspecific symptom of ill health is preferable. If one is focussed on one single symptom face validity of the questionnaire (or the whole study) may be challenged. For instance a hypersensitive person with a clear a priori perception of the problem could say: why do they ask about concentration difficulties? My problem is completely different. On the other hand, a questionnaire could include items that are irrelevant for the study purpose to act as positive control items (no change is expected). Of course, when specific symptoms are hypothesized to be associated with radio or microwave frequency exposure studies can be designed to focus on specific symptoms.

Additionally, if one does study specific exposure situations, it may be appropriate to focus on a single (or a few) symptom. For instance it may be justified to focus on symptoms of the head in association with mobile phone use; or to focus on sleep quality in association with night time exposure in the bedroom.

4.1.3 Conclusion: health outcomes appropriate for investigation in epidemiologic studies

Possible outcomes of a base station study are grouped into three categories of chronic diseases, physiological measurements (both hard outcomes) and well-being (soft outcomes). From the perspective of outcome selection criteria, to investigate chronic diseases is obviously justified (of course methodological problems arises from the exposure perspectives with regard to long latencies). Physiological measurements and well-being are both crucial to a certain amount.

Physiological measurements are objective and one tends to trust in them. However, a large natural variability makes them often not that easy to interpret. Moreover, it is often not clear whether physiological changes are related to health at all. The human body is in a permanent process of adaptation to changing environmental conditions such as temperature, light condition etc. The associated physiological changes could be measured. Such changes within the natural range are not harmful, of course. However, the reverse conclusion does not necessarily hold: even if a physiological change lies within the normal range, it can be health relevant. Assume that we measure lung function after smoking a cigarette in a healthy (voluntary) study group. We would measure only a slight reduction of the lung function (if any at all) which would lie within the normal range. Nevertheless, we would not conclude that cigarette smoking does not have any health relevance.

Well-being is obviously part of the health concept and thus relevant. However, characterizing well being is based on subjective instruments which one tends to trust less. Basic principles should be taken into account (see chapter 'general aspects of symptoms questionnaire methods'). With respect to base station studies the following conclusions can be drawn:

1. Studies of long term effects are problematic. Quality of life or symptom reporting may be calibrated on the own general condition and thus, may be representative primary for short scale or mood related changes. (People with objectively worse health condition were sometimes observed to rate a better quality of life than healthy people.)

2. Between subject comparisons are problematic. There are many factors influencing symptom reporting. Such factors have to be taken into account, either by design or in the analyses of the data. Possibility of bias is large.
3. Within subject comparisons are most accurate, but are only possible on a relatively short time scale.
4. Questionnaires should be validated before use. The same criteria which were introduced to judge development and selection of study outcomes (see chapter 4.1.2.3) can be applied also for the questionnaire itself.
5. Obviously, subjective rating of symptoms becomes a major problem in base station studies, when study participants are not blind with respect to exposure status (see chapter 4.3.4).

4.2 Exposure assessment in epidemiological studies

Exposure assessment has been identified as the most crucial issue for possible base station studies (*Röösli et al., 2002b; Schüz and Mann, 2000).* Thus, this issue will be discussed extensively from an epidemiological perspective. First, general aspects are introduced (chapter 4.2), second specific issues with respect to exposure to emission from base stations are discussed (chapter 4.3).

4.2.1 Basic principle of epidemiologic exposure assessment: a proxy

Exposure assessment in epidemiology is often misunderstood by non-specialists. In order to clarify this issue, a chapter from the book ‘modern epidemiology *(Rothman, 1986)* is summarized (Information on exposure p.141-143). To a certain extent, every variable measured in an epidemiologic study can be considered only a surrogate variable for some more appropriate measure of the underlying phenomenon. Consider measuring cigarette smoking as a cause of lung cancer. Assume for discussion purposes that it is the inhaled amount of benzo[a]pyrene that best predicts lung cancer risk. Even in a cohort study and certainly in a case-control study, one cannot hope to measure the inhaled amount of benzo[a]pyrene. What can be measured? Perhaps the daily consumption of cigarettes. But then one needs to know what type of tobacco is used, how far down each cigarette is smoked, whether there is a filter on the cigarette, and how deeply the individual inhales, among other things. Generally, none of this can be determined with any reasonable accuracy. Even if it could be, the ideal measure of exposure must integrate this information over a period of time and allow for a reasonable but usually unknown induction period. In studying cigarette smoking and lung cancer, one would theoretically need accurate cigarette-smoking information for some period of time long before the lung cancer occurs or might occur. Since the relevant time is uncertain, in principle one needs accurate exposure information for a period covering many decades, including the details of how the exposure varied by time during this period. Because historical information of such accuracy is not attainable, some misclassification of relevant exposures is unavoidable.

Nevertheless, taking a crude exposure measure being a current smoker or not being a smoker would reveal a substantial increasing lung cancer rate for a smoker compared to a non-smoker. In this case being a smoker is a surrogate (or a proxy) of the benzo[a]pyrene exposure. And even if the benzo[a]pyrene exposure between smokers would vary in a wide range, the benzo[a]pyrene exposure of smokers would on average be much larger than that of non-smokers. Thus, the exposure classification smoker vs. non smoker is an appropriate, albeit far from perfect, proxy for benzo[a]pyrene exposure.

In conclusion, the goal of each epidemiological exposure assessment is to find a good proxy representative of exposure of interest. Thus, the first priority is not to obtain an exact value for the total exposure for the past, but rather to divide the study collective accurately in exposed or non-exposed groups (or in groups which are exposed to a varying degree).

4.2.2 Exposure assessment errors (sensitivity and specificity)

4.2.2.1 Differential vs. non-differential exposure misclassification

As discussed above (chapter 4.2.1) some misclassification of exposure is unavoidable in epidemiologic studies. But some misclassification does not automatically lead to severe bias in the risk estimates, because this bias depends on the magnitude and the nature of exposure misclassification. There are scenarios, where a large misclassification error does introduce only negligible bias, while in other situations presumably small misclassification errors already hamper the interpretation of the risk estimates. Consequently, the impact of bias from misclassification has to be discussed for every specific study design. Hence, the goal of this chapter is to clarify the impact of exposure misclassification on the study result.

Exposure misclassification is measured as sensitivity and specificity. Both terms are originally used in medicine to describe the quality of a diagnostic test:

- Sensitivity refers to the proportion of people with disease who have a positive test result.
- Specificity refers to the proportion of people without disease who have a negative test result.

Analogue terms are used with respect to exposure classification. For the sake of simplicity let us assume a binary exposure status: either being exposed or not exposed. With respect to true exposure status, exposure assessment can result in classification of individuals into four combinations (see Table 11): (a) those classified as exposed who are really exposed; (b) those classified as exposed who are in fact unexposed; (c) those classified as unexposed who are in fact exposed; and (d) those classified as unexposed who are truly unexposed. Of course one tries to make (a) and (d) as big as possible and b and c as small as achievable. Sensitivity refers to the proportion of people being exposed and being (correctly) classified as exposed (=a/(a+c)). And sensitivity refers to the proportion of people being unexposed and being (correctly) classified as unexposed (=d/(b+d)).

		True exposure status	
		Exposed	Not exposed
Exposure classification	exposed	a	b
	not exposed	c	d

Table 11: Table of the four possible combination of exposure classification with true exposure status.

An exposure assessment with a specificity of 90 percent and a sensitivity of 80 percent means, that 90 percent of the unexposed people are correctly classified as unexposed and 80 percent of the exposed individuals are correctly classified as exposed. The remaining study participants are erroneously assigned to the wrong exposure category, leading to 10% false positives and 20% false negatives in our example.

Exposure misclassification can be either systematic (differential) or non-differential. The former means that the misclassification is dependent on the disease status. For instance this can happen in case control studies if cases reflected more intensely on past exposure situations than controls and thus are more likely to be classified as exposed than controls (recall bias). This is a serious problem as it creates a systematic bias in the study resulting in either an overestimation or an underestimation of the true effect estimate depending on the type of systematic exposure misclassification. This can easily be understood and is not further discussed. (With respect to a specific study, however, it is more difficult to determine whether such bias was likely to occur or not.)

In many situations exposure classification is non differential. Actually, an appropriate exposure proxy is chosen in a way that misclassification will be only non-differential (i.e. same for cases and non-cases. With respect to base station studies, reasons for misclassification may be measurement errors, spatial and temporal variability, or if study subjects themselves estimate the exposure, etc.

The consequence of non-differential exposure misclassification on the effect estimate (RR, OR) is different when using individual-level exposure data compared to group-level exposure data. Individual-level exposure data are often used in cohort or case-control studies when for each person an individual exposure value is assessed. In contrast group-level exposure data means that the same exposure value is assigned to a group of persons (in ecological studies). The group membership may be defined by determinants such as occupation or residential area. The next chapter (4.2.2.2) deals with individual-level exposure data. Group-level exposure data are introduced later (chapter 4.2.2.3).

4.2.2.2 Individual-level exposure data

In order to clarify the impact of a non differential exposure misclassification in individual-level exposure data, some simple models are presented in the following.

Let us assume a very simplified situation of a cohort study in a given area with a few base stations. Typically only a small proportion of the population is exposed to somewhat higher values (e.g. average exposure level in the dwelling >1 V/m). So, let's say from the cohort of 21,000 individuals who are followed during one year 1,000 persons are exposed to a field value of more than 1 V/m; the remaining are considered as unexposed. During one year, we observe 10 cases in the exposed group and 40 cases in the unexposed group (see Table 12). Thus, the exposed group contributes 1,000 person years to the study and the unexposed group 20,000 person years (further assumptions: no drop outs, no confounding, no bias, etc).

	Exposed	Not exposed
Cases	10	40
Person time	1,000	20,000

Table 12: A hypothetical cohort study: true exposure and disease status

The risk from exposure can therefore obtained by dividing the disease rate in the exposed group with the disease rate in the unexposed group:

$$RR = \frac{10 / 1{,}000}{40 / 20{,}000} = 5 \qquad (4.2.1)$$

A rate ratio (RR) of 5 means that exposed individuals are 5 times more likely to get the disease. Unfortunately, assuming exposure misclassification means that we cannot observe the 'true' situation as described above. Our data collection would yield an erroneous table. Assuming a specificity of 90% would mean that from the 20,000 unexposed person years, 2,000 person years would be classified as exposed and correspondingly from the 40 unexposed cases (see Table 12) 4 cases would be classified as exposed. A sensitivity of 80% percent would result in 2 misclassified exposed cases and correspondingly 200 person years. Actually we would observe 12 exposed cases based on 2,800 person years and 38 unexposed cases based on 18,200 person years (Table 13).

	Exposed	Not exposed
Cases	8+4	36+2
Person time	800 +2,000	18,000+200

Table 13: A hypothetical cohort study: observed exposure and disease status assuming an exposure assessment with 90% specificity and 80% sensitivity.

The corresponding rate ratio calculation would yield:

$$RR = \frac{12 / 2{,}800}{38 / 18{,}200} = 2.05 \qquad (4.2.2)$$

Obviously, the obtained rate ratio of about 2 is a substantial underestimation of the true exposure-disease association. In Figure 43 modelled rate ratios for different values of the sensitivity and specificity for this example are shown. In a 2*2 situation, non-differential exposure misclassification yields always an underestimation of the true exposure-disease association.[9] It is striking that in our example we observe only little underestimated rate ratio when the specificity is 1, even when sensitivity is very low (e.g. 0.1). In contrast, even a slight reduced specificity of 0.9 yields to a substantial underestimation of the true exposure-disease association, even if sensitivity is perfect. This is characteristic for cohort study with a low proportion of exposed people. Identical results would be obtained for odds ratio calculations in a case-control study.

For the sake of simplicity standard errors are not calculated in the example. Low sensitivity would result in larger standard errors. Thus, the power of the study would be reduced, meaning that the confidence interval of the effect estimate would be increased. However, to compensate this disadvantage, the sample size of the study population can be increased, if feasible.

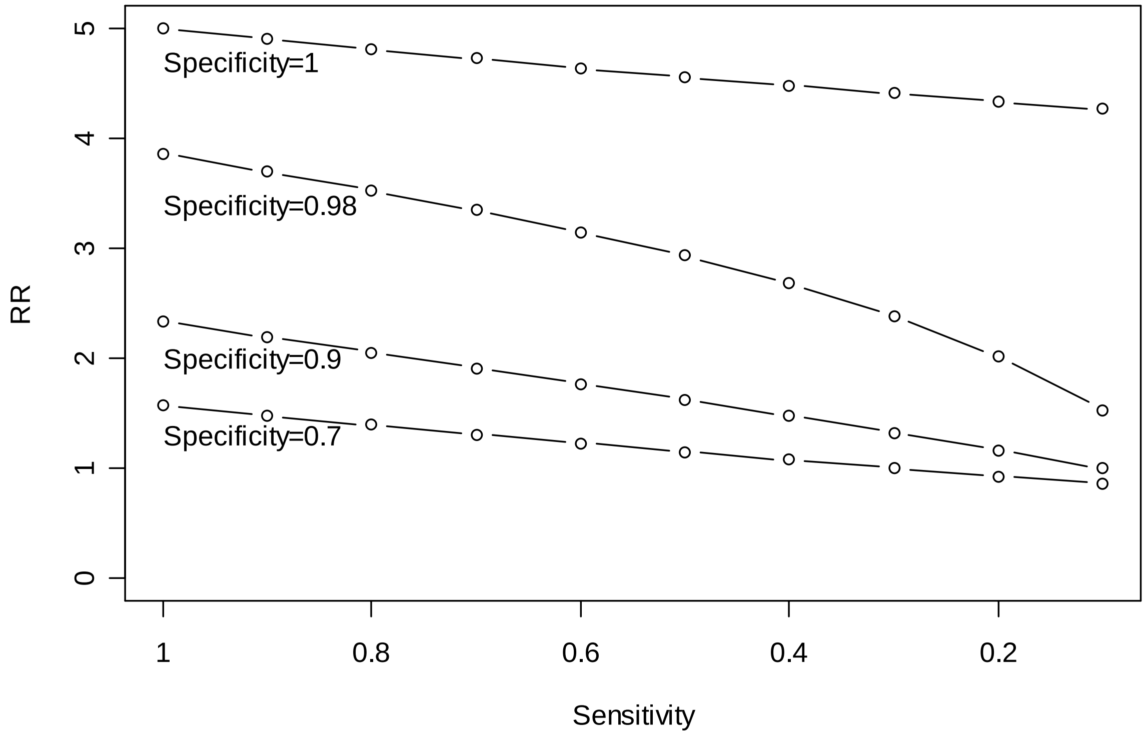


Figure 43: Modelled rate ratio (RR) for different assumptions about sensitivity and specificity of the exposure assessment for a specific example with a low proportion of exposed individuals. (True rate ratio is assumed to be 5.)

Below are shown (Figure 44) modelled rate ratio of a cohort with an equal number of exposed and unexposed individuals. Again the true rate ratio is 5. In this example the extent of underestimation is about the same for reduced specificity and reduced sensitivity.

What would occur, if there does not exist an increased risk in truth? In this case non-differential exposure misclassification would not introduce a false risk. Rate ratio would be 1, or rather scatter randomly around 1. Thus, non-differential misclassification is of particular concern in studies that show no association between exposure and disease. If so, the differentiation between ‘no true association’ and substantial underestimation of the true exposure response association due to erroneous exposure assessment is crucial. If an association was found, the observed exposure response association is the

---

[9] In such a simple model non-differential exposure misclassification results always in an underestimation of the true exposure response association. In practice overestimation could theoretically also occur under unusual circumstances. E.g. by chance (because non-differential misclassification is a random process), or if the variance is correlated to the exposure or under some circumstances when adjusting for covariates. If exposure is not dichotomised, the true exposure response association will be generally underestimated, too.

lowest estimate of the true association (assuming only non-differential misclassification and no other bias).

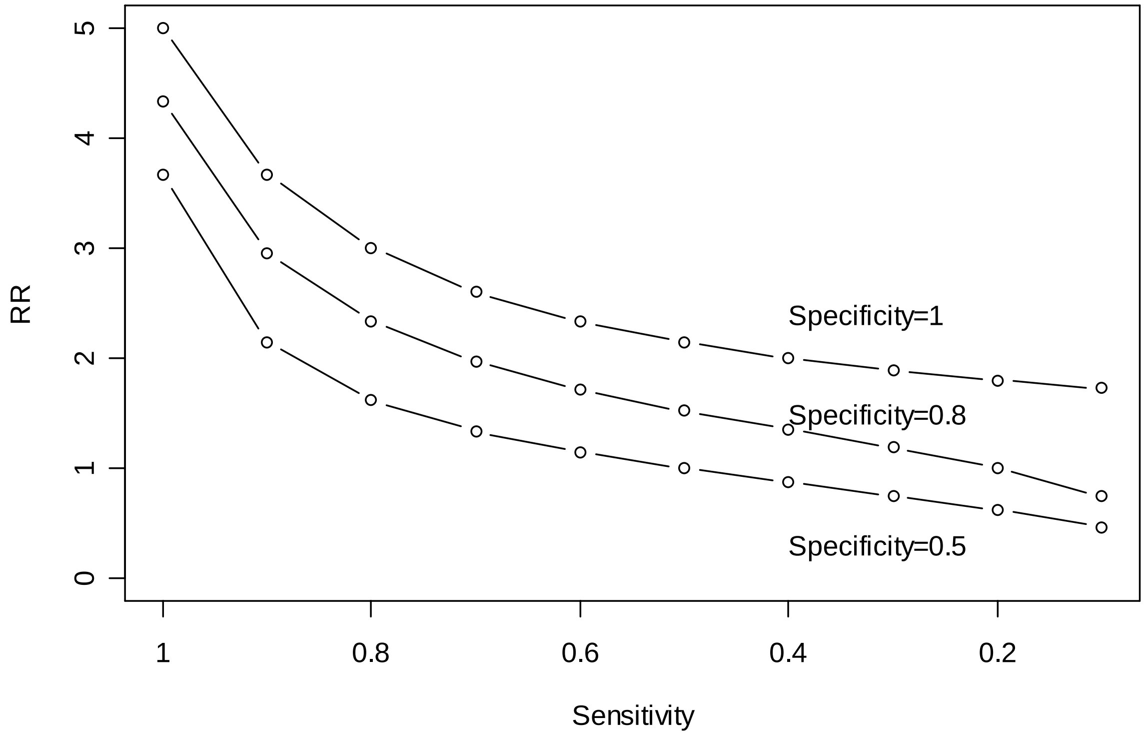


Figure 44: Modelled rate ratio(RR) for different assumption on sensitivity and specificity of the exposure assessment for a specific example with equal number of exposed and unexposed individuals.

In conclusion, the models show that in the context of base station studies with a low proportion of considerably (let's say >1 V/m) exposed individuals the specificity of the exposure assessment must be as high as possible whereas sensitivity is less crucial. So, we do not have to worry too much about persons we classify as unexposed though being exposed. However, we must be careful that those who are indeed unexposed are not falsely classified as exposed. This is a major requirement in the construction of an exposure metric for a base station study.

Classifying everybody living close to a base station as exposed would create many false positive exposure assignment, meaning a low specificity and a substantial underestimation of a true exposure-disease association. It is obvious that far away from a base station high exposure levels (from base station) cannot occur. Thus, persons far away can be smoothly classified as unexposed. Even if there are exposed (e.g. due to other sources) this would not affect the rate ratio substantially. Only the power of the study would be reduced leading to larger confidence intervals. Major effort has to be done close to the base station to differentiate between exposed and unexposed people.

In this context the question arises how to deal with other exposure sources in the radio or microwave frequency. Such aspects are discussed in chapter 4.3.2).

4.2.2.3 Group-level exposure data

Group-level exposure data are usually used in ecologic studies, with comparisons of prevalence or (better) incidence rates and group-level exposure measures. Furthermore, group-level exposure data are used in cohort (or sometimes in case-control) studies of semi-individual design (i.e. individual health data and collectively sampled exposure data). Group-level exposure values may be determined by averages of sample measurements.

Such a design can be considered an individual-level analysis with measurement error in the exposure variable. The underlying error model is called Berkson model *(Berkson J., 1950)* in contrast to the classical error model, where erroneous exposure measurements were performed individually for each study subject. Assuming non-differential misclassification, it is less well appreciated that if the Berkson model holds, then the estimate of exposure effect obtained by ordinary linear regression is in fact unbiased and robust to random measurement errors *(Prentice and Sheppard, 1995; Sheppard et al., 1996).* However, the standard error is increased, resulting in less power or precision.

4.3 Base station exposure assessment

4.3.1 Exposure metric

There has been proposed various exposure metrics for base station studies. One has to be aware that different exposure metrics may imply different biological mechanism. As presently biological mechanisms are unknown, thus there does not exist one justified exposure metric. Instead one has to evaluate one or several exposure metrics based on plausibility with respect to the outcome of interest. In the following a few conceptual thoughts will be introduced.

4.3.1.1 Threshold, cumulative and temporal variable exposure

Assuming that adverse effects occur only above a given threshold value implies that only exposure above this level is relevant. All exposure below that threshold can be ignored. In contrast, assuming a linear dose-response association without a threshold would imply that the occurrence of adverse effects can be best modelled using a cumulative exposure measure. The sum of the whole past exposure is relevant. Additionally, a third characteristic of the exposure may play a role: variability. It is conceivable that a high constant exposure level affects human body less than highly variable exposure level. Adaptation may be easier to the former than to the latter. A typical example for such a phenomena is noise associated sleep disturbances. In this example, a highly variable noise level is much more effective than a higher constant noise level.

For all three exposure concepts, it is not known whether whole body exposure, organ-specific exposure or both are biologically relevant. This may depend on the outcome of interest. Theoretically, a mixture of these three concepts is also conceivable, e.g. when the exposure-response association is a non linear function of the exposure level. In this case it would be preferable to calculate weighted cumulative exposure according to the shape of the exposure-response association. However, in practice complex curve forms could rarely be identified. As long as the exposure-response association is steadily increasing with increasing exposure level non-linear functions would suffice because such a function would be acceptably correlated to a linear assumption.

What are the implications of these three concepts on base station exposure? Assuming a threshold concept leads to the conclusion that base station exposure is rarely relevant to the general population exposure. It is well established that momentarily exposure from other sources in the microwave frequency range are much higher than from base station. E.g. SAR values in the head during a phone call with a mobile phone are several orders of magnitude higher than the SAR values in the head when being close to a base station (below standard limits for general population). Though, with respect to other organs the difference is smaller.

However, it is less well appreciated that with respect to 24h whole-body SAR value moderate use of mobile phones and moderate exposure from a base station are about the same size *(Dale C. and Wiart J., 2004).* Thus, in terms of cumulative exposure above a threshold, the contribution from base stations may be relevant. In terms of temporal exposure variability use of mobile phone may be considered more important than base station.

4.3.1.2 Exposure timing

Exposure timing may also be a relevant parameter. This can be considered on different scales: life time, day time, etc.

Childhood exposure has been discussed to be more relevant with respect to lifetime exposure. Possible explanation: higher susceptibility, longer follow up time to develop a disease and accumulate exposure, etc. When studying diseases with a long latency such as cancer the relevant exposure had taken place long before the disease occurs. Usually, in such studies assumptions about latency have to be made.

It is also conceivable that exposure during certain times of the day is particularly relevant as many human processes follows a circadian rhythm. Exposure during night has been suggested to be most effective because of possibly increased susceptibility. Additionally, the outcome may determine relevant exposure time period. The relevant exposure time is different for a study on immediate occurrence of headache due to exposure compared to a sleep disturbance study. If focussed on the latter night time exposure is the most relevant. Thus, contribution from base stations is larger than from mobile phones (which is not used during sleep). In many cases, however, it is not clear how long an exposure effect can last.

4.3.1.3 Physical property of the exposure

Emissions from base station can be measured on different scales: electric field strengths (V/m), power density (W/m^2) or specific absorption rate (SAR, W/kg). These intensity measures represent different physical properties of the radiation. Depending on the assumed underlying biological mechanism one might prefer one of those measures. As each of these measures can be converted into each other, choice of measure is not critical. If one takes the ‘wrong’ measure, the choice of the statistical model could compensate for it. For instance assume that the true effect is proportional to the SAR value and field strengths have been measured, then modelling a quadratic exposure-response association would fit the data. Beside intensity, the physical properties of base station radiation include frequency, modulation, polarization, etc. These characteristics are different for different base station types. GSM base stations in Europe uses different frequency bands in the 900 MHz range (925-960 MHz) and the 1800 MHz (1805-1880) range; in North America and Asia different bands in the 1900 MHz range are used. UMTS EMF from base station emits between 2110 and 2170 MHz. Note that for uplink (i.e. communication from handset to base station) slightly different frequency bands are used.

GSM mobile communication is based on a 217 Hz pulsed signal. The amplitude of pulsation in real communication setting is varying due to power control and different workload of the base station. Thus, the actual signal form is variable and not absolutely deterministic. How this impacts exposure assessment is illustrated in the next chapter (4.3.2).

4.3.2 Exposure from other source in the radio and microwave frequency range

As discussed above (chapter 4.3.1.3), each source in the radio and microwave frequency range has different signal characteristic. (Even the same source has different characteristic in different settings.) In principle there are two opposite viewpoints of the consequence of different physical properties of radio and microwave frequency radiation. One position assumes that physical characteristics are not relevant. Every exposure in the microwave frequency range has the same effect on health (further called a non specific effect). The opposite viewpoint is frequency and signal specific effects. This means that only specific frequencies, intensities and/or modulation affect human health. Moreover, the effective signal characteristic might differ between different persons according to their characteristics. At present one cannot justify one viewpoint above the other. Of course, almost infinite shades between these two opposites have been discussed. Different assumptions on the specificity of the radiation effect imply different concepts in epidemiological exposure assessment.

Assuming a non-specific effect from microwave exposure implies that in an epidemiological study all microwave exposure can (and should) be summarized. What is the consequence if one does not include all sources:

1. If the considered exposure contribution is substantially larger than the omitted one, the consequences are not serious. The exposure misclassification would be minor
2. More serious consequences can be expected if the considered exposure contribution is small compared to other sources. If so two cases can be distinguished. Exposure to other sources is not correlated to the considered exposure source(s). This is a typical case of non differential exposure misclassification. The consequences would be a substantial loss of power and generally a substantial underestimation of the true exposure-response association (see chapter 0). With a high likelihood such a study would not find an exposure-response association (false negative finding). If exposure to other sources is correlated to the exposure of interest, the study result can be biased in any direction. In this case exposure to other sources could be treated as a confounder (assuming the presence of a health effect).

In contrast, assuming a specific microwave effect implies that to focus on only one specific source is justified, even if the exposure contribution from other sources is much higher. Very crucial is the assumption that each person reacts on different type of signals Epidemiological studies might look hopeless in this case. However, this is not necessarily the case. Choosing an appropriate exposure proxy which guarantees that a substantial number of persons are exposed to ‘their’ relevant exposure setting would elucidate adverse exposure patterns for an average collective. Such a proxy would probably have a low sensitivity, however specificity could (and should) be high.

A particular relevant co-exposure in a base station study would be exposure from the mobile phone handset because frequency and modulation is relatively similar to the base station radiation. Thus, regardless of the assumption about effect specificity exposure from handsets seems appropriate to be considered. First, the exposure contribution from the handset can be compared to the one from base station. Exposure during a phone call is much higher than being close to a base station. Contributions of these two sources to 24 h whole-body exposure are of the same order of magnitude *(Dale C. and Wiart J., 2004)* (see also chapter 4.3.1.1). Secondly, it has to be taken into account that exposure from the handset may be negatively correlated with base station exposure. In Sweden in rural areas where base stations are sparse, the output power level used by mobile phones are on average considerably higher than in more densely populated areas *(Lönn et al., 2004).* This suggests that use of mobile phone should be treated as confounding factor in a base station study.

In conclusion knowledge of the effect specificity, if it exists, of microwave exposure would be beneficial in planning epidemiological studies. As long as knowledge on effect specificity is limited total exposure should be considered first. This implies that all relevant exposure sources may be recorded and various analyses may be performed. In such a way clarification is obtained for a signal specific effect as well as a possible unspecific effect.

4.3.3 Proxy used for base station exposure assessment

An extensive discussion about the existing exposure assessment methodologies for base station as well as for other RF sources is given in chapter 2.4.5.1. Up to now for exposure from base stations distance between base station and a residence has been used most often as a proxy. Doubtless power density in the radiation beam is decreasing with increasing distance. However, actual radiation level at a given site is a function of several factors, not only distance, but also output power of the antenna, direction of transmission, attenuation due to obstacles or walls (indoor), etc.

Thus, not surprisingly observed correlations between distance and exposure level are generally low (e.g. Figure 45). It can be concluded that distance is a very poor proxy for exposure from base station emission.

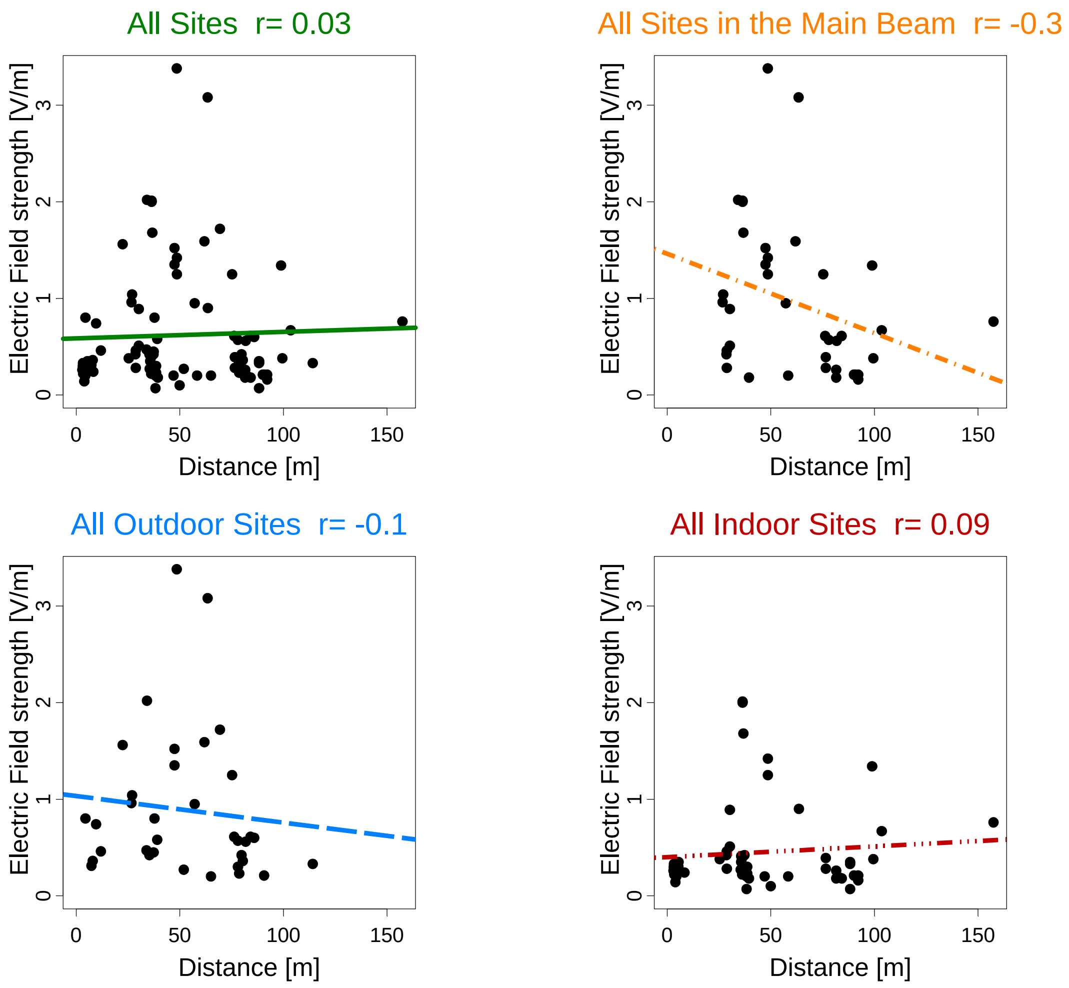


Figure 45: Correlation between electric field strengths and distance from base station at 91 measurement points in the city of Basel, Switzerland *(Wanner, 2001).*

Another proxy for base station exposure are simple calculation models, which take into account power output and geometric transmitting pattern from the antenna, as well as distance. Such calculations can be easily performed with a few input data assuming free space wave propagation. However, the accuracy is modest. Comparisons between 91 measurements and corresponding calculations concluded that exposure misclassification would be substantial *(Röösli et al., 2002a).* The number of sites which allocated to the same exposure category based on measurements as compared to calculations was only slightly better than expected by chance.

A third proxy for exposure from base station radiation is spot measurements. The appropriateness of such a proxy should be carefully evaluated.

4.3.4 Exposure blinding when determining the outcome

Exposure blinding is a well established prerequisite in experimental studies used to minimize bias. What about exposure blinding in epidemiological studies?

The answer to this question depends on the outcome studied. In studying chronic diseases exposure blinding of study participants is less important, as the diagnosis can not be affected either deliberately or subconsciously. Of course, diagnosis should be made without knowledge of the exposure status. In case-control studies subjects' exposure assessment should be designed to minimize a potential for bias.

In studying physiological changes exposure blinding is more crucial. Most physiological processes may not be affected on purpose, however psychological processes may play a role (e.g. being afraid of exposure). If so, underlying physiological changes cannot be attributed with any certainty to the physical exposure only.

With respect to soft outcomes exposure blinding is most crucial. Soft outcomes are usually based on subjective statements of the study participants. Obviously, subjective rating of symptoms becomes a major problem, when study participants are not blind with respect to exposure status. Let us assume that a panel study is done around a base station which is switched on and off. If the study participants are aware of it, this is likely to affect their subjective symptom rating. Such an influence could be deliberate or subconscious. Knowledge of exposure status may also trigger a direct psychological pathway: being afraid of exposure may cause health symptoms. This problem can be remedied if actual exposure levels are available. As the correlation between actual exposure and distance is poor, examination of soft outcomes with actual exposures might be informative even if reporting is biased. However, the ability of the study to detect an association will be reduced. Therefore, the question arises whether individuals can ever be blinded against exposure from mobile phone base station. Base stations are observable in most cases. Mobile phone handsets can be used as a rough measurement devices (extent of connection), or fields can be measured using a sophisticated device. With a mobile phone from the corresponding provider of the base station, study participants could figure out relatively easily whether the base station is transmitting or not. More difficult would be to guess the extent of exposure. A possibility to reduce the dilemma is to generate artificial signals which cannot be detected on the handset. If only the extent of exposure is relevant (rather than a base station which is turned off or on) one could argue that subjective exposure status would mainly be based on distance to the base station which is not correlated to measured levels. Thus, blinding can be postulated to some extent.

4.4 Aspects in study design

A primary objective of an epidemiological investigation is to describe an exposure-response association that is unlikely to be explained by extraneous differences between the study groups, thereby elucidating cause-effect relationships. However, random errors or bias can affect the study result. Random errors are inevitable and are minimized or quantified, respectively by appropriate statistical methods. Possible bias should be carefully evaluated when designing or interpreting a study.

4.4.1 Control of bias and confounding

4.4.1.1 Confounder and effect modifier

Confounding can produce biased study results. (The following paragraph is summarized from modern epidemiology *(Rothman, 1986)).* Generally speaking, a confounder can either create or hide an association.

In order to be a confounder a factor must fulfil two criteria:

1. It must be a risk factor for the disease (although it needs not to be a cause of disease).
2. It must be associated with the exposure variable in the source population from which the subject arise.

Thus, not every risk factor is a confounder. Furthermore, both of these associations have to be strong (e.g. on the order of 5 to explain the association of about 2).

A third criterion has to be added to the list, in order to avoid bias due to inappropriate control of variables:

3. It must **not** be affected by exposure or disease (although it may affect exposure).

Intermediate steps along the (biological) pathways must not be treated as confounder. For instance in a study on lung cancer and smoking, adjusting for coughing (as a result of smoking) would produce an absolutely wrong effect estimate.

A strategy to prevent confounding is adjusting for potential confounding in the statistical analyses. For that purpose information on the confounding factors must be collected. An inappropriate adjustment (e.g. linear adjustment if the effect is a quadratic function in truth) leaves residual confounding. In a small data set adjusting too extensively may create an unstable effect estimate due to loss of degrees of freedom.

A second strategy to prevent a variable from becoming a confounder and thus eliminate the burden of adjusting for the variable is restriction of the study base when designing the study. By altering the source population (e.g. by taking a subset of homogenous individuals with respect to a potential confounding factor) or other design strategies, etc. Restriction of subjects to a single level of a variable will prevent it from being a confounder in the study, but will also prevent one from examining whether the exposure effect varies across levels of the variable. Thus, transferability of the study results to other population is hampered.

One should well distinguish between effect-measure modification and confounding. Effect-measure modification differs from confounding in several ways. The most central difference is that, whereas confounding is a bias that the investigator hopes to prevent or remove from the effect estimate, effect-measure modification is a property of the effect under study. Thus, effect-measure modification is a finding to be reported rather than a bias to be avoided. Effect-measure modification refers to variation in the magnitude of a measure of effect of exposure across levels of another variable. Effect-measure modification is also known as heterogeneity of effect, non-uniformity of effect, and effect variation. Effect modifiers can be age, sex or ethnic group, etc meaning that in different strata of this variable different effects could be observed.

The best way to estimate effect modification is through stratified analyses. If so, stratum specific effect estimates and effect heterogeneity across strata can be evaluated. Note that the stratified variable cannot act as a confounder. Thus, stratification is also useful for control of confounding. Stratification may be limited due to the study size. If the strata become too small, effects estimates are not stable and interpretation becomes ambiguous.

Unfortunately, it is never possible to know the effects of all potential confounders. Thus, confounding is often suspected. Practice has shown that strong confounding does not happen very often. By statistical modelling, the effects of confounding can be evaluated for different scenarios. Langholz calculated some examples to show how strong a factor must be a risk factor for childhood leukaemia to explain the observed association between high wire codes and the risk of childhood leukaemia *(Langholz, 2001).* These simulations ruled out a number of factors that were considered as potential confounders, because of their rather weak association with childhood leukaemia risk. Over adjusting can also happen (thus minimizing the association), if adjustment for factors which are affected by the disease and exposure is done.

4.4.1.2 Type of bias

Bias is a systematic error resulting from methodological features of study design and analysis. Beside confounding bias, two major types of bias are known. First, selection bias refers to a distortion in the estimate of effect resulting from a systematic bias in the manner in which subjects are selected (or participated) for the study population. Selection must be related to both exposure and disease for selection bias to occur. It can enlarge or decrease the true exposure-response effect. A typical selection bias is the so called healthy-worker effect. A working collective is likely to be healthier and more exposed than the general population. Thus, comparing those two groups may create a bias.

Another typical example of selection bias might have taken place in the French and Spanish cross-sectional base station studies. By advertising the study in the media as a mobile phone base station study a highly selective study population can be expected. On the one hand a few unconcerned people distributed more or less randomly over the study area would agree to participate. On the other hand individuals with health symptoms which they ascribe to base station exposure are very likely to take part in such a study. Obviously such individuals might have more problems than a random population sample and must live close to a base station; otherwise they would not ascribe their symptoms to that specific exposure. In that way a spurious association between symptom prevalence and distance from base station is likely to occur.

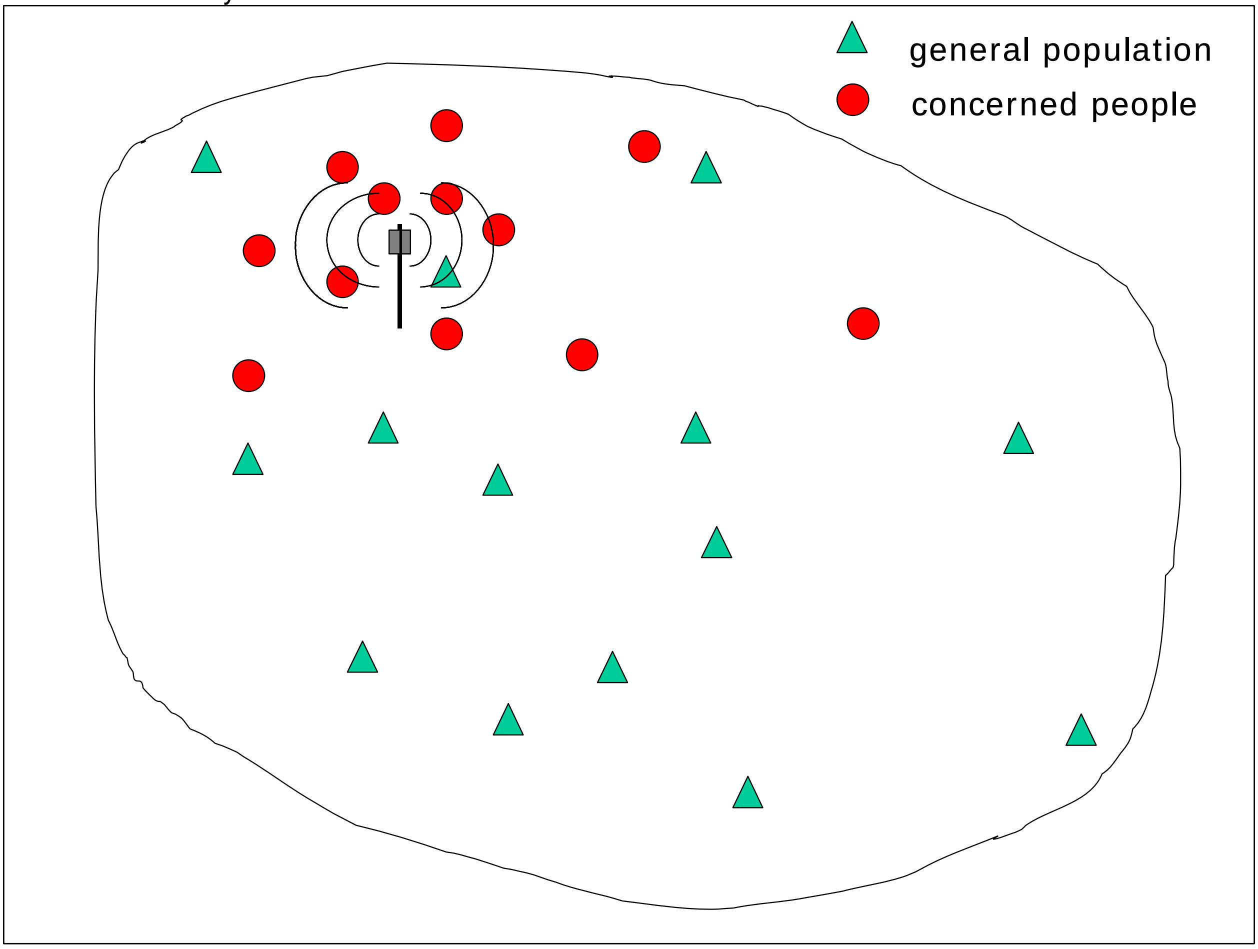


Figure 46: Possible selection bias in a base station study.

The second type of bias is information bias. It occurs if misclassification is related to the instruments and techniques used to collect information on exposure, health outcomes, or other study factors. Non-differential information bias occurs when the likelihood of misclassification of the disease is the same for exposed and non exposed groups, and when the likelihood of misclassification of the exposure is the same for subjects with and without the disease. As discussed in chapter 4.2.2.1 with respect to exposure assessment, bias from non-differential misclassification is likely to be in the direction of no effect. This is true for dichotomous exposure categorizations, but not for trend analyses. Differential information bias occurs when the likelihood of misclassification is different for various exposure groups. It can bias the observed effect estimate either toward or away from the null value. Recall bias is a typical example of such a differential misclassification. Recall bias might occur in case control studies if cases reflected more intensively on past exposure situations than controls and thus are more likely to report exposure situations and thus, to be classified as exposed than controls.

4.5 Criteria for an appropriate epidemiological RF field study

Obviously not every study type is appropriate for each type of outcome. Thus, choice of the appropriate study type is important. Table 14 gives an overview on the health outcomes with respect to the study design. Combination of study designs and health outcomes which are feasible are marked (+). Some of these have already been done (see Table 14). It is obvious that a number of health outcomes cannot be addressed by certain study types. These cells are filled using a (**-**). For instance, it is not feasible to study long term effects in a laboratory. Case-control studies are feasible for binary outcomes, either having a disease (and being a case) or not having. Case-identification on a continuous scale is problematic and even impossible when addressing immediate or short term effects which might be reversible. Ecologic studies of immediate and short term effects would be impossible as such data is not available. Other combinations of study types and outcomes which have not been done so far, but might be feasible in principle or under defined circumstances are marked with a question mark.

	Laboratory	Field	Cohort	Case-control	Cross-sectional[1)]	Ecologic
Immediate physiological effects	+	**?**	**?**	**-**	+	**-**
Short term physiological effects	**?**	+	**?**	**-**	+	**-**
Long term physiological effects	**-**	+	**?**	**-**	+	**-**
Immediate effects on the well being	+	+	**?**	**-**	+	**-**
Short term effects on well being	**?**	+	**?**	**-**	+	**-**
Long term effects on well being	**-**	**?**	**?**	**-**	+	**?**
Long term chronic disease	**-**	**?**	+	+	**?**	+
Long term reproduction outcomes	**-**	**?**	+	+	+	**?**
Long term all cause mortality	**-**	**?**	+	**?**	**?**	**?**

Table 14: Overview about health outcomes with respect to study type.
[1)] Time dimension in cross-sectional studies cannot be defined clearly as outcome and exposure measurements are performed at the same time point (see text).

Legend:
+ feasible
? feasible under restricted circumstances
- impossible

At present, with respect to the feasibility of a mobile phone base station study many questions remain open. A number of suggestions for more or less promising approaches can be done, if one is interested primarily in base station exposure effects.

1. Exposure to base station emission is important in terms of 24h whole body exposure, however, it is negligible in terms of current exposure levels at a specific body site (e.g. head) compared to other sources (e.g. mobile phones). Thus, base station exposure may be relevant for cumulative effect mechanisms. Base station exposures are hardly relevant for effects which can be expected only above a threshold value.
2. Base station exposure is spatially highly variable. Thus, accurate exposure assessment is possible for places where individuals stay over longer time in a limited area (e.g. bed, office). It should be evaluated whether moving around does introduce much exposure uncertainty. And if so, what kind of patterns can be identified (e.g. moving in urban areas, moving in rural areas,

moving in a car, moving by foot, etc.) Identification and quantification of such patterns would increase accuracy of exposure assessment.

3. Given the fact that only a small proportion of the population is exposed to substantially increased levels from base stations (or from other radio frequency sources) implies that specificity in exposure assessment is important. One should make sure that those who are considered as exposed really are exposed. If the sensitivity is low, and a part of the really exposed individuals are treated as unexposed, this would not create much underestimation if an effect would be present. The majority of the unexposed group would still be unexposed.
4. According to the hypothesis about specificity of effect, co-exposure to other sources in the radio and microwave frequency range should (or should not) be taken into account. Though scientific rationale is not given, assuming an effect from only one specific signal characteristic (e.g. base station) would make co-exposure less crucial. However, as long as effect specificity is not known, it is recommended to take into account all relevant exposure sources. Thus, if exposure from all sources is recorded, multiple analyses (for different sources) can be performed and may inform on effect specificity.
5. With respect to other exposure than base stations, use of mobile phones should be taken into account. The signal characteristic and frequency is similar to base station exposure. Thus, even assuming a specific signal effect would mean that mobile phone exposure is likely to be relevant. For most individuals mobile phone exposure contribution would be substantial compared to base station exposure. There is some evidence that mobile phone exposure level may be (negatively) correlated to base station exposure. (Note that this is not true in terms of quantity: number of calls, etc.). A correlation would imply that use of mobile phone should be included in the exposure assessment.
6. It has to be evaluated whether other sources in the radio frequency range are correlated to base station exposure (e.g. are radio transmitters generally on the same mast as mobile phone base stations?). If a correlation does not exist, omitting their contribution would introduce non-differential exposure misclassification. The extent of misclassification depends on the proportion of that source compared to the total exposure. Non-differential exposure misclassification is expected to result in an underestimation of the true exposure-response association, but would not result in a false positive effect.
7. Given the major problem in exposure assessment we propose to initially focus on immediate or short term effect. Studies to evaluate effects with potentially long latency can be designed once more is learned about exposure.
8. With respect to soft outcomes, exposure blinding is important. Subjective rating of symptoms may be intently or unconsciously influenced by the knowledge of the exposure status. More objective measurements of both outcomes and exposure, if available will lead to improved study design.
9. Long term effects on soft health outcomes are methodologically problematic and cannot be suggested.

4.6 Requirements on future measurements

Future measurements should make it possible to assess personal exposure. It has to be possible to differentiate between the contributions from different types of RF sources meaning that methods should be used to allow frequency selective assessment. The exposure should be determined versus a relevant period of time to take the variations versus time into account. For certain endpoints, e.g. sleep, it might be sufficient to restrict the assessment to certain periods or locations. It is crucial to be able to distinguish between the exposure from different sources. One has to take into account that the exposure arising from base stations is often not dominant. Due to the fact that possible mechanisms between a specific RF signal and biological systems apart from thermal effects are not established or even unknown it is not an adequate approach to focus on specific types of sources, e.g. GSM base stations alone. Different types of other sources might lead to relevant contributions: GSM phones, DECT systems, TETRA systems, Broadcast applications, radar systems, office applications like WLAN and Bluetooth, industrial or medical applications (plastic sealing, diathermy).

Exposure misclassification would be a problem for any study focusing purely on signals from base stations, as subjects not exposed to radiowaves from mobile phone base stations but exposed to radiowaves from other sources would be falsely classified as unexposed. Under these circumstances, the misclassification would be random (non-differential), i.e., spread equally between the groups defined as cases and controls. (*Schüz and Mann, 2000*).

4.6.1 Calculations – Range of application of analytical and numerical tools

Distance from fixed installed RF transmitters seems to be a quite attractive surrogate for RF exposure due to its practicability for large populations. However, several investigations have shown that distance and exposure are not well correlated. The reason for this is complex field distribution conditions that are caused by fading effects, multipath propagation and meteorological factors that to highly variable exposure conditions. It can therefore not be recommended to use distance as metric for epidemiological studies on health effects of the electromagnetic fields from fixed installed RF transmitters. The use of distance as surrogate can lead to an important number of misclassified subjects.

Simple analytical calculations are more advanced metrics compared to distance. Based on the assumption of plane wave conditions the exposure in the vicinity of fixed installed RF transmitters can be easily estimated by simple means. Due to the fact that technical properties from transmitters like gain, side attenuation and input power can be taken into account, analytical calculations are a good tool for a first estimation of the exposure due to a single considered source at a specific position. However, such calculations do not take variations versus time, multipath propagation, shadowing effects and attenuation on one hand and multisource exposure on the other hand into account. Simple analytical calculations are therefore a good tool for pre-analysis of exposure but they are not suitable to give detailed information on personal exposure.

Another approach is the use of numerical tools to examine the field distribution in the vicinity from fixed installed RF transmitters. Depending on the applied tool, they allow rather detailed investigations of the field distribution taking large scale fading effects and shadowing from large obstacles into account. Such tools are quite suitable to distinguish between highly and less exposed areas in the environment of transmitters and very helpful to define areas where higher exposure can be expected. Often the prediction is limited to outdoor conditions. An example of a large scale field distribution determined with a numerical tool is shown in Figure 47. They can be an excellent tool for pre-analysis giving good overview on the field distribution; however they usually take only the contribution from one source into account and are not well suited to deal with variations versus time.

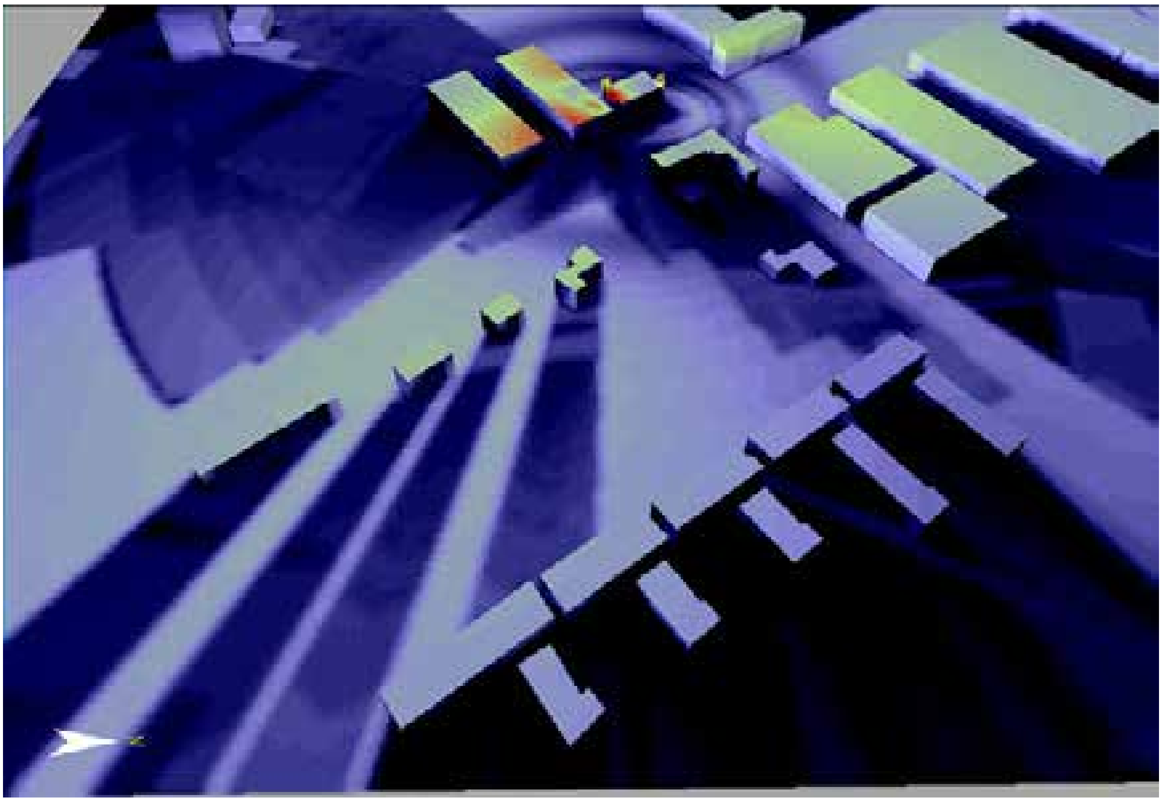


Figure 47: Field distribution around a base station in the city of Salzburg (OFCOM, 2002)

In summary it can be stated that both analytical and to a higher degree numerical tools are quite suitable for pre-analysis of exposure. However, such tools are usually not adequate to deal with personal exposure. There are two reasons for this: numerical tools only deal with the contribution from a single source (overlapping of calculations might be an approach), they cannot deal with the exposure from mobile sources and their accuracy is limited.

However, an investigation performed by MCA in Malta obtained correlations between calculated and measured fields in the order of 0.84 - 0.91.

4.6.2 Spot measurements

In the frame of about 10 epidemiological studies on RF electromagnetic fields spot measurements were applied to determine exposure. In most cases broadband probes were used being in some cases an appropriate approach. As long as the exposure due to a very dominant source has to be determined and the sensitivity of the measurement device is good enough, such methods seem to be suitable for exposure assessment purposes. In addition approaches are needed to determine historical exposure. Such scenarios typically correspond to occupational exposure.

The use of non frequency selective broadband probes to assess the exposure of the general public has to be discussed. First of all, the levels to which the public is exposed to are often very low in respect of the sensitivity of such devices. In such cases the probes indicate mainly noise and not only the contribution from a specific source. This can lead to exposure misclassification. But even if the levels are elevated enough, it is not possible to distinguish between the contributions from different sources, e.g. it is unknown if the exposure arises mainly from a mobile phone or a base station. Broadband probes are only suited to give statements on the total exposure within the frequency range they are specified for.

A more advanced approach is the use of frequency selective equipment making it possible to distinguish between the contributions from different RF sources to the total exposure. In many cases the sensitivity of frequency selective devices is better compared to broadband probes. It has to be mentioned that handling of frequency selective equipment requires more time and higher educated personnel compared to broadband probes.

Spot measurements have in general the disadvantage that neither long term nor short term variations versus time and also not variations in space (or only to a limited degree depending on the protocol) are taken into account. Their meaning for epidemiological studies is therefore limited, they might be applied for cross sectional studies (assuming that present exposure is correlated to historical exposure) to investigate immediate effects when additional methods are applied to estimate variations in space.

4.6.3 Monitoring of exposure

Two types of monitoring devices are available: frequency selective and broadband equipment. Both types have the advantage to take time variations of field levels into account but, while the use of broadband equipment is often limited by the fact that a distinction between the contributions from different sources is not possible, frequency selective monitoring allows assessing every single contribution to the entire exposure separately. Typically the sensitivity (ability to detect small signals) of frequency selective equipment is superior to broadband equipment. The disadvantage of monitoring devices is that their use is restricted to one fix place, personal exposure can only be determined in some special cases. The exposure in an environment where the subject is changing his position with respect to the sources of radiation would be in some cases overestimated. On the contrary, this method is best suited for fix scenarios, like sleeping time (home locations in general) or work environments where the worker stands still.

A good approach for assessing exposure would be a selective frequency monitoring system. The duration of exposure should be selected according to the investigated endpoint and also in respect of the expected exposure variations in time and also due to multi source exposure.

To date no epidemiological investigation of radio frequency electromagnetic fields and health aspects has used monitoring of the exposure as a surrogate, and such systems have only been used for other applications (Chapter 7.1.4.6) to assess the compliance of RF installations with limits and/or risk communication purposes. Most of such systems are broadband devices.

4.6.4 Dosimeter

Dosimeters seem to be together with monitoring systems one of the most suitable approaches to determine exposure within epidemiological studies. They offer good approaches to determine personal exposure, a few systems also allow at least partially frequency selective exposure assessment making the distinction between the contributions from different types of sources possible. It has to be taken into account that the body of subject has a certain impact on the field distribution that needs to be investigated in pilot studies.

A combination of frequency selective dosimeters, monitoring systems and analytical or numerical tools for pre-analysis might be a reliable approach for exposure assessment in the frame of epidemiological studies dealing with base stations or other types of fixed RF transmitters.

4.7 Suggested assessment methods

The exposure due to base stations is very often not dominant compared to the contributions from other sources and highly variable both in time and space. It is therefore very delicate to make retrospective reliable exposure estimation from base station. The contributions from other sources can not be neglected, at least not a priori, because they can be relevant or even dominant. Therefore prospective approaches based on personal measurements are recommended in future epidemiological studies.

Such measurements might be performed using personal dosimeters or monitoring equipments. Both types of devices have the advantage that they can assess different contributions arising from different technologies, e.g. GSM, UMTS, and Broadcast. Such systems are even able to distinguish between fixed installed and mobile devices. When using frequency selective monitoring equipment it is possible to distinguish between the emissions from different base stations operating in the same band. Besides, time variations of the exposure are taken in both cases into account.

The dosimeters have also the advantage that they can be used as monitoring systems when they are not carried by the subject, too (e.g. sleeping time).

The specific metric (e.g. maximum, mean, rate of change) should be selected according to the specific endpoint. However, as long as the equipment recommended is used it is possible to use all types of metrics.

4.7.1 Methods for immediate effects

When immediate effects on health are investigated, laboratory studies can be considered as good approach due to well controlled exposure conditions.

Another approach is field trials. For such purposes the use of numerical tools is a suitable approach at least for the pre-analysis phase. For such studies prospective design using dosimeters and/or monitoring devices can be recommended. Blinding of the exposure is important, i.e. subjects should not be able to know their actual exposure conditions.

4.7.2 Methods for short term effects

When dealing with short term physiological effects field studies (natural experimental field trials) are recommended. In these studies exposure might be assessed by frequency selective dosimeters carried on by the subjects during the experiment.

In experiments like investigations of sleep disturbances, monitoring devices are adequate and suited when located close to the bed of the subject under test.

Pre analyses to assess exposure by using analytical calculations or software tools might be an approach for selection of subjects.

A special case is reproduction outcomes. The investigation of the effects of exposure to RF in reproduction outcomes could be performed with a prospective follow-up study. Voluntary chosen pregnant women could carry a dosimeter from the date of prediction (about 6 months) to some months or even a year after the birth. This method could also allow a prospective study of children diseases if the follow-up is continued thereafter.

4.7.3 Methods for long term effects

The performance of long term studies is discouraged because of the difficulty of the personal assessment of the exposure for long periods of time: exposure assessment for such periods is associated with many problems and expensive (in respect of time and money), especially when large

populations are involved. Long term studies are usually based on retrospective exposure assessment. Assessment of past exposure is in particular problematic for dead persons, makes studies on mortality difficult.
When assessing personal exposure, the usage of dosimeters is recommended. In a follow up of various years the subjects might carry the dosimeters one or two days per year, or a sufficient number of times in a way that relevant exposure contributions can be taken into account. These regular measurements might also allow to assess possible changes, not only in the exposure scenarios where the subject lives (e.g. change of job or residences) but the new telecommunication systems that could appear in future years would also be taken into account.

Another approach would be the performance of a pilot study including an exposure matrix based on multiple possible scenarios or patterns of exposure. This matrix should capture all types of exposures according to job, residence and sort of person (age, genus, habits) conditions, and measurements should be performed (again preferable with dosimeters or monitoring systems, also follow-up could be desirable) to evaluate the exposure for every condition.
The principal drawback of such model can be the broadband of the matrix, because many scenarios or conditions will derive in a quite complicated matrix.

5 Discussion

The increasing use of mobile phones in the last decade triggered an important deployment of mobile telephone base stations worldwide and in particular in Europe. Concerns of parts of the population and decision makers about potential health effects of emissions from base stations resulted in needs for society to have information on exposure and the effects of exposure, leading to the demand for epidemiological studies on potential health effects.

The feasibility of future epidemiological studies on health effects, including well being of populations around mobile phone base stations was evaluated by a multinational team of experts in the fields of epidemiology and dosimetry. The feasibility of such a study depends on finding solutions to scientific problems, e.g. reliable estimates of exposure, control for bias and confounding, selection of health outcomes. Because studies using inadequate design could lead to wrong conclusions and/or increasing concerns in the population, we include recommendations and quality criteria for such studies.

The project is based on analysis of existing study designs, results of existing residential and occupational epidemiological studies, epidemiological studies on mobile devices and large scale exposure assessment studies. Relevant studies were selected, analysed and discussed.

Based on this evaluation epidemiological study designs for the investigation of potential health effects of RF exposure were developed. Types of health outcome to be investigated, basic principles of exposure assessment, definition of metrics, and the relevance of other RF sources, proxies and exposure blinding were considered. The relevance of control for bias and confounding was discussed. Suggested methods are given for immediate, short term and long term effects. Because exposure assessment is crucial requirements on future assessments are given. Calculations, spot measurements, monitoring of exposure and the use of dosimeters are discussed.

One of the crucial aspects of epidemiological base station studies is the question whether base station exposure is relevant compared to exposure from all other EMF sources or whether it can be neglected in any circumstance. In order to answer this question one major problem is that we do not know which exposure circumstances might be biologically relevant or critical. Base station exposure might be relevant if one is interested in total exposure time above a very low threshold, e.g. > 0.5 V/m, it may be relevant for 24 hours whole body exposure, but seems not to be relevant for momentary exposure levels at a specific body site. If an effect is extremely frequency and/or signal specific, base station exposure might be relevant, too. In contrast, if the focus is on rather high and local exposure levels, mobile phone exposure or the contributions from other local sources might be most relevant.

Another crucial aspect of epidemiological base station studies is the way exposure is assessed. Past residential RF exposure assessments were based on the distance to the source and in a few cases simple analytical calculations or spot measurements. Distance is poorly correlated to exposure levels and, therefore, the use of distance as an exposure metric is not recommended. Analytical tools and spot measurements are problematic in studies involving retrospective exposure assessment approaches and might lead to severe exposure misclassification. Reasons for exposure misclassification are the contribution from other RF sources and the exposure variations in time and space and variations due to changing weather conditions. In many countries measurement campaigns have been performed using different protocols. Spot measurements have been most common, but, in some cases monitoring equipment was used as well. All of these measurements have been stationary, and usually broadband equipment was used which does not distinguish contribution from different RF sources. These measurements have usually been made as a result of public concern about base station exposures or other specific sources, and do not reflect the RF exposure in the general population. No information on personal exposure was found in any of the examined studies. Thus, at present, little information on individuals’ exposure in the general population is available, making it problematic to estimate the exposure from all radio frequency sources in the general population. A better knowledge of the distribution of total exposure, as well as a contribution from different sources would allow for a design of more efficient studies.

Hence, more measurement campaigns focusing on exposure in samples representative for general population are urgently needed. An attempt should also be made to develop good proxies. It is not the first priority to obtain an exact value for the total exposure, but rather to know factors which can be relatively easily obtained and allow to divide the study collective accurately in exposed and non exposed groups or in groups which are exposed to a varying degree. A suitable proxy has to capture all relevant sources of exposure in the radio frequency and microwave frequency range. Given the limited knowledge at present, a single exposure assessment approach can not be recommended. There may exist specific populations which have only one dominant exposure source (e.g., in occupational settings or people living close to strong transmitters), however this will rarely happen for base stations. The importance of co-exposure to other sources depends on the assumption of effect specificity and the proportion of their contribution to the overall exposure. Neglecting of such sources will introduce exposure misclassification. If only a low proportion of the study population is exposed, a high specificity (truly unexposed) is more important than a high sensitivity (truly exposed).

Possible dosimetric approaches are summarized below:

- One approach might be the use of monitoring systems to assess variations in time of different contributions, in particular in studies where people are expected to stay at the same location
- Another approach might be the use of dosimeters to assess individuals exposure where people are expected to change their location
- Numerical and/or analytical tools could be used to provide crude estimates (for stratification) of exposures from specific fixed transmitting installations

Regarding selection of relevant outcomes, it needs to be stressed that there is little scientific evidence for specific candidates. Given paucity of data, selection of the outcome may be based on anecdotal reports and/or on analogy from ELF research. Physiological measures can be objectively measured and are useful to evaluate biological mechanisms. On the other hand, soft outcomes, e.g. sleep, headache, well-being are more difficult to assess. Soft outcome measurements are primarily based on questionnaires and are only occasionally complemented by objective methods. Long term measurements of soft outcomes and between subject comparisons can be problematic. For “electromagnetic hypersensitivity” there are currently no diagnostic criteria, objective signs, or measurement instruments available. The concept “electromagnetic hypersensitivity” is in itself problematic as the exposure is included in the definition of the condition. The concept relies solely on the subject’s own attribution of his/her symptoms to electromagnetic fields. Chronic diseases can be objectively diagnosed, however, investigating such diseases need long term follow up and often rely on a retrospective exposure assessment.

In the context of base station research, researchers also have to be aware of Nocebo effects. The Nocebo effect is the inverse of the Placebo effect and means that adverse symptoms due to expectations (due to concerns). The Nocebo effect has to be addressed when designing studies on soft outcomes. The development of study designs including truly exposed subjects, subjects who perceive exposure but are unexposed, subjects who don’t perceive an exposure but are exposed, and truly unexposed subjects is encouraged, as it is then possible to separate between physical and psychological effects. It is furthermore recommended that, for soft outcomes, diagnostic methods are used which are as objective as possible, e.g. actigraphs for sleep or validated questionnaires for assessing well-being. Note that the use of questionnaires is always very problematic if study participants are aware of their exposure status.

6 Conclusions

General aspects

One has to be aware that we are just at the beginning stages of addressing exposure and potential health problems associated with the new technology of mobile communications. More knowledge is needed mainly in development of exposure proxies and methods that minimize bias in the measures of soft outcomes.

A very important first step to improve research in this field is to gain knowledge on the exposure distribution and variability of exposure in the general population from different RF sources. Exposure surveys with personal RF exposure measurements in randomly selected samples of the general population are strongly encouraged. One aim of such surveys is to estimate the contribution of the different RF exposure sources to the total exposure, in different subjects, at different points in time. A second aim is to identify characteristics that allow a valid prediction of individual exposure levels and can be used in large-scale studies.

Investigations of soft outcomes are often based on questionnaire methods. Thus, blinding of the study participants regarding exposure status is an important requirement of such studies. Blinding is less of a problem for chronic diseases which can be assessed using objective diagnostic tools. However, for these outcomes retrospective exposure assessment methods need to be developed.

Exposure assessment

It is not generally recommended to neglect a priori the contributions from other RF sources than mobile phone base stations. Thus, an exposure proxy has to capture all relevant sources in the RF and microwave frequency range. Systematic measurement studies in different populations are needed to obtain more data on individual’s exposure as a mixture of exposures from different sources. In terms of both cumulative and time weighted average exposure and exposure above a certain threshold it has to be investigated whether there is sufficient variability between subjects and if so, what are the main reasons, for this variability and whether it can be reliably (albeit approximately) captured in a large population. The outcome of these investigations will have significant impact on which hypothesis can be tested in the future.

Immediate effects

In this project, the analysis were performed separately for immediate effects (effects that occur within hours), short term effects (occurring within days or weeks) and long term effects (occurring within several months or years).

The best approach to investigate immediate effects is laboratory provocation studies because they can use randomization and blinding. Cross-over designs may be applied to minimize effects of between-subjects variability, but carry over effects from exposure and the possibility of accrued learning from previous testing need to be avoided. Human experiments should include healthy volunteers as well as groups of people who report to be affected by EMF exposures. Studies of immediate effects could measure physiological parameters. The use of validated questionnaires to assess total well being or particular aspects of well being is recommended. The exposure conditions have to be well controlled. An adequate design can minimize bias.

Alternatives to human experiments are field trials or cross-sectional studies, which have the advantage of being conducted under normal life conditions. Exposure assessment methods can be frequency selective and should give a proxy for total exposure (the latter one would be an excellent first step). Blinding of subjects regarding exposure status is a major problem of such studies. It is likely that studies in the general population and not only around a few single base stations would be less prone to such bias. Study concepts have to consider that immediate effects in people living in the vicinity of base stations may be due either exposure to electromagnetic fields or to concerns (Nocebo effects). In the studies on immediate effects, blinding of subjects regarding exposure status is a crucial requirement.

Short term effects

Effects that appear after weeks or months of exposure are not detectable in human laboratory experiments, therefore other study concepts have to be applied for such outcomes. In principle, several types of studies can be used to investigate short term effects: field trials (including interventions), cross-sectional studies and prospective cohort studies. Cross-sectional studies are useful for descriptive purposes, but cannot be used to determine if the exposure can cause various outcomes. In both field trials and cross sectional studies it is essential that subjects are selected randomly from the population, and that non-participation can be assessed and evaluated. Otherwise, selection bias might be a severe limitation. The use of validated questionnaires to assess total well-being or particular aspects of well-being is necessary. Estimates of changes in well-being are often more relevant and easier to measure, and is a prerequisite if the purpose is to study whether the exposure can cause various symptoms. Under certain assumptions, sleep quality seems to be an appropriate outcome to be studied. Sleep actigraphs might be used as an objective measure of sleep outcomes. It has to be taken into account that rare outcomes need adequately large study size. No exposure assessment protocol should be applied without pilot or validation study, however some methods involving measurements seem to be promising. Exposure monitoring systems seem to be a good approach if the movement of subjects is negligible for study purposes, e.g. in sleep studies. The implementation of dosimeters needs to be demonstrated. Simple calculations might be used for stratification of samples into high or low probability of exposure. More sophisticated models are yet to be developed.

Long term effects

Focussing on long term effects, epidemiological studies on morbidity and mortality are feasible in populations in which a dominant RF source can be identified and/or a valid distinction between exposed and non-exposed persons can be made (e.g. in the vicinity of strong transmitters or in occupational settings). Such studies should be designed to have sufficient statistical power to detect effects at realistic magnitudes. The validity of the exposure metric to be applied has to be demonstrated, in pilot or validation studies. In principle, several types of studies could be envisaged: prospective cohort studies, retrospective cohort or case-control studies. The latter two types are only feasible if reliable estimates of historical exposure can be calculated. Classical biases, e.g. selection bias and confounding have to be minimized. For base station studies, no adequate exposure metric for studying long-term effects is available at the moment. The accuracy of personal dosimeters for its use in prospective studies has to be demonstrated. Attempts were made to use calculations, however the validity of such methods has still to be evaluated. If new methods to assess exposures are developed, it seems appropriate to study effects of total RF exposure rather than studies solely of base stations.

7 ANNEX

7.1 Existing exposure assessment concepts

7.1.1 Residential exposure assessment concepts

7.1.1.1 Studies based on measurements

Altpeter et al., 2000 have investigated for ten years possible health related effects arising from the exposure due to the Short-Wave Radio transmitter installed in 1954 in Schwarzenburg (Switzerland).

The frequencies of the emissions were between 6.1 and 21.8 MHz and the emitted power was three times 150 kW, although 300 kW were effectively used. In 1971 a new antenna with a power of 250 kW was installed for cases of failure but it has hardly been used.

During these years several epidemiological studies were performed: two cross-sectional studies in 1992 and 1996, 3 short cohort studies (1992, 1993 and 1998, two of them about melatonin levels), and 2 studies with animals (1993 and 1998).

The exposure was assessed by the former PTT (SWISSCOM) under the supervision of the Technical School of Zurich and Lausanne in 1992 and 1993. In 1992 a loop antenna (model Rhode & Schwartz HFH-72) was used which measured fields in the frequency range from 100 to 30,000 kHz with a precision of ± 1.5 dB. In 1993, 1996 and 1998 an isotropic probe EH30KW from EMC Baden Ltd. was used, which measured in the frequency range from 2 to 30 MHz. While the loop antenna was moved manually in the three spatial directions to assess the value of the fields, the isotropic probe allowed automatic 24 hour measurements. This way, exposure in the bedrooms of the participants was already assessed in 1993.

In line with the cross sectional studies the areas surrounding the mast were divided first in 3 (1992) and then in 4 (1996) zones, according to the exposure level: very low exposure (zone C, 92 and 96), low exposure (zone R, 96), moderate exposure (zone B, 92 and 96) and high exposure (zone A, 92 and 96), as can be seen in Figure A-1.

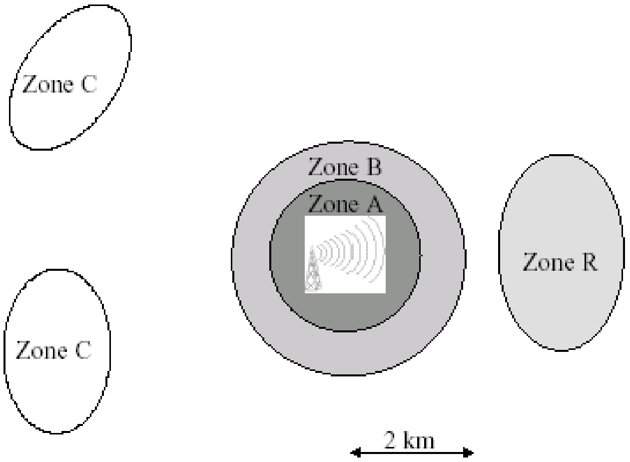


Figure A-1: Areas of exposure considered in the investigations of *Altpeter et al., 2000*.

In Figure A-2 the values of H-field obtained in 1993 are shown:

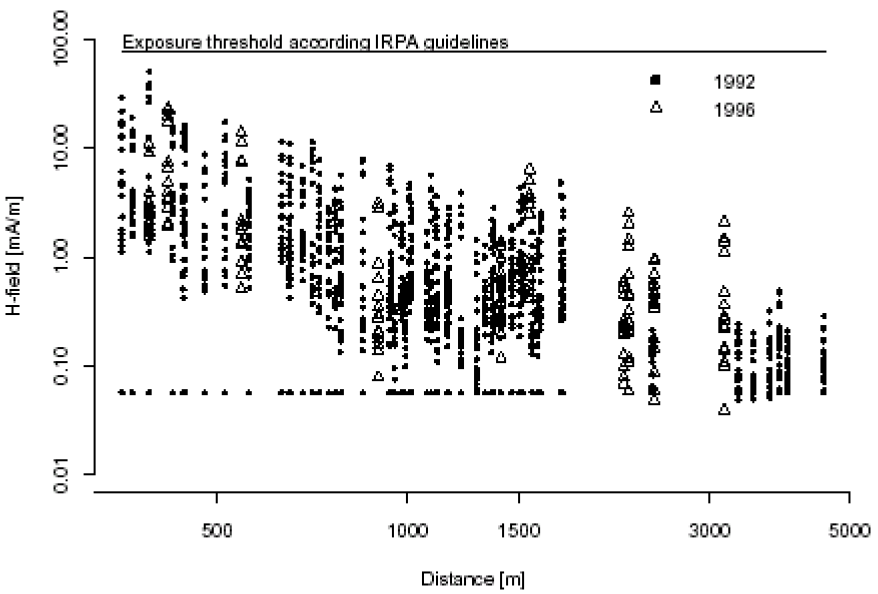


Figure A-2: H-field values of the bedroom measurements (*Altpeter et al., 1995*)

The bedroom values of the E- and H-fields are shown in Figure A-2 (measurements performed in 1995) and Figure A-3 (measurements performed in 2000) for the different distances to the station in the above mentioned areas. Each dot represents a mean value over an emission period of, generally, 105 minutes at every bedroom. Background level and exposure limits are also emphasized in the graphic.

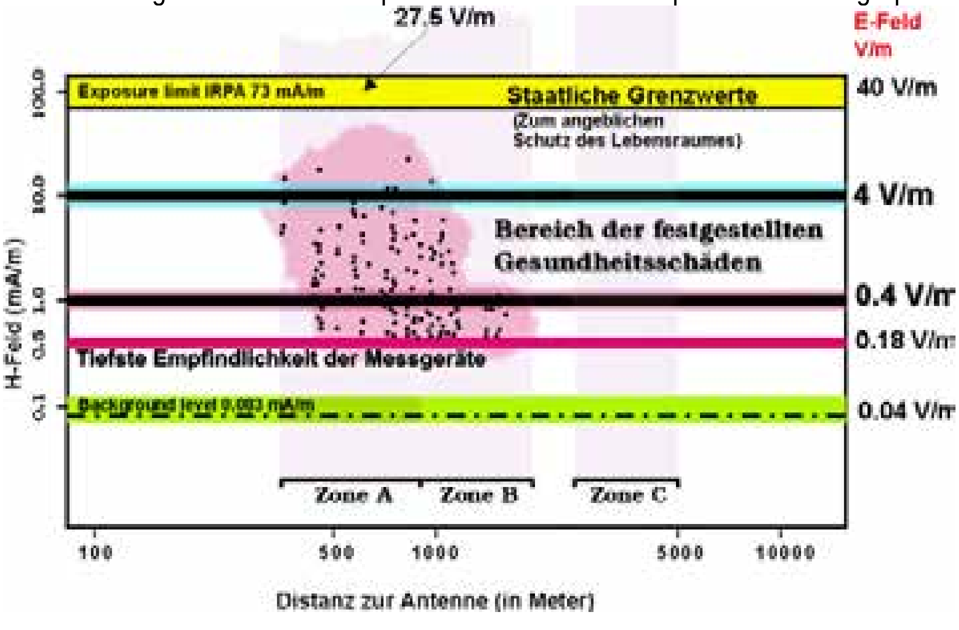


Figure A-3: H- and E-field values of the bedroom measurements (Altpeter et al., 2000) Each dot represents a mean value over an emission period (in general 105 minutes), at a particular location. Indicated is the distance to the transmitter-antenna. The sensitivity of the sensor EH30KW is limited by physical reasons to 0.5 mA/m, values below that level could not be measured.

Large efforts were made to perform reliable exposure assessments in the frame of these studies, especially because this was an unusual installation in that the direction of emission changed every two hours, which can be appreciated in the Figures, in the large spread of spot measurements made at the same distance. However, one of the remaining open questions is to what extent the spot measurements and the 24h monitoring correspond to the exposure of the test persons. Another problem arises due to the sensitivity of the measurement systems that might be above levels suspected to provoke biological effects. We don't know what level is "of health relevance".

The investigations of *Navarro et al., 2001* focus on symptoms experienced by subjects in the surroundings from base stations having in mind the studies from *Lilienfeld, 1978* which reported a "microwave syndrome" among those exposed to the low levels of radar microwave power density.

Broadband measurements of the RF electromagnetic field (GSM and DCS bands) were taken in the bedrooms of each home of 97 subjects in two different days, but at similar times of the day. To perform such measures, a portable broadband electric field meter (EFM) was used. The EFM was hold by hand to measure the maximum strength of the field above the bed, a scanning procedure was applied. The electric field presented a standing wave pattern because of the reflection of the waves in the building structures, but the levels obtained were low with only 21 subjects in the 0.6 - 2.0 V/m categories and 76 between 0 and 0.5 V/m according to the authors.

To check the number of working channels of the cellular phone base stations and to assess that almost all the contribution to the exposure comes from the base station, measurements of the spectral power density were also carried out with an antenna and a spectrum analyser. The test device was mounted at a height of 1.2 meters and 20 meters away from the BS. The spectrum was scanned in the GSM and DCS band with values averaged over 5 minutes. The values obtained were similar both days, with differences in the peaks estimation (carriers of the channel) which were within the limits for error of the spectrum analyser.

The use of additional frequency selective measurements to verify the dominance of the immissions arising from the base stations needs further attention. As long as these measurements are not performed at the same time as the broadband measurements, there is always the possibility that the contributions from other sources like mobile phones might lead to an overestimation of the contribution of the base stations. A more suitable approach might be the use of frequency selective equipment to estimate personal exposure. Scanning procedures in general have to be considered with some caution: under certain circumstances the body of the engineer performing the measurement can have some impact on the measurement result. Another dosimetric problem of this particular study are the very narrow amplitude bands used to classify the exposure levels at steps of 0,5 V/m (0 – 0,5 V/m, 0,5 – 1 V/m and so on). Taking only the variations of the levels of broadcast channels of GSM base stations versus time into account that can readily reach 3 dB or more the risk for exposure misclassification seems not to be negligible.

Hutter et al., 2002 also investigated health symptoms (complaints, sleep quality and cognitive performance) near base stations in Austria in a cross sectional study which included 365 subjects.

Exposure was assessed with electromagnetic field measurements. For that purpose, 10 base stations, five in the rural area (180 subjects) and five in densely occupied urban areas (185 subjects) were selected following the conditions:

a. The antenna must be already operating for at least two years.
b. There should have been no protest of neighbours to the erection of the base station.
c. There should be no other base station nearby (which was possible only in rural area).
d. There should be preferentially only transmission in the 900MHz band.
e. At least 18 subjects were living in the surrounding of the base station.

An inner and outer area was specified and within them an equal number of people were included to ensure a sufficient gradient of exposure.

The measurements were done with a biconic field probe connected to a spectrum analyser in the sleeping room and, in the rural area, additionally at a place where the maximum immission was expected. The values of high frequency EMF obtained were generally low and ranged from 0.0002 to

1.4 mW/m², the greater portion of the immission was from mobile telecommunication (70 % approx) that was between 0.00001 and 1.412 mW/m².

The study of Hutter and colleagues has some advantages compared to that of Navarro et al: the use of frequency selective equipment makes exposure misclassification due to other RF sources very unlikely and the use of this type of equipment leads to a higher sensitivity in particular in the range of very low levels. However, also in this case the classification of exposure levels is very narrow and makes misclassification between the different exposure groups due to the uncertainty arising from the variations of the field levels in time and space possible.

7.1.1.2 Studies based on other concepts

Distance

Concerning residential exposure, most of the available studies have focused on radio frequency transmitters such as TV and radio transmitters. More recently a few studies have focused on base stations from cellular telephony systems.

To date most of the studies have used only distance from the telecommunication tower as a surrogate for the exposure to radio frequency electromagnetic fields. The obvious drawback of this method is that personal exposure and the characteristics of the environment that affect the field parameters are not considered.

The investigations of *Selvin et al., 1992* and *Maskarinec et al., 1994*, fall in this category using distance from the station as an exposure metric. *Selvin et al., 1992* investigated the possible relation between leukaemia, Hodgkin and non-Hodgkin lymphoma incidence and distance to a large microwave tower located in San Francisco (Sutra Tower, which transmitted UHF TV, VHF TV and FM radio) by comparing subjects living up to 3.5 km from the transmitter with those living between 3.5 km and 10 km without finding significant results. Selvin and colleagues assumed that field levels diminish linearly with the distance, but measurements performed later (*Hammett and Edison, 1997*) at the same locations demonstrated that this assumption was wrong.

Maskarinec et al., 1994 performed a case control study with 12 childhood leukaemia cases diagnosed in Hawaii between 1979 and 1990 (48 matched controls, from a list of patients of an health centre) and distance to a military transmitter transmitting waves at 23.4 kHz and in operation since the 1940s. Exposure was defined as having lived within 2.6 miles (4 km) from the transmitter, the median of the distribution for all distances, where distance from the house to the tower was obtained both manually and with the help of a geographical software package. Although no measurements were made for this study, the measurements performed by the U.S. Environmental Protection Agency (EPA) did not reveal levels of EMF exceeding the limits of existing guidelines.

Due to the fact that no attempts were made to assess exposure there is no possibility to distinguish between the contribution from the mentioned military transmitter and other sources. The antenna characteristics, topography and objects like buildings can also have an important impact on the field propagation, it is therefore not sure that exposure is higher in all cases within the area of 2.6 miles around the transmitter. Therefore exposure misclassification cannot be excluded.

In Great Britain two consecutive studies regarding cancer incidence near TV transmitter were performed by *Dolk et al., 1997a and 1997b, and Cooper and Saunders 2001*. Within the first study the TV tower near Sutton Coldfield was considered and the second studies focussed on 20 high power broadcast sites in Great Britain.

The Sutton Coldfield tower transmits 4 TV channels of 1 MW ERP each and 3 broadcast channels of 250 kW ERP (VHF). The area of study was defined by a circle of 10 km radius centred on the

transmitter. The population inside that circle was 408.000 persons. Within the study area, ten bands of outer radius of 0.5, 1.2, 4.9, 6.3, 7.4, 8.3, 9.2 and 10 km were defined.
In the second and third study the authors investigated 20 other high power broadcast stations in Great Britain using the same methods.

In dosimetric terms these studies suffer from similar limitations as the studies from Selvin and Maskarinec. Distance is a very weak surrogate for exposure, due to the increasing impact of the environment on the propagation pattern with increasing frequency, the situation is getting worse with augmenting frequencies. Apart from the fact that shadowing effects, antenna pattern and variations in time were not taken into account, the contribution from other sources might be relevant under certain circumstances. A decline in distance from a fixed installed transmitter must not always correlate with a decline of exposure.

More recent studies are those performed by *Michelozzi et al., 2002*, where adult and childhood leukaemia near a high-power radio station in Rome, are investigated. The radio station (owned by Vatican Radio) is installed in an area which covers about 2 km² and includes 3 rotating and 28 fixed antennas which transmit at different power levels ranging from 5 to 600 kW, and different frequencies (9 short-wave transmitters operating at 4.005 - 21.850 kHz, and 3 transmitters for medium waves at 527 - 1.611 kHz).
Measurements were not performed for this particular study, but the results of tests made between 1998 and 2001 by regional and national environment protection agencies are commented in the study. These values were obtained in locations typically within 1 km from the short wave transmitter and showed values exceeding the indoor and outdoor legal Italian national limits as can be seen in Table A-1. Nonetheless, the measurements were made with broadband devices (without frequency selection) and they do not capture neither personal exposures nor variability of the fields.

Organization, year, (instrument)	Frequency range	Indoor/outdoor	Distance from the radio station (km)	Electric field (V/m) highest value at each location
National Agency for energy and environment (ENEA), 1988 (Holaday, model HI-4418)	Broad band	Indoor*	<1 (2 houses)	13.6; 20
National Agency for energy and environment (ENEA), 1988 (Holaday 442)	Broad band	Indoor*	=1 (2 houses)	3.5; 8.0
	Broad band	Indoor*	>4 (1 house)	1.8
National Environmental Protection Agency (ANPA), 1999 (Wandel-Godlamn MR300-PMM8053)	Broad band	Indoor+	=1 (2 houses)	12.7; 16.1
	Broad band	Outdoor+	=1	> 20.0
Local Health Authority (ASL RM/A), 1999 (EM PMM 8051 + spectrometer AVANTEST)	1530 kHz – 9585 kHz	Indoor+	=1 (public building, 1 house)	3.0; 4.6
	1530 kHz – 9585 kHz	Outdoor+	<1	8.9
	Broadband	Outdoor+	=1	15.0
National Agency for energy and environment (ENEA), 2001 (EMI, spectrometer HP8568B, HP85685)	1531 kHz	Indoor+	=3 (1 house)	12.2
	11630 – 17520 kHz	Outdoor+	<0.5 (sports ground; 3 sties)	30.0; 54.0; 95.0
Regional Environment Protection Agency (ARPA), 2001 (PMM8053, EP330)	Broad band	Outdoor+	=1 (3 sites)	18.4; 22.5;22.3

**: 24 hour prolonged measurements*
+: spot measurements

Table A-1: Results of the environmental protection measurements obtained around the Vatican Radio Station.

The surrogate for exposure chosen was distance, specifically the area was divided in circles up to 10 km from the short wave transmitter (316 km²), divided in five 2 km bands.

The group of *Santini et al., 2001a, 2001b and 2002* has recently performed several survey studies about symptoms experienced by people living in the vicinity of base stations. 530 people (270 men, 260 women) living at different distances from cellular base stations were included, the surrogate for exposure was the distance from the base station. This exposure was estimated by the subjects themselves in the questionnaires. The subjects had to report distance to the base station (<10 m, 10-50 m, 50-100 m, 100-200 m, 200-300 m, and > 300m), the position of the antenna of the base station, the time lived near the base station (less than a year to more than five years), the time spent in the vicinity of the antenna (days per week, hours per day). The questionnaire also assessed the use of computers, mobile telephones, living close to transmission lines or transformers or the presence of other RF transmitters (radio or TV) in the proximity.

People living at different distances (100 m, 200 m and 300 m) from base station were compared with those living far away.

Apart from severe drawbacks in the study design, the dosimetric concept of this study is also not adequate to examine the relation between exposure from base stations and health symptoms. The potential for exposure misclassification is very high as distance to base station is not a valid proxy for exposure to high-frequency electromagnetic fields. One reason is that, in the closer vicinity of a base station, distance alone is not well correlated with field strength, another reason is that contributions from other RF sources are not taken into account. In this particular study it is an additional shortcoming that distance was estimated by the subjects themselves, which is another likely source of measurement error.

Hocking et al., 1996 performed an “ecological study” by comparing cancer incidence and mortality in 9 municipalities of Sydney, Australia, three of which surround TV towers and the other 6 further away. Data on frequency, power and period of broadcasting for the three TV towers were obtained from authorities. The TV signals are composed of 100 kW video AM and 10 kW audio FM signals, transmitted at carrier frequencies which range from 63 to 215 MHz. In this case, they compared the cancer incidence in municipalities where a transmitter was situated to that in municipalities without a transmitter.

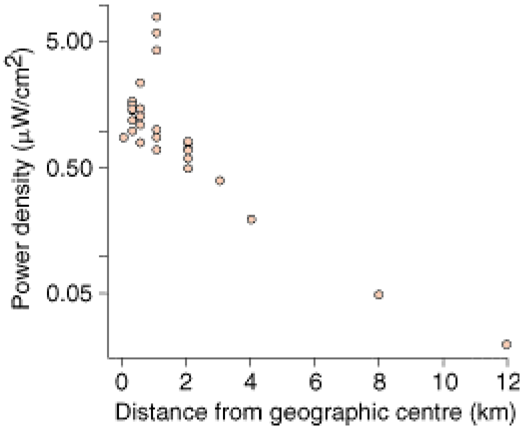


Figure A-4: Logarithm of calculated power densities (µW/cm²) for TV signals from the three TV towers against distance in kilometres from the centre of the towers.

The combined field strengths at increasing distances were calculated by a method developed by the US National Council on Radiation Protection and Measurement. The power density at the centre was calculated to be approximately 1 µW/cm², with the maximum in the area being approximately 8 µW/cm² and reducing to 0.2 µW/cm² at 4 km and to 0.02 µW/cm² at 12 km. *Some measurements made in the region of Tower 1 by the Commonwealth Department of Communications found actual levels to be five times less than those calculated (DCA, 1994).* The calculated power densities (see Figure 4) are the power sum of the four TV signals, the power density of each channel being calculated individually, taking into account distance from the relevant antenna and the gain reduction at the calculated angle below the horizon.

No account was taken of ground reflections, which lead to fading effects at distances of about half a wavelength (2.5 m at 60 MHz to 0.7 m at 215 MHz), nor of signal reduction (even cancellation) by buildings, vegetation or ground undulations, and the authors address the disparity between calculated and measured levels to these factors.

These investigations were continued by *McKenzie et al., 1998* with similar methods and statistically significant results.

Hallberg and Johansson, 2002 studied a possible association between the increase of melanoma incidence since the 1960s and the expansion of the FM broadcasting network in an ecological correlation study. This investigation included data on expansion of the FM broadcasting towers of 4 countries (USA, Norway, Sweden and Denmark). Exposure-time-specific incidence was extracted from exposure and incidence data from 4 different countries, and this was compared with reported age-specific incidence of melanoma. Geographic differences in melanoma incidence were compared with the magnitude of exposure. Both power density and melanoma incidence (obtained from 288 communities for 1992-1996 in Sweden, Norway and Denmark) were superimposed and displayed in maps. Exposure was only available on a community-level, which is very crude.

The Investigation of Cancer Incidence in the vicinity of Cranlome Telecommunications Mast in Northern Ireland, by *Catney and Gavin, 2004* provides a typical example of what is done in the frame of such investigations. A putative cluster of cancer was investigated, but while the identification of cases was exhaustively assessed through access to hospital databases, regarding exposure to electromagnetic fields, the solely approximation was the distance to the mast. The number of cancers diagnosed in areas representing concentric circles of radius 1, 2, 3, 4 and 5 km from the tower is compared with those diagnosed in comparison populations living far away from that particular mast (Northern Ireland and Dungannon), However, it needs to be demonstrated how well distance to the mast is correlated with exposure to RF electromagnetic fields.

7.1.2 Occupational exposure assessment concepts

7.1.2.1 Studies based on measurements

A quite interesting study in this category was performed by *Lotz et al., 1995* for the U.S. National Institute for Occupational Safety and Health, they investigated exposure of police officers to microwave radiation from traffic radar devices.

Assessment consisted of the measurement and evaluation of microwave emissions from, and operator exposure to ten models of radar guns operating in the K (24.15 GHz) and X (10.525 GHz) frequency bands. The devices used by the police emitted all less than 100 mW of power, being most of the radar devices manufactured in the last 20 years in the power range of 15 to 50 mW, which is quite below other radar devices used for military, marine or commercial aviation.

The measurements procedures were based upon the IEEE Recommended Practice for the measurement of Potential Hazardous EM Fields-RF and Microwave.

Test equipment included power density meters, with frequency specific power sensors and standard gain horn antennas, frequency counters, survey meters and voltmeters.

Measurements from both fixed mounted and handheld radars were done while operating under normal conditions, at distances of 5 and 30 cm in front of the antenna, around and behind the unit and in the position of the operator. Aperture power density was defined as “the maximum power density external to the radar antenna” and occurs “at the interface between the radar antenna and the open space directly in front of the antenna”. Potential operator exposures were measured at the head and groin levels in absence of an operator and at the eyes, waist and knees in the presence of the operator.

The results of the measurements showed that only in cases where the person would be actually in the main path in close proximity to the radar the exposure would be above the MDL (minimum detectable level, 20 μW/cm²).

In Table A-2 the potential operator exposures at different locations are shown. The first column refers to the type of radar device used.

Potential operator exposure power density measurements made with a Narda 640 (X) or 638 (K) Horn and HP 435B Power Meter (mW/sq cm).

ID	Eyes	Waist	Knees	Mount Location	Radar Facing
E	0.07	ND	ND	Inside Rear Window - Driver Side	Back
E	0.07	0.05	ND	Inside Rear Window - Passenger Side	Front
F	0.10	0.01	ND	Front Dash Mount - Centred	Front
F	0.07	2.60	ND	Resting on Front Passenger Seat	Driver
F	0.04	0.01	ND	Resting on Front Passenger Seat	Pass. Door
F	0.07	ND	ND	Over Operator's Shoulder	Back
G	0.16	0.16	ND	Resting On Front Passenger Seat	Driver
G	0.13	0.13	ND	Resting On Front Passenger Seat	Pass. Door
J	0.20	0.42	ND	Resting On Front Passenger Seat	Driver
J	0.97	0.97	ND	Resting On Front Passenger Seat	Pass. Door
J	ND	ND	ND	Over Operator's Shoulder	Back

Abbreviations: E = MVR724, F = Speed-Gun 8, G = K-15K, J = HR-8., ND=not defined

Table A-2: Power density measurements of radar devices (*Lotz et al., 1995*)

The dosimetric approach of Lotz and colleagues is quite suitable, however due to the lack of adequate records the past exposure was not taken into account.

Tynes et al., 1996 performed a study of breast-cancer incidence in seagoing female radio and telegraph operators in Norway who potentially had been exposed to light at night, RFEMF at frequencies in the range from 405 kHz to 25 MHz, and ELF (50 Hz).

The authors derived data from a Norwegian Telecom cohort (TC) of 2,619 women who had been certified as radio and telegraph operators between 1920 and 1980, of which 98 % had worked on Norwegian merchant ships. The cohort was followed from 1961 through 1991.

Spot measurements of the RF fields were made in the radio rooms of three Norwegian ships that still had old-fashioned transmitters (ITT types ST 1600A and ST 1610A) representative of those used in the last three decades. For those measurements, the transmitters were operated at maximum power. The unmodulated transmitted power for telegraphy in the frequency range 410-535 kHz was 1.5 kW. The transmitted powers for both unmodulated and amplitude-modulated telephony were 400 W in the range 1.6-3.6 MHz and 1.5 kW in the range 3.6-25 MHz. A Holaday Industries Model HI-3002 isotropic broad-band field-strength meter with electric and magnetic probes was used. The meter was calibrated in a TEM cell (Crawford, 1974) at the National Institute of Occupational Health in Umeå, Sweden, before use. Correction factors for measurements below the specified frequency ranges of the meter extended the ranges down to 5 MHz for magnetic fields and 0.5 MHz for electric fields. Exposure to the RF fields in the radio rooms was ascribed primarily to leakage from the unshielded feed lines between the antenna and transmitters. The rooms were large, and the radio officers were generally about 1-2 meters from the transmitters and feed lines and a distance of at least 0.5 m between a field probe and any person was maintained, in order to avoid perturbations of the field. At the operator's desk, the levels of the electric field and magnetic field were below the detection levels of the instrument, which were about

20 V/m at all RF frequencies, and 0.05 A/m for frequencies above 3 MHz and 0.15 A/m below 3 MHz. The highest values, 1.4 kV/m and 7.5 A/m, were found close to the unshielded feed lines. Measurements were also made of the ELF magnetic flux density (B) in two of the ships, with the transmitters active and off. The values of B varied from less than 0.002 mT than 0.002 mT to about 6 mT to about 6 mT at the operator's position, with the highest level when the transmitter was active. The authors remarked: "In summary, the field levels at the operator's desk were comparable to those in normal working places in Norway, and the background level in the radio room was comparable to levels measured in Norwegian homes".

To further investigate the issue, the group of Tynes (*Kliukiene et al., 2003*) extended their previous study on the cohort of Norwegian female radio and telegraph operators to 31 May 2002, including 99 breast cancer cases. In a subsequent nested case-control study, exposure to radio frequency (405 kHz-25 MHz) and extremely low-frequency (50 Hz) fields due to the stay in the radio room during day and night was cumulated by years of employment and workload according to ship type. The risk of breast cancer due to RF exposure was assessed in two age groups (<50, 50+), exposure assessment was performed in the same way as in the previous study.

Operators of RF plastic sealers are an occupational category of highly RF exposed persons at frequencies around 27 MHz. RF is used to produce heat to seal for instance plastic for rain clothes, tents or covers. RF fields around a plastic sealer comprise both electric and magnetic components, where near field conditions are valid, and sometimes “whole body exposure” is experienced. Typical welding exposure times are between 1 and 10 seconds, depending on the material being weld (*Wilen et al., 2004*).

Several epidemiological investigations have been performed on this type of exposure, the first considered here is the cross sectional study of *Bini et al., 1986* performed in Italy about exposure of female workers to elevated RF electromagnetic fields from plastic sealers.

The measurements were made in a room where 67 plastic sealers worked. The frequencies applied were 27.12 MHz (most of the sealers were operated at this frequency, with deviations of several MHz, depending on load conditions and type of applicator) and 13.56 MHz and the results of the measurements showed that the electric field near most of the units exceeded the levels of the Italian exposure guidelines, but the fields were confined to the immediate vicinity of the units so the workers´ hands were mainly exposed. 63 women were also interviewed about general health complaints and 30 persons reported on health effects like eye irritation, upper limb paresthesias, and vitreous body disorganization.

Grajewski et al., 2000 investigated semen quality among RF heater operators due to increased adverse reproductive effects. The study included 12 cases and 32 controls, all of which’s semen quality parameters were tested.

They measured incident RF heater EMF exposures and RF-induced foot currents at four companies. Despite wide variation in individual exposure levels, near field strengths and induced foot currents did not exceed limits of current standard levels and guidelines. The values measured obtained by the use of broadband field probes ranged from 35 to 95 V/m, time weighted averages were determined.

The most recent investigation to date in that field is from *Wilen et al., 2004*, a study made in Sweden. The exposure of 35 RF operators was compared to that of 37 controls. Afterwards, the health symptoms of both groups were compared. The investigation includes a good detailed exposure assessment method with selection criteria of the companies whose workers are examined.

The selection criteria of the subjects were:

- The RF operators had to be people working with RF sealers on a daily basis, full time, or part time. It had to be possible for the employees to leave their work for 1 h to participate in the examination.

- Control persons also had to be available at the same company or at least in the same neighbourhood, who had the same age and gender distribution and similar work tasks as the selected RF operators.
- RF operators as well as controls should not have a diagnosed heart disease, diabetes, or be on heart medication.

In total 46 RF sealer devices operated by 35 RF operators were examined. In front of each RF sealer device used by any of the subjects included in the study, the electric and magnetic field strengths were measured in seven positions: head, trunk, waist, knees, feet, and both hands. In every position, four measurements were performed in each of the three orthogonal directions. A Holaday HI-4413P (Cedar Park, TX) Optical Modem connected to a PC, with an electric field probe (HI-4433-STE) and magnetic field probe (HI-4433-HCH) were used. Both the welding time and the duty cycle were documented in order to estimate time integrated and time averaged exposure. The induced current in the ankles and in the wrists during normal work was measured with a Holaday current probe (HI 3702) connected to HI-4413P. The current was logged during a period of time when a number of welds were made. The contact current was measured with Narda 8850 (Happauge, LI, NY) contact current meter, and these measurements were taken in positions on the RF sealer where the RF operators regularly or accidentally could place their hands/fingers. Some of the RF operators worked with more than one RF sealer; for those a mean value of the daily exposure has been used.

Mean E- and H-fields of all positions were calculated, and also E- and H-ICNIRP, E- and H-spatial, E- and H-weld, E-life and H-life as estimates of total lifetime exposure, or currents induced in ankles and wrists (see formulas).

$$E-field=\frac{Ehead+Echest+Ewaist+Eknees+Ehands+Efeet}{6} \tag{7.1-1}$$

$$H-field=\frac{Hhead+Hchest+Hwaist+Hknees+Hhands+Hfeet}{6} \tag{7.1-2}$$

E-ICNIRP (V/m) and H-ICNIRP (A/m) were calculated as 6 min spatial average E^2 and H^2 values, according to ICNIRP's recommendations, where T = 6 min and t_n = time of n_{th} welding cycle in minutes.

$$E-spatial=\frac{\sqrt{E^2head+E^2chest+E^2waist+E^2knees+E^2hands+E^2feet}}{6} \tag{7.1-3}$$

$$H-spatial=\frac{\sqrt{H^2head+H^2chest+H^2waist+H^2knees+H^2hands+H^2feet}}{6} \tag{7.1-4}$$

$$E-ICNIRP=\sqrt{\sum_n\frac{(E-spatial)_n^2\cdot t_n}{T}} \tag{7.1-5}$$

$$H-ICNIRP=\sqrt{\sum_n\frac{(H-spatial)_n^2\cdot t_n}{T}} \tag{7.1-6}$$

E-weld (V/m.s) and H-weld (A/m.s) were calculated as integrated E and H fields over the time of one welding cycle in seconds (t_{weld}):

$$E-weld=E-field\cdot t_{weld} \tag{7.1-7}$$

$$H-weld=H-field\cdot t_{weld} \tag{7.1-8}$$

E-day (V/m.h) and H-day (A/m.h) are estimates of the daily exposure for each individual calculated in the same way as the last equation, but replacing t_{weld} with t_{day} , which is the approximated total welding time per day in hours.

Finally, E-life (V/m.h) and H-life (A/m.h) are estimates of the lifetime exposure for each individual, taking into account the total employment time where t_{weld} in the last equation has been replaced by t_{life}, which approximates the total welding time up to this point in operators' lives.

For the induced current, ankle and wrist represent the total current (mA) passing through both ankles/ wrists during a weld. The parameters ankle-weld and wrist-weld (mA.s), ankle-day and wrist-day (mA.h), ankle-life and wrist-life (mA.h) are calculated as above. A 6 min average value of the induced current ankle (6 min) and wrist (6 min) (mA) is calculated in the next equation, where t_n is the time of the nth welding process in minutes and T= 6 min:

$$Ankle - 6\min = \sqrt{\sum_n \frac{ankle_n^2 \cdot t_n}{T}} \tag{7.1-9}$$

$$Wrist - 6\min = \sqrt{\sum_n \frac{wrist_n^2 \cdot t_n}{T}} \tag{7.1-10}$$

The mean value (SD, standard deviation in brackets) of the electric and magnetic field strengths, linearly averaged over the entire body, for the RF operators were 88 (102)V/m and 0.19 (0.19) A/m respectively. The induced current value was 101 (147) mA as a sum through both feet. The mean value of the induced current in the wrists was 102 (146) mA, calculated as an average value of the maximum measured value of the current passing through the left or right arm for each subject.

The maximum value of the electric field strength of 2 kV/m, was measured at the position of the hands during the welding process. The corresponding magnetic field strength was 1.5 A/m, measured close to the area where the hands were kept during a weld. For the induced current, a maximum value of 1 A was measured in the wrists in front of a manually controlled RF sealer.

The evaluation of the association between these parameters and the health symptoms reported by the operators is made through grouping the subjects according to the median values (25th and 75th percentiles) of the parameters.

Schilling, 1997 investigated the situation of three workers who installed antennas (TV) at masts and were accidentally exposed to high levels of very high frequency (VHF) radiofrequency electromagnetic fields (785 MHz).

The three men were employed to service the main four channel UHF television antenna array, consisting of 12 Sira 2-wavelength panels arranged in four tiers (mean frequency 785 MHz) with about 1.75 kW mean power at the array input per channel.

The workers were exposed in the reactive "near field" region of the antenna. They were likely highly exposed between 50 seconds and 2.5 minutes. Their dosimeters showed a maximal value of 200 W/m² (about 275 V/m), measured at a distance of 10 cm from the antenna although the exposures are supposed to have been even higher. The workers experienced strong headache, among other symptoms, about an hour after the exposure. The two workers that suffered the highest exposure had, 3 years after the accidents, headaches in the left side of the head, which were higher when exposed to the sun or to heat.

A similar case was reported by *Hocking and Westerman, 2001*, where values of 7.5 (shoulder) and 15 V/m (head), relative small for GSM antennas, were measured during 1-2 hours of exposure of an antenna operator that worked nearby GSM base stations. The man suffered from headaches and insomnia the night after the exposure, and the day after the accident he experienced blurred vision. Sensitivity impairments were noticeable until six months after the exposure. *Hocking and Westerman, 2000* had also reported a case of prolonged use of a GSM mobile phone by a 72 year old businessman who suffered from neurological abnormalities, but, in this case, no assessment of exposure was performed.

It has to be pointed out that these studies dealt with occupational exposure; exposure of such magnitudes is very unlikely to occur ever in areas where the general public has access. The exposure measured with a dosimeter has several advantages as a continuous monitoring. It is a very promising approach; however one has to be aware that the body of the person wearing this instrument can have significant impact on the reading of the instrument.

Szmigielski, 1996 examined cancer morbidity for the entire population of personnel with military careers in Poland during 1971–1985. The author gathered data on exposure of personnel to RF/MW from military EMF-safety groups that operated health hygienic services and that had responsibilities for measuring field intensities at and around service posts where RF/MW-equipment was used and repaired, and for keeping personnel health records at those posts. The author established the number of people exposed occupationally, but the evaluation of the exposure was rather difficult.

The measurements obtained showed that the microwave fields (mostly pulse modulated, frequency range from 150 - 3500 MHz) did not exceed 2 W/m² [0.2 mW/cm²] in 80 - 85 % of the posts. At the other posts, the fields were between 2 - 6 W/m² [0.2 - 0.6 mW/cm²], with frequent, short duration exposures exceeding 6 W/m² [0.6 mW/cm²]. Not presented were the specific kinds of duties performed by those at RF/MW posts versus those for non RF/MW personnel at the same posts, to provide a better basis for assessing the findings.

7.1.2.2 Studies based on other concepts

Classification by a job title alone can be considered as a very crude surrogate as it does not necessarily reflect the subjects' main work areas or job activities, e.g. electrical engineers often work in an office and are then only exposed to background levels like other office workers. With this approach, subjects with the same job title are all classified as exposed or unexposed, which leads to a huge potential of exposure misclassification. A slight improvement is the classification of job profiles, which is usually done by expert rating. This enables researchers to take into account not only the occupation of persons, but also the job history to assess cumulative exposure or to consider potential confounders. An advanced approach is to establish a job exposure matrix (JEM). By means of systematic measurement campaigns the typical exposure of different occupations or work areas is assessed. In the frame of an epidemiological study each person is assigned to an exposure value from a job exposure matrix according to his occupation, work area or job activity.

Exposure classification was based on job titles in 11 studies out 12 found on occupational exposure due to RF EMF, in one case (*Grayson, 1996*) a job exposure matrix was used. In the frame of 7 out of 11 studies expert ratings were used to estimate exposure. In most cases information on the job title was obtained by means of a census, company records or hospitalisation records. Detailed information can be found in the annex.

The investigations of *Thomas et al., 1987* and *Hayes et al., 1990*, are studies which investigate occupational exposure based on job title and mortality registries. The first report deals with brain tumour mortality in electric and electronic occupations, where the worker's exposure to RF-EMF is assigned to a job category or a code according to personal occupational history.

Hayes et al., 1990, is a quite similar case control study about occupational risk and testicular cancer. An industrial hygienist classified the occupations according to their potential exposures: "exposed to microwaves and other radio waves" or "radar equipment". It is not clear why these two categories were not presented as one.

A more recent study was performed by *De Roos et al., 2001*, which investigated a possible association between parental occupational exposure to EMF and radiation and the incidence of neuroblastoma in the offspring.

This case control study is focused on children but considers parental exposure as a risk of developing neuroblastoma in children. Exposure was assessed with self reported information and by criteria of

industrial hygienists. Parents of the children were interviewed to retrieve general information but also to assess EMF exposure and occupational history. They were asked to report on any occupation within 30 feet of any electrical equipment or radiation sources, or exposure to any of the 47 sources listed in the interview (characteristics were: average distance to the source, hours per week spent working near the source while it was turned on, the dates that exposure began and ended, use of protective equipment). Then, the parents were coded as exposed to the specific source according to the reports. Industrial hygienists (IG), checked all the self-reported exposures and classified each parent as *unexposed* (working an average of zero hours close to a source and working at an average distance greater than a pre-specified maximum critical distance), *possibly exposed* and *probably exposed*.
Sources were grouped by the “major frequency produced” into 3 groups: ELF EMF, RF radiation and Ionizing radiation.
The RF radiation was considered *qualitatively* in exposure groups.

Fabbro-Peray et al., 2001, is also a case control study about environmental factors and health risks (in this case NHL is the endpoint disease). 445 cases (1992-1995) and 1025 randomly selected controls are included. The data were collected by personal interviews taking the following aspects into account: general characteristics, medical history, professional history, environmental, occupational exposure to chemicals and occupational exposure to electromagnetic fields and smoking habits. Qualitative exposure to EM radiation was examined according to a list of specific jobs. In each case age at onset (>20yrs or <20yrs) and duration of exposure (<9.5yrs or >9.5yrs) were the variables chosen. The job titles related to RFR were radio operator, radar operator, and telegrapher. *Cano and Pollán, 2001* performed a similar study. They investigated NHL and occupational exposure in Sweden. The study was retrospective, with a follow-up of 19 years from 1970 to 1989 based on data taken from a census. The number of individuals was 1,779.646 men and 1,101.669 women with 7.610 cases during the follow up.
RF occupations considered were telecommunication traffic officers, telegraph radio operators and radio and television repairmen. The study is quite big including millions of subjects and tens of job titles, but the definition of exposure is rather limited therefore diluting risk estimates and diminishing the opportunity to detect an increased cancer risk related to RF exposure, should one exist.

Several studies about army personnel were performed in the past years. For instance the series of publications of *Garland et al., 1987, 1988a and b, and 1990* about disease incidence among naval personnel have to be mentioned. They compared the rates of first hospitalizations for different diseases (NHL, leukaemia, testicular cancer, HD) in naval personnel with general population data (from the National Cancer Institute, USA) and with total navy rates. Normally those occupations with higher risks involved also daily exposure to a variety of chemical agents and also to ELF EMF.

Robinette et al., 1980 studied health and occupational exposure to microwave radiation. The cohort comprised 20.781 men from the US naval personnel classified as low exposed (radioman, radarman, and aviation electrician’s mate) and 20.109 men classified as high exposed (electronics technician, fire control technician and aviation electronics technician) to microwave radiation.
As it was not possible to assign exposure doses to any individuals, a Hazard Number was defined to measure not actual exposure but *potential exposure*. The hazard number considered the length of time of occupation and also the power of equipment on the ship or aircraft at the time of exposure. Because of the big number of people considered and the need to review individual men’s records, only the records of those men who died from disease, suicide or homicide (435) and for a 5 % randomly selected living men were included. The Hazard Number consisted of the sum of the power ratings of all fire control radars aboard the ship, or search radars aboard the aircraft to which the technician was assigned, multiplied by the number of months of assignment. Types and power ratings of navigational radars were not available.

No adverse effects of radiation were found in the results, but the authors also state that the measure of *potential exposure* imply that the high exposure group could be a mixture, in unknown proportions, of men whose actual exposures varied from large to negligible.

Groves et al., 2002, is a follow up of the work of *Robinette et al., 1980*, with the same type of exposure assessment and the consideration that the high exposure group could have potential exposures of around 100 mW/cm², although their usual exposures were well below 1 mW/cm², and that ELF exposures were also to be considered.

In the study, the actual exposures are unknown and no information is available about lifestyle factors or exposures after their service experience. *The control group may have had levels of RF exposure higher than the general population.*

Among the occupations with high risks we have already mentioned plastic sealing. *Lagorio et al., 1997* performed a prospective mortality study of 481 women who were plastic ware workers. The follow-up went from October 1962 or the date of hire to 1992 or the date of death. Exposure definition relies on individual information about job title and the period of assignment to each job. Based on time of job there were 3 sub cohorts: (i) sealer operators, (ii) other laborers, and (iii) white collar workers. *"A quantitative RF exposure was considered unattainable, due to high turnover of machines whose technical and operating characteristics greatly affect the intensity of exposure and to lack of information in the personnel files about the changing assignments over time of workers to different RF-dielectric heating plastic sealer"*.

Some sources of bias were mentioned: scant number of person-years at risk and that the time weighted average as a better exposure surrogate was not available because of high personnel turnover, assignment changes and differences in the heat sealer characteristics. Exposure to other carcinogens or other organic solvents was not estimated individually.

Another group of interest is workers in companies manufacturing mobile communication devices such as investigated in *Morgan et al., 2000*, a RF exposure study which examines mortality from cancer of the brain and lymphatic and haematopoietic systems on employees of Motorola.

The cohort study included 195,775 employees (6,296 deaths, 72,775 active workers and 116,704 living retirees) who had worked at least for six months during the years 1976-1996.

Data were taken from company records on job code, work location, employment dates and status and personal data. Exposure classifications were based on business sectors, work site, job codes and descriptions, calendar period and an expert assessment.

Likely RF exposures were estimated for each of the 9,724 job titles and classified into *background* (unexposed), *low*, *moderate* and *high*, with relative levels of RF exposure coded as 0, 1, 6, and 100, (data derived from an exposure validation study). The job titles more likely to have RF exposures were paging, administration and cellular telephone business sectors.

Limited RF measurements data had been collected (made primarily for *leakage detection*) in some sectors of the company but were not utilized as a quantitative way to estimate historical workplace exposures to RF.

Scores considered in the analysis were usual (RF exposure level for the job held longest at Motorola), peak (job with the highest RF level) and cumulative (sum of the products of the RF levels assigned to each job title multiplied by the duration of employment in all jobs throughout an employee's Motorola work history) exposure. Different latency periods were also considered: 5, 10 and 20-year lag periods or hiring before 1975, between 1975-85 and after 1985.

The limitations of the study are the use of a qualitative JEM rather than actual exposure measurements of each subject, and the relatively young age of the cohort. In the JEM it was not possible to separate job titles into historical RF exposure categories based on specific frequency ranges. Furthermore, the exposure information is limited; the likely exposure of various groups of workers are not defined and no estimates of levels of exposures are given (for instance, if the maximum levels of exposure are within current standards, the negative association is less informative). Exposure misclassification is said to be, if it really exists, non differential and not significant.

Finally, we include in this category the reports of *Milham et al., 1985, 1988a and 1988b*, about mortality among radio amateurs.
These cross-sectional studies comprised a cohort of 67,829 radio amateurs during the period 1979-84, with 2,485 deaths among them. Exposure was categorized according to the license class without performing any measurements.

Grayson, 1996 performed a nested case-control study on possible brain-tumour risk from presumed exposure to non-ionizing and ionizing radiation of a group within a cohort of 880,000 Air-Force personnel who had at least one year of service during the years 1979-1989. The cases were ascertained by screening Air-Force hospital discharge records of men who had served during that period and had been diagnosed for primary malignant brain tumour. Included were also those persons who had been treated at other than Air-Force facilities.
The author provided separate estimates of case exposures to extremely-low-frequency (ELF) fields, RFEMF, and ionizing radiation. The estimates for exposure to RFEMF were derived from a central registry of all incidents of Air-Force personnel who were reported to have been exposed at levels that exceeded 10 mW/cm^2 [the frequency-independent maximum permissible power density in ANSI (1974)] since 1972. Based on that Air-Force registry, he developed a job-exposure matrix that categorized Air-Force job titles over time as having had "no", "possible", or "probable potential" exposure to RFEMF.
"Probable intensity" scores were assigned to occupations in which the overexposures had been reported, as well as to closely related job titles. As noted by the author, this included all occupations involved in the maintenance and repair of RFEMF emitters. The "possible intensity" score was assigned to those occupations requiring operation of RFEMF emitters for which excessive exposures had not been reported. All other job titles were assigned to the "non-exposed" category. However, the author did not provide a list of the specific occupational job titles, the scores for those titles, and the number of persons in each.
For each subject, estimates of his cumulative exposures to RFEMF and ELF were made by multiplying the exposure score by the number of months in each job title held during his career, and by summing those products. (*Heynick, 1998*).

7.1.3 Exposure assessment concepts for mobile devices

7.1.3.1 Studies based on measurements

No epidemiological studies on potential health effects based on measurement as metrics were found. It needs to be mentioned, however, that within the framework of an ongoing large multinational case-control study on causes of brain cancer (Interphone), measurements are performed to validate exposure metrics based on questionnaire information. Software-modified mobile telephones (SMP) will be used in 13 countries to evaluate to what extent the average output power of the mobile phones is related to patterns of mobile phone use. Measurements with phantom heads are used to identify the areas in the brain where the most energy is absorbed. These are improvements compared to previous studies on this topic, as illustrated in the next chapter.

7.1.3.2 Studies based on other concepts

The exposure due to mobile devices is usually estimated by questionnaires billing records. In the reports described here, the surrogates for the exposure are based on questionnaires, information was obtained from interviews (*Hansson-Mild et al., 1998, Chia et al., 2000, Muscat et al., 2000, Stang et al.,* *2001, Inskip et al., 2001, Hardell et al., 1999, 2002a, 2002b and 2003, Warren et al., 2003, Christensen et al., 2004, Lönn et al., 2004*) or from subscribers lists provided by the telecommunication companies (*Rothman et al., 1996, Dreyer et al., 1999, Auvinen et al., 2002, Johansen et al., 2001, 2002*), no other methods were found. The fact that no measurements were used to assess exposure can be considered as shortcoming, however new studies use superior approaches (see chapter 2.1.3.1).

Billing records

In the frame of the studies where exposure was assessed with billing records from network providers, the data were processed in different ways. Within the US cohort study from *Dreyer et al., 1999* (a total of 1,574,615 people were identified in subscriber lists between 1994 and 1995), exposure was estimated in *minutes of phone use* and *number of calls made and received*. Average monthly minutes and calls were calculated using the data from two-month samples obtained for each cohort year. Three equally sized groups were made defining *high*, *medium* and *low* exposure. The duration of exposure was estimated according to the number of years that each person had been a customer of the particular carrier that contributed their data. The aim of the study was to compare those people exposed to handheld phones with those who used cellular phones were the antenna was not in the handset (bag or car phones). A conclusion of the study was that this record linkage could be a useful measure to compare mortality rates of different exposures to mobile phone, but however, not good for quantifying individual exposures to RF.

In *Auvinen et al., 2002,* a case control study (398 subjects with newly diagnosed brain tumour in 1996) about brain tumours and salivary gland cancers among cellular phone users, exposure was assessed via a computer linkage for personal subscriptions to the two cellular network operators in Finland in 1996, but no actual use of phones was assessed.

When subscriber lists are used as surrogate, exposure misclassification can become an issue, as not all subscribers of mobile phone are users and not all users are subscribers (phone use not only by the owner but by other persons (a relative or employees which share a phone)). As this kind of exposure misclassification is independent of case-control status, one should rather expect a bias towards a null effect.

Johansen et al., 2001, 2002, performed a retrospective cohort study about cellular telephone and cancer in Denmark with a follow-up from 1982 to 1995 (average follow up of 3.1 years) of 420,095 subscribers (80.3% of the initial list). Data on subscription were provided by telecommunication companies for the time period of the follow-up, and included personal information, year of subscription, age at first subscription, system at first subscription (NMT 450, NMT 900 or GSM) and duration of subscription for GSM users. As there was only provision of number of minutes billed for outgoing digital calls and furthermore data collection was partial (only from one company and only up to 1992), these data were not analyzed.

Interviews and questionnaires

Several studies are based on the assessment of exposure by questionnaires obtaining data directly from subjects via direct interviews (personal or by telephone) or indirectly by written forms sent to the participants.

One of the first studies on mobile phone use and symptoms experienced by the users was performed by *Hansson-Mild et al., 1998* in Sweden and Norway.
The participants were subscribers of either GSM (digital phones) or NMT (analogue phones) phones in Sweden and Norway. Exposure was assessed through questionnaires with questions about transmitter system, model, *calling time* (categories: 2 - 15 min/d, 15-60 min/d and >60 min/d) and *number of calls per day*.

The approach of *Chia et al., 2000* is similar. They performed a cross sectional study in Singapore to determine the prevalence of specific CNS symptoms among hand-held cellular telephone users compared to non-users.
The exposure due to mobile phone use was estimated by personal interviews and was quantified in *duration per day* (<2 minutes, 2-60 minutes, and >2 hours), *times of use per day* (0, >5, 5-10, and >10) and *use of hand-free equipment* (never, some of the time, all the time).

Muscat et al., 2000 studied the relation between handheld telephone use and risk of brain cancer and acoustic neuroma *(2002)* in the frame of a case-control study and used a well elaborated questionnaire, which included description of each type of cellular telephone, regular use of telephone defined as *ever having a subscription, years of use, minutes/hours per month of use, year of first use*, *manufacturer of the mobile phone and reported average monthly costs calculated from the bills*. Subscriber's lists were not available; therefore, users had to estimate their average monthly telephone costs
The exposure measures used were: *hours of use per month*, *years of use* and *lifetime cumulative exposure*.

Stang et al., 2001 performed a hospital-based and population-based case-control study about RF exposure and uveal melanoma in Germany, where subjects were recruited from two sources:
. There were questions about RF exposures which permitted to classify the subjects as:

- Exposed only to radio receivers that do not transmit RF and were therefore classified as unexposed,
- Exposed to walkie-talkies and radio sets,
- Possibly exposed to mobile phones,
- Probably or certainly exposed to mobile phones.

Then, the subjects were divided according to the time of exposure in *ever exposed, >5yrs before reference date and >3 years duration.*
Two authors classified the subjects separately and dissenting cases were evaluated and resolved.
Some disadvantages of the study are:

- The study is part of another larger study about cancer and environmental exposure so that questions and concerns about RF radiation were few (no specification of the RFR devices used, hours per day of use, or relation *laterality of the cancer-hand used to hold the phone*).
- Exposure was assessed only in a rather indirect way, because the questionnaire comprised no questions on mobile phones
- Ultraviolet radiation was not considered being a risk factor for ocular melanoma.
- The study is based on small numbers of exposed subjects

The authors did not expect an overreporting of the use of radio sets by the cases, because the controls were also patients with eye diseases.

Inskip et al., 2001 performed a case control study about cellular telephone use and brain tumour with subjects taken form hospitals.
Cases and controls answered questions in a personal interview about the exposure considering characteristics of the device used, calendar years of first and last use, the duration of regular use (defined as at least two calls per week), the usual frequency of use (in minutes per day) and the hand usually used to hold the handset.
The categories of use of cellular phones considered were:

- Use of hand-held cellular phones (times)
- Average daily use (min).
- Duration of regular use (years).
- Cumulative use (hours).
- Year when use began.

The group *Hardell et al* performed two case-control studies of brain tumors in relation to mobile phone use (reported in several articles: *1999, 2002a, 2002b and 2003*). The exposure, due to cellular and cordless telephones was always assessed via questionnaires or, in cases where subjects denied answering the questionnaires, via telephone interviews. The questions included type of the phone, years of use and brand name. A distinction between analogue 450MHz or 900MHz cellular phones, digital and cordless phones was also made because of the different power characteristics of the different technologies; the maximum exposure from cordless phones is likely to be lower than from cellular phones due to the lower input power which might lead to a lower risk but calls made with cordless phones were obtained to be 2-3 times longer than with the cellular phones. Regarding these differences, the length of exposure has also to be mentioned.
Other parameters inquired were mean number and length of daily calls in minutes to calculate the cumulative use in hours for all years. Data on use in car with fixed external antenna or hands free device with an earpiece outside the car were considered as without exposure. To take the laterality of the tumor into account, questions about the ear used most frequently during phone calls were made.

Warren et al., 2003 studied the risk of developing intratemporal facial nerve (IFN) tumor, associated with lateral use of the mobile phone. The authors mention that as previous studies (*Funch et al., 1996*) have demonstrated the reliability of self recall on cellular telephone use (*high positive correlation with billing records: amount telephone use obtained r = 0.74 and telephone type r = 0.92*), a questionnaire was used to assess the exposure. Such information could help to identify the frequency of use, however the question on the assessment of the dose remains open.
Occupations associated with elevated RF exposure were service as a police officer, fire fighter, or paramedic, service in the military, and employment at a radio station and therefore taken into account. Assessment of exposure included all types of cellular telephones including cordless, handheld cellular and automobile cellular phones, as well as ham radios, citizen’s bands, and walkie-talkies.
The evaluation addressed the type of signal transmitted by the phone (analogue, digital or both), the duration of exposure, regular use of the device (specified as more than one call a week). For regular users there was a more detailed quantification of the use (*average minutes per day*, *average duration of a call*, *average number of call per week*, *minutes per month*, *and regional area of use and preferred ear of use*).

Christensen et al., 2004 and Lönn et al., 2004, studied the risk of acoustic neuroma (vestibular schwanoma) assessing exposure to cellular telephone by personal interviews. Regular use was compared with never or rarely use, and this category was used as reference, and was also compared with different periods of use regarding length of use, time since first use, lifetime cumulative number of calls or cumulative use (years) before diagnosis. These reports are part of the Interphone study mentioned in chapter 2.1.3.1.

7.1.4 Large Scale Studies for exposure assessment of the population next to base stations – available information

7.1.4.1 MESSREIHE, RegTP (Germany)

The RegTP (Regulierungsbehörde für Telekommunikation und Post) performed in the years 1992 (*Bornkessel and Schubert., 2004),* 1996/1997 and 1999/2000 several series of measurements to assess the immissions of radio frequency electromagnetic fields. The results are available on the net (http://emf.regtp.de/GisInternet/)

As the measures from 1999/2000 were performed according to the EU Recommendation (02)04 and not according to the German standard DIN VDE 0848 Part 2 (10/91), which was used as basis for the measures of 1992 and 1996/97, the results are not comparable in the range from 0 to 10 MHz and therefore, the frequency ranges are separately analysed.

Within the first Messreihe (*IMST 1, 1992*) the fields were measured directly in the whereabouts around base stations using the sweeping method to search for the maximum exposure values, often special places with high immissions were also investigated and both indoor and outdoor locations were examined. The number of spot measurements was 88, the maximal and minimal values of power density obtained were, 0.14 W/m^2 and 0.000014 W/m^2, respectively, with a mean of 0.0065 W/m^2 and 0.0050 W/m^2 when max. and min. values were not included. The uncertainty of the measurements was stated to be 3 dB.

The measurements were performed using broadband equipment in the frequency range from 9 kHz and 1 GHz, but in addition also selective to consider separately GSM 900 and GSM 1800 contributions, as can be seen in Figure .

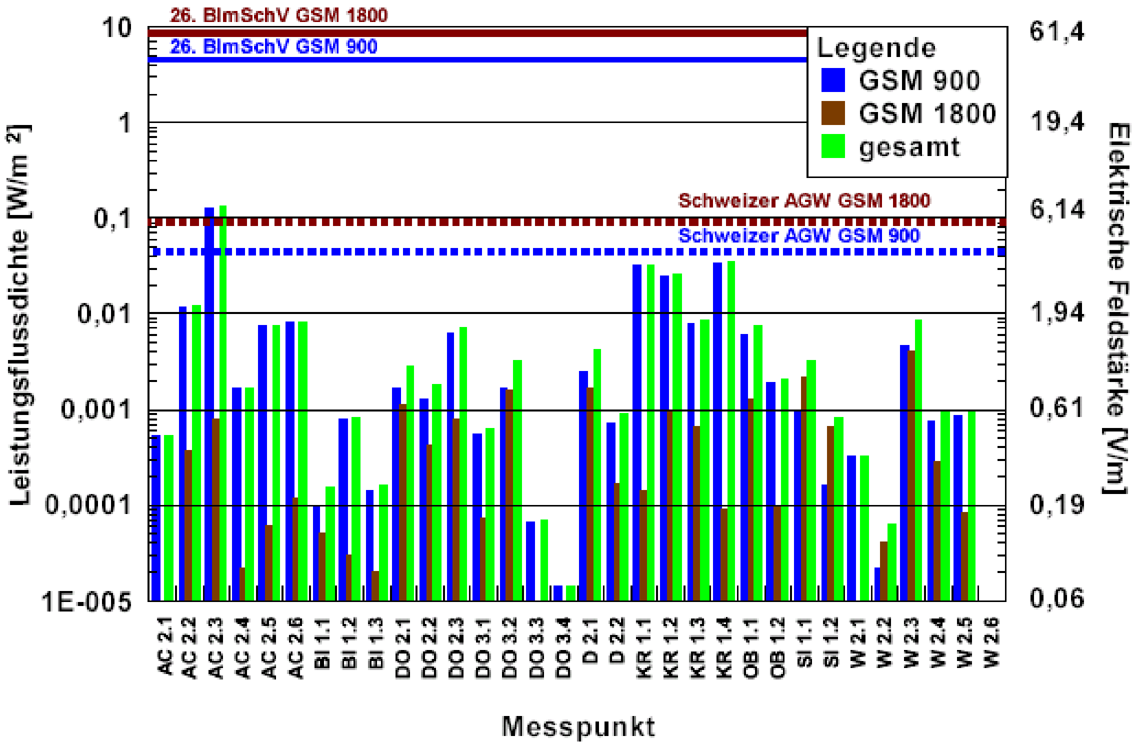


Figure A-5: Summarized results of the 1992 Messreihen.

The results were compared with German and Swiss guidelines as depicted in the graphic.

The second Messreihe (*1997)*), was quite similar to the first one *(1992)*. The locations chosen where also near base stations, and sensitive places (i.e. hospitals or schools) were also added. The maximum and minimum power densities measured were 0.04 W/m^2 and 0.0000016 W/m^2, respectively. The mean value was 0.0052 W/m^2 and 0.0046 W/m^2 when not considering the extreme values.

The IMST 3 series, performed in 1999/2000, were dedicated to take into account complaints from citizens living near to base stations and locations were selected without special interest in places with elevated immissions (that means, places which are not direct near base station but about 200 m away). For this reasons the maximal and minimal values, 0.05 and 0.00000073 W/m^2, with means 0.0014 and 0.00031 W/m^2 when the maximal and minimal values are excluded, are clearly below those obtained in the former series.

7.1.4.2 NIR Study in Salzburg, OFCOM (Switzerland) and ARCS (Austria)

Another project of some importance is that performed by OFCOM (Swiss Office of Communications), ARCS and the assistance of local authorities in Salzburg. In this project, a set of measurements and calculations where carried out to verify the “Salzburg Model”. The purpose was to find out whether an exposure of 1 mW/m² (imposed in 1998 in Salzburg) can be complied with, and if so, what network structures are required for that purpose. OFCOM proposed that the exposure values should be determined for each network operator in the vicinity of 3 different base station types (mast, roof mounted and microcells) in each case. At the proposal of the regional sanitary administration of Salzburg, the choice of the individual sites was determined on 27 July 2001 by the casting of lots, under notarial supervision, by a representative of the environmental protection office of the Salzburg municipal authorities. An investigation of the already known antenna sites which are critical in regard to exposure was deliberately not undertaken.

OFCOM subsequently derived the exposure situations using numerical software tools (Quickplan). The environmental data necessary for this purpose (land registry maps) as well as the data on the transmitting installations were made available by the Salzburg authorities, the office for environmental protection and the network operators. The three-dimensional visualization of the electromagnetic fields generated by the antennas allowed a reliable analysis not only of the NIR-exposure but also of the coverage situations.

ARC Seibersdorf Research GmbH, was entrusted with the practical execution of the measurements. The practical measurements were made between 12 November and 19 December 2001. For the frequency selective measurements, a combination of the sweeping (defined measuring volume (cylinder of 1 m diameter and 1 m height, 0.75 m above ground) and the Add3D method was applied.

The positions of the maximum were identified by the sweeping method. The sweeping range was extended to an entire room (always with 0.5 m distance to walls and objects, and up to a height of 2 m). The field strengths were determined according to the Add3D method (three measurements with orthogonal orientation were taken and added up to the total field strength) on the location determined by the sweeping method.

At each location the BCCH frequencies from the base station under investigation the field strengths of GSM900 and GSM1800 were measured, also the TCH were measured. However, in the final analysis the total exposure was derived based on the exposure arising due to the BCCHs by calculating the reference operating mode by assuming that all TCHs were operated with maximum power.

A main outcome was that at 8 of the total of 13 antenna sites selected at random the value of 1 mW/m² was exceeded by up to a factor of 40. The results of the investigations are shown in Table A-3.

Number of investigated base station	Name of location of GSM base station	Max. value of all channels from base station [mW/m²]	Max. value of all channels from base station [V/m]
1	Liefering	0,356	0,366
2	Grazer Bundesstrasse	2,092	0,888
3	Gaisberg	0,0036	0,0368
4	Vogelweider-strasse	2,654	1,00
5	Ernst - Greinstrasse	2,368	0,945
6	Ginzkeyplatz	8,307	1,77
7	Gaswerkstrasse	39,618	3,865
8	Friedhofstrasse	0,098	0,192
9	Bachstrasse	1,048	0,629
10	Hübnergasse	21,330	2,836
11	Berchtesgardener-strasse	0,915	0,587
12	Maria -Cebotaristrasse	1,314	0,704
13	Makartplatz	0,164	0,248

Table A-3: Maximum of the sum of all channels at the investigated locations in the vicinity of the examined GSM transmitters.

7.1.4.3 CAMPAGNE DE MESURES (ANFR, France)

The Campaign of Measurements (Campagne de Mesures) performed by the ANFR (National Agency of Frequencies) in France was performed to provide information about the exposure of the general public to electromagnetic fields in order to allow comparison with the limits.

The French protocol measurement is based on the ECC recommendation (02)04, considering the three decision levels, performing first a broadband scanning with isotropic probes, than a selective frequency check in those places where the first decision level (fields higher than 0.28 V/m) is exceeded, and a detailed analysis when the second decision level (> 2.8 V/m) is also exceeded. In Table A-4 a more detailed description of the frequency bands investigated and the decision levels can be found.

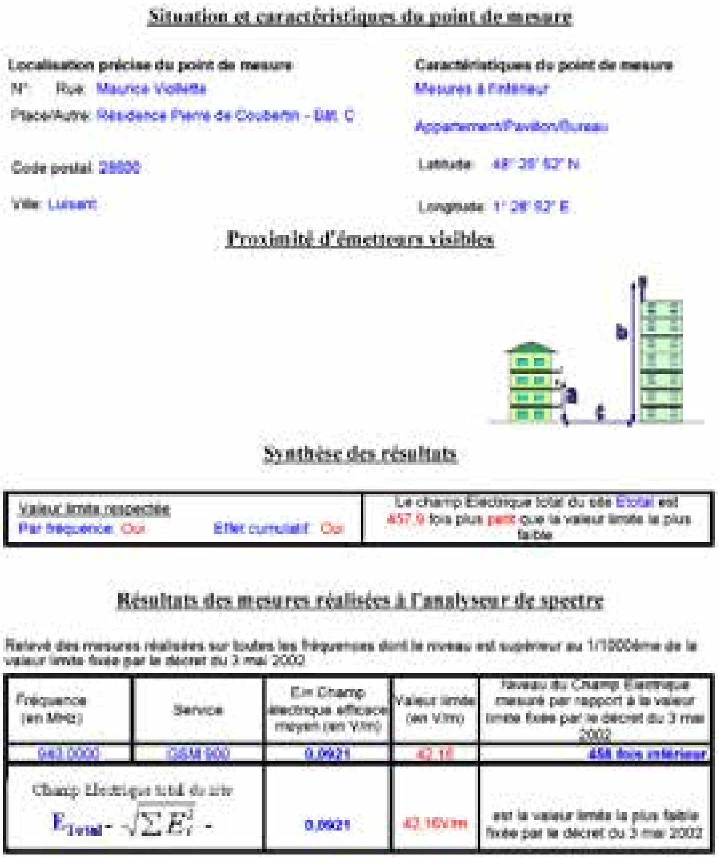
Frequency bands	Services	Minimum reference level	Decision level
9 kHz - 30 MHz	Services HF	28 V/m	0,3 V/m
30 MHz - 87,5 MHz	PMR	28 V/m	0,3 V/m
87,5 MHz - 108 MHz	FM	28 V/m	0,3 V/m
108 MHz – 880 MHz (except TV)	PMR - BALISES	28 V/m	0,3 V/m
47 - 68 MHz; 174 223 MHz;	TV	28 V/m	0,3 V/m
	TV	28 V/m	0,3 V/m
470 – 830 MHz			
880 MHz - 960 MHz	GSM 900	40,4 V/m	0,4 V/m
960 MHz - 1710 MHz	RADARS - DAB	42,6 V/m	0,4 V/m
1710 MHz - 1880 MHz	GSM 1800	56,8 V/m	0,6 V/m
1880 - 1900 MHz	DECT	59,6 V/m	0,6 V/m
1900 - 2200 MHz	UMTS	59,9 V/m	0,6 V/m
2200 - 3000 MHz	RADARS - BLR – FH	61 V/m	0,6 V/m

Table A-4: Frequency bands and services examined in the “Campagne de Mesures” project.

Spot measurements were done in the vicinity of GSM-base stations and radio and TV transmitters, both in the inside and outside from houses. The antennas used were a magnetic loop for HF, broad band dipole antennas (log-periodic) for broad band measurements and, 3-axes selective probes and selective antennas for frequency selective measurements in combination with spectral analyzers.

In the measurement at lower frequencies, where the wavelength is large, a distance of more than once the wavelength was kept between the antenna and the closest obstacle, when passive electric antennas were used. For measurements of frequencies lower than 600 MHz broadband magnetic or electric antennas, electrically short, were used at a height over 50 cm instead of dipole antennas.

The results displayed in a database, are available for the public on the Internet (http://www.anfr.fr/). With a geographical information system the results for every location of a measurement can be easily accessed. The database displays the values of the measurements, as well as the comparison with the limits of the national French guidelines and a graphical representation of the levels of the E-field obtained.



Situation et caractéristiques du point de mesure

Localisation précise du point de mesure	Caractéristiques du point de mesure
N°: Rue: Maurice Viollette	Mesures à l'intérieur
Place/Autre: Résidence Pierre de Coubertin - Bât. C	Appartement/Pavillon/Bureau
Code postal: 28000	Latitude: 48° 26' 52" N
Ville: Luisant	Longitude: 1° 28' 52" E

Proximité d'émetteurs visibles

Synthèse des résultats

Valeur limite respectée Par fréquence: Oui Effet cumulatif: Oui	Le champ Electrique total du site Etotal est 457,9 fois plus petit que la valeur limite la plus faible

Résultats des mesures réalisées à l'analyseur de spectre

Relevé des mesures réalisées sur toutes les fréquences dont le niveau est supérieur au 1/1000ème de la valeur limite fixée par le décret du 3 mai 2002

Fréquence (en MHz)	Service	Ei= Champ électrique efficace moyen (en V/m)	Valeur limite (en V/m)	Niveau du Champ Electrique mesuré par rapport à la valeur limite fixée par le décret du 3 mai 2002
943,0000	GSM 900	0,0921	42,16	458 fois inférieur
Champ Electrique total du site $E_{Total} = \sqrt{\sum E_i^2} =$		0,0921	42,16V/m	est la valeur limite la plus faible fixée par le décret du 3 mai 2002

Figure A-6: Results of a spot measurement of the “Campagne de Mesures”.

7.1.4.4 RADIO WAVE SURVEY, NRPB (UNITED KINGDOM)

The National Radiological Protection Board (NRPB, www.nrpb.org) carries out surveys of exposure levels in the environment around mobile phone base stations. The program called NRPB Radio Wave Surveys (http://www.nrpbdev.org.uk/basestations/index.cfm), includes measurements carried out on a commercial basis in different environments such as schools, homes, public places, or work places.

The measurements were done with a Hewlett Packard E4407B spectral analyser connected to one of a choice of broadband antennas, as shown in the Table A-A-5 via a coaxial cable. This set-up allowed measurements to be made over a range of frequencies from 30 MHz to 3000 MHz using a narrow bandwidth, which made the detection of power densities as low as 0.001µW/m² possible.

Manufacturer	Model	Type	Frequency Range
Schaffner-Chase	VBA6196A	Biconical	30 – 300 MHz
Schaffner-Chase	UPA6108	Log-periodic	300 – 1000 MHz
EMCO	3115	Ridgeguide	1 – 18 GHz

Table A-5: Antennas used for radiofrequency measurements.

The maximum field strength from every band was then recorded in order to calculate the worst case exposure quotient at each measurement location and compare it with the limits of the ICNIRP guidelines.

Within the survey the contribution from base stations, VHF/UHF, TETRA, Broadcast Radio and TV towers and even Radar installations were measured. The percentage of every signal to the total exposure was calculated as well and shown in pie charts as in Figure A-7.

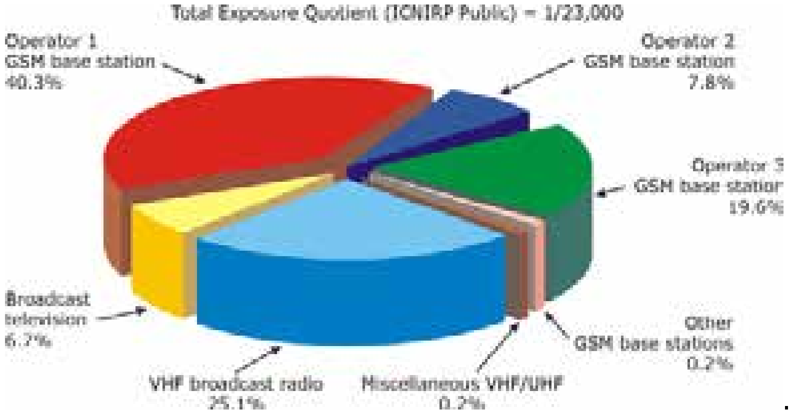


Figure A-7: Contribution of every source to the total exposure quotient as obtained in UK by the NRPB.

On the website there is overview graphic of all the surveys carried out showing the exposure quotient for every location and the contribution of every source to this quotient (see Figure A-8). A summary of the main results is also available with an indication if the determined fields are in compliance with the ICNIRP guidelines.

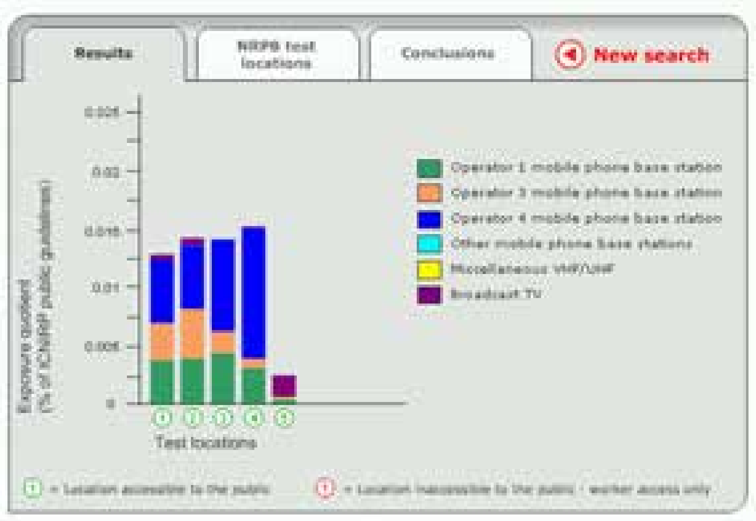


Figure A-8: Screenshot of the Flash animation that presents the outcomes of NRPB measurements.

7.1.4.5 COST 244bis, Short Term Action

In Europe, commercial land based cellular mobile telephony started to spread in the 1980's. Since especially the 1990’s, with the introduction of the digital GSM 900/1800 systems, coverage has enhanced substantially. Growing demands to use mobile phones have led to an increased deployment of base stations and antennas. As a reaction to this development, public debates, and, in several situations, worries about the possibility of adverse health consequences due to exposure to radiofrequency fields from base station antennas have also increased. Thus, throughout the European community, there was and is a need for data on this exposure to radio frequency fields in order to evaluate compliance with European and national recommendations and regulations, and for use in risk communication.

In many European nations, data exist and existed that responded to this need for information, but their use would be strongly enhanced if there was a common base for the interpretation of such data. Therefore within the COST 244bis Action “Biomedical Effects of Electromagnetic Fields”, it was decided that a project addressing some of these aspects would be valuable.

The aim of this project was to compile data from several European nations, i.e. Austria, Belgium, France, Germany, Hungary and Sweden on the exposure levels from base stations and to evaluate comparability and usability of the data and to find gaps of knowledge concerning the data and the procedure by which they are obtained so that a basis for further action by responsible bodies may be provided.

A large number of measurements from different countries was compiled for this project and presented in data sheets with the same layout. The data cover a broad range of situations, site selections and measurement methods. All measured levels were well below the recommendations of the European Council and varied by orders of magnitude, due to different factors.

Having analyzed the sources of these differences, the authors concluded that comparisons of exposure data sets of various countries are only meaningful if the selection criteria of the measurement positions are comparable.

7.1.4.6 Other Projects

Many other projects are being promoted and developed in other countries in Europe. For instance, several monitoring systems are presently working in Greece (Hermes Project), Italy (Fundazione Ugo Bordoni), Portugal (MonIT, see Figures A-9 and A-10) or Malta (Progett Gardjola). A monitoring system is used to monitor the levels of electromagnetic fields constantly, usually using broadband equipment. The monitoring station typically located in a place near a RF emitting facility, consists of an E/M radiation sensor (normally isotropic triaxial probes), which sweeps the frequency range from 100 kHz to 3 GHz (which includes the contribution of all sources, e.g. radio and television broadcasting antennas, cellular telephony antennas, etc) and an embedded device, which processes, stores and transmits the measurement data to the central control station.

Figure A-9: Monitoring Station (MonIT, Portugal)

Usually, the results of these measurements are available on the net where the access to plots with daily, weekly or monthly graphics of the exposure levels is easy and free. These levels are than compared to the limits applied in the respective country.

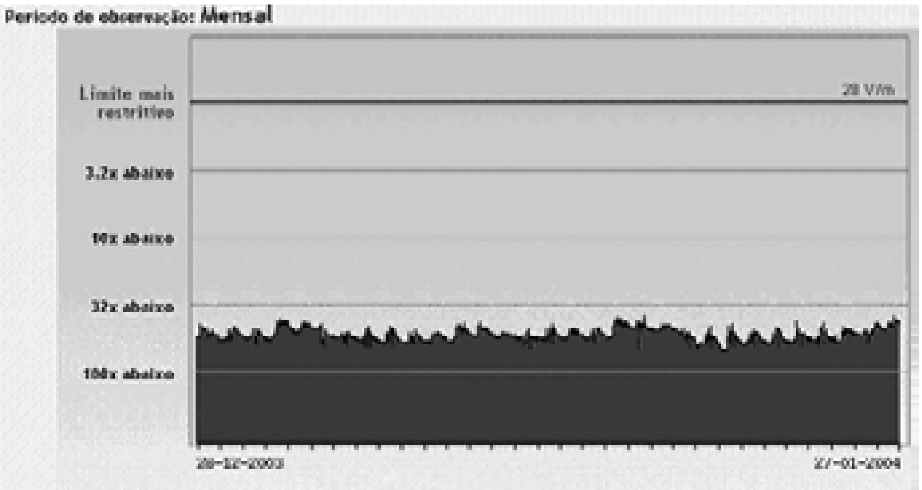


Figure A-10 Monthly representation of the results of a monitoring station in Portugal (MonIT)

7.2 Specific aspects of the field distribution in the environment of base stations

The field distribution in the environment of base stations can be described, theoretically, exactly through Maxwell's electromagnetic field equations. Together with the additional boundary conditions of the field problem, like material parameters and geometry dimensions as in every electromagnetic problem, we are able to find the solution. But in the real situation the boundary conditions are dependent on time, and these dependences are mainly caused by moving objects like cars, persons, trees moved from the wind and similar objects.

In mathematical terms this situation is called time variant system: for every new boundary condition we have to make a new calculation with Maxwell's equations that can be used only for a linear time invariant systems (LTI).
Given a general operator in the time domain,

$$y(t) = F\{x(t)\} \tag{7.2.1}$$

Linearity is given if:

$$F\{a_1 x_1(t) + a_2 x_2(t)\} = a_1 \cdot F\{x_1(t)\} + a_2 \cdot F\{x_2(t)\}. \tag{7.2.2}$$

The condition of time invariance (time invariantly):

$$y(t-\tau) = S_\tau\{y(t)\} = S_\tau\{F[x(t)]\} = F\{S_\tau[x(t)]\} = F\{x(t)\} \tag{7.2.3}$$

with $S_\tau\{\ \}$ the operator that produces a time shift.
Systems which fulfill both equations are linear and time-invariant (LTI) and under this condition the principle of superposition can be used. If this is not given, we have to use different kind of mathematic: the use of statistical methods arises inevitably, as shown in chapter 7.2.1.2 for the *small scale fading* effect.

The physical description of the mobile radio wave propagation is done usually by channel models. In a first approach it can be seen in a common LTI system. A simple LTI model for the base band mobile fading channel is represented in Figure A-11. An idealized high frequency transmitter and receiver consisting of two ideal modulators and an ideal low pass filter are considered as a part of the channel.

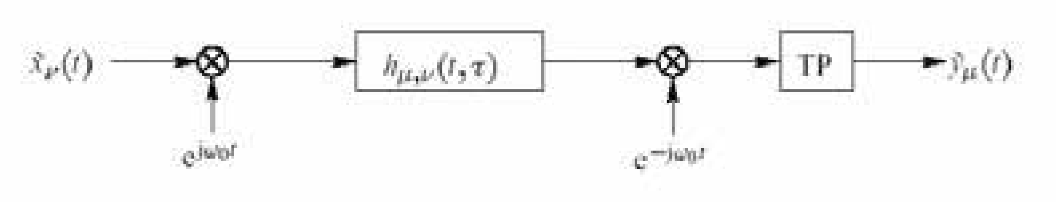


Figure A-11: The base band channel

In this case we call $\tilde{h}(t,\tau)$ the impulse channel response in the base band, with the input vector $\tilde{x}(t)$ and the output vector $\tilde{y}(t)$.

With the low pass cut-off frequency ω_g and the angular frequency ω_0 is:

$$\tilde{h}(t,\tau) = \frac{\omega_g}{\pi} \int_{-\infty}^{\infty} si(\omega_g(\tau - \xi)) \cdot h(t - \tau + \xi, \xi) e^{-j\omega_0 \xi} d\xi \qquad (7.2.4)$$

the impulse response from the mobile channel.

For estimations sometimes only the absolute value from the Fourier transformed channel impulse response for a certain ω and not the total frequency response will be considered; this corresponds to a single frequency analysis.

The channel impulse response can be measured with a so called *channel-sounder*. In case of bigger distances a grouping with a separated transmitter and receiver is necessary; the synchronization in time is therefore expensive. The operating mode from a channel sounder is shown in Figure A-12.

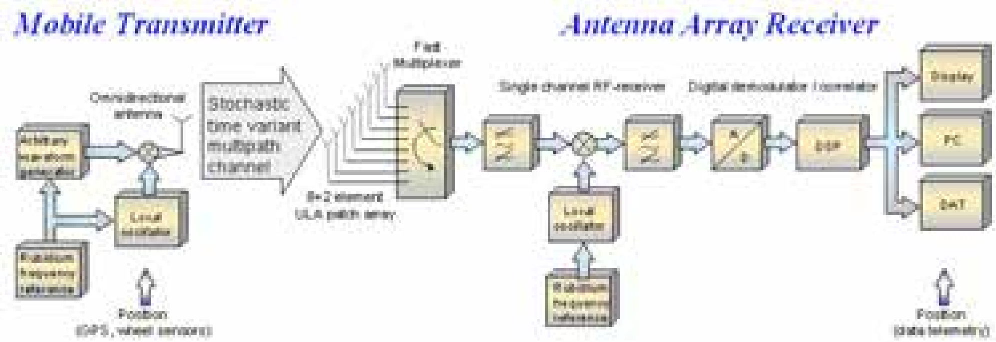


Figure A-12: Working concept from a channel sounder (Source: http://www.vadgmbh.de)

The mobile transmitter sends an exactly defined electromagnetic impulse, and the receiver performs the analysis in the time domain.

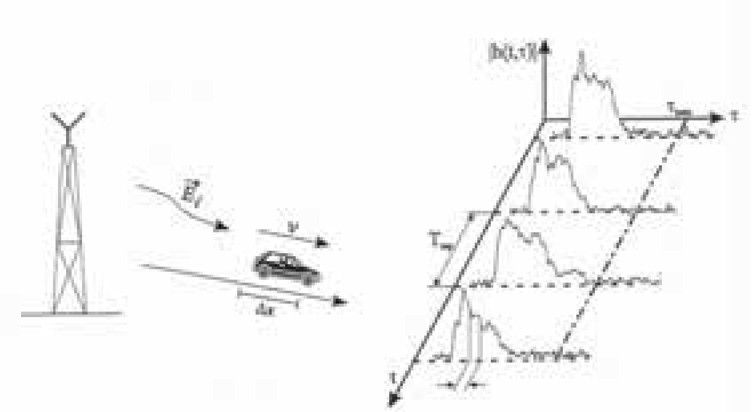


Figure A-13: Example for a time variant impulse response (*Bonek and Molisch, 2000*)

Figure A-13 shows a typical impulse response of a mobile radio Channel with a moving transmitter and a sample repetition time with the value T_{REP}. In the right part of Figure A-13 a clear time variance is recognizable, this is coherent with the moving car.

7.2.1 Variations in space

The spatial variation of the field strength (fading), can be divided in two different types. The distinction is conditionally made by the cause of its origin (*Parsons, 2000*, *Pätzold, 1999*):

- *Large-scale fading (also: long-term fading, shadowing*)
- *Small-scale fading (also: short-term fading, fast fading)*

Large scale fading is a phenomenon that happens in the range over 10 wavelengths of the propagating wave; under 10 wavelengths we speak from small scale fading.

At first the field strength sways very quickly around the local mean average value. These fluctuations happen within a wavelength. This phenomenon is called *small scale fading*; and it is provoked by interference between the propagation waves, that arrive through different paths to the receiver.

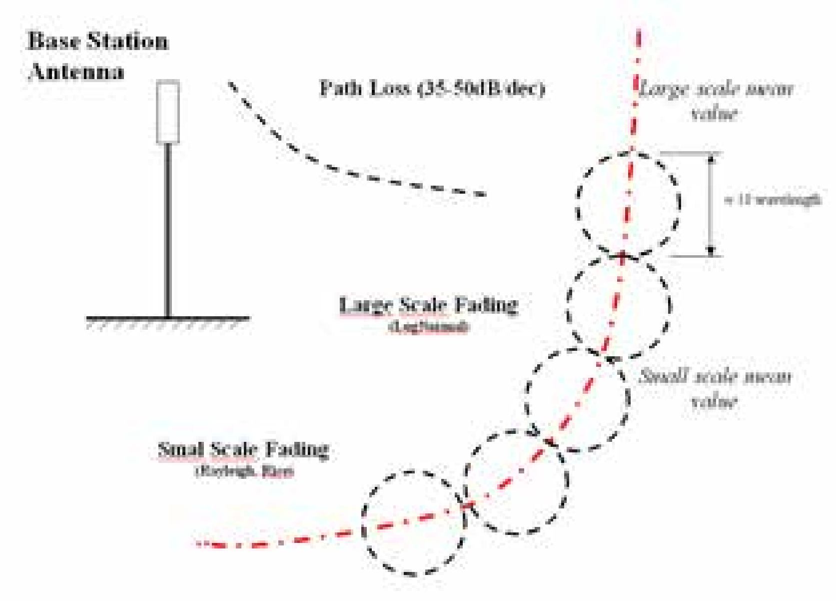


Figure A-14: Different types of Fading (*Bonek and Molisch, 2000*)

If we obtain the mean average value over more than 10 wavelengths, then it oscillates around a global mean average value. Shadowing effects are the reason for these fluctuations. If all these fluctuations are averaged by statistic methods, the received field strength will also be decreased monotonously with the distance to the base station. The large scale fading and small scale fading effects usually are described with statistical methods.

7.2.1.1 Large scale fading

The large scale fading effect has its origin mainly in the shadowing caused by objects, like buildings or trees, while the small scale fading is caused due to diffraction on objects through constructive and destructive components of the propagating wave.

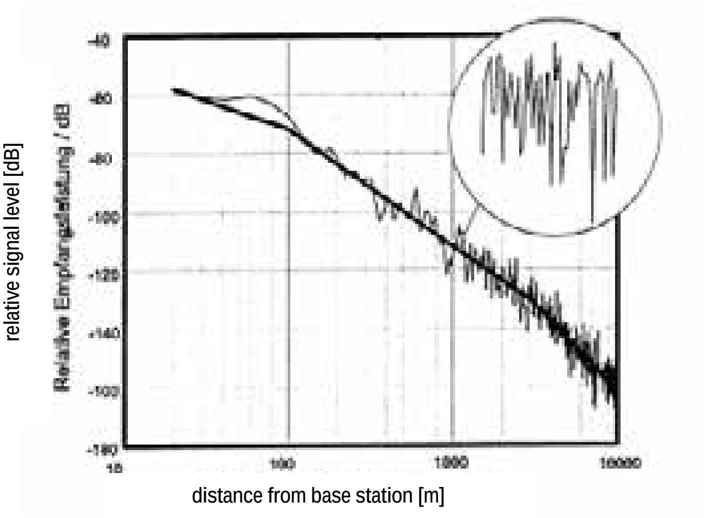


Figure A-15: Superposition of large and small scale fading (*Bonek and Molisch, 2000*)

The large scale fading effect is overlapped with the small scaling effect, like depicted in Figure A-15. As describing parameter of a large scale and a small scale a median value is often used.

For the description of the field distribution the *cumulative distribution function* (CDF) and its first derivative, the *probability density function* (PDF), are used.

The CDF lays between 0 and 1 corresponding to 0 or 100 % probability. The probability that a value is between these two limits *a* and *b* can be calculated by:

$$\mathrm{P(a < E \leq b) = cdf_x(b) - cdf_x(a) = \int_a^b pdf_x(x) \cdot dx} \tag{7.2.5}$$

The relation between CDF and PDF is:

$$\mathrm{pdf_x(x) = \frac{d(cdf_x(x))}{dx}} \tag{7.2.6}$$

with the relation:

$$\int_{-\infty}^{+\infty} \mathrm{pdf_x(x) \cdot dx = 1} \tag{7.2.7}$$

corresponding to an overall probability of 1 and the characteristic from the CDF for $\mathrm{f_x(x) \geq 0}$ and $-\infty < \mathrm{x} < +\infty$ to have only positive values.

The large scale fading in the amplitude distribution can be described with a *Log-Normal* distribution. This can be written as:

$$pdf_{LogNormal}(r) = \frac{1}{r\sqrt{2\pi\sigma^2}} \exp\left\{-\frac{[\ln(r) - m]^2}{2\sigma^2}\right\} \tag{7.2.8}$$

where *m* is the arithmetic mean value, and σ the standard deviation from the corresponding Normal distribution, that we obtain through the transformation $y = \ln(r)$.

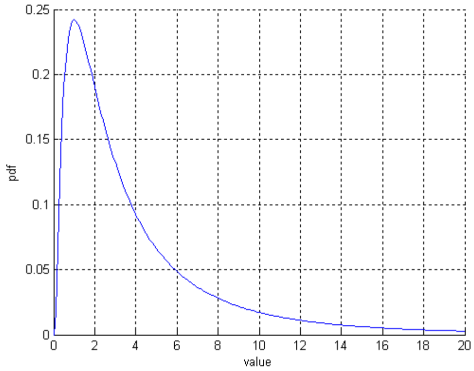


Figure A-16: PDF for the Log-Normal-distribution with the parameters m=1 and σ=1

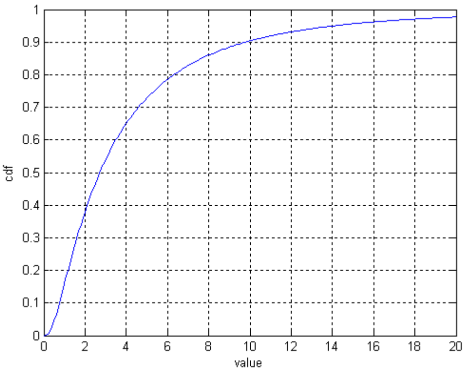


Figure A-17: CDF for the Log-Normal-distribution with the parameters m=1 and σ=1

The integral of the probability density function (pdf) is the cumulative distribution function (cdf), shown in Figure A-17, and it allows a faster calculation of the probability *y* for a given value *x*.

In the literature, we can find distributions like Rice and Rayleigh to describe the channel model.

Which model and distribution are useful in practice is a difficult question that can be answered only after further investigations through measurements and numerical simulations. Up to now no laws of a relation between specific exposure scenarios, e.g. LOS (line of sight) in rural areas and specific distributions was found for realistic exposure conditions.

7.2.1.2 Small scale fading

In the literature there are various mathematical models to obtain the channel characteristics of the small scale fading. The models are quite complex and differ, among other things, in the number of degrees of freedom. Before the different models are discussed, at first, as introduction, the results of a simple computer experiment are shown.

Given that in a two-dimensional room, 10 waves propagate with approximately similar amplitude, overlapped in all directions and are equally distributed arbitrarily.
We have:

$$E_i(x,y) = A_i\left(e^{-jk_0(x\cdot\cos\alpha_i + y\cdot\sin\alpha_i)}\cdot e^{j\Phi_i}\right) \qquad (7.2.9)$$

with A_i= *{1.1; 0.9; 1.15; 1.25; 0.92; 0.79; 0.94; 1.21;0.82;1.05}*; α_i= *{172; 48; 216; 97; 14; 272; 74; 118; 352; 291}*; Φ_i= *{11; 308; 36; 152; 225; 347; 197; 56; 259; 143}*

The waves E_i have the amplitudes A_i, the angle to the x-axis is α_i and the phase is Φ_i .The time dependence exp(jωt) is not take in consideration and the total field strength is the sum of each single field strength.
We also assume the simplification, that the wave has no propagation losses. The total field strength distribution is shown in Figure and the discrete amplitude density distribution in Figure A-19.

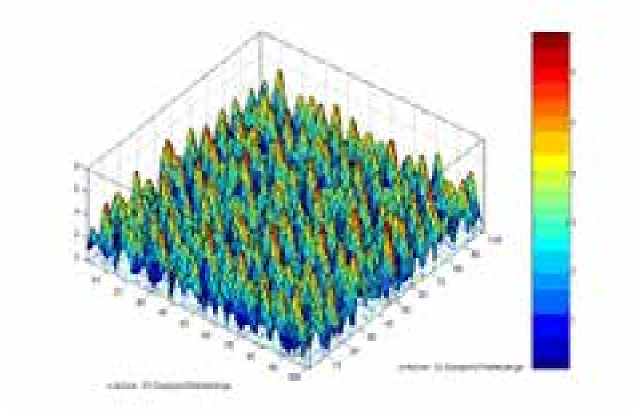


Figure A-18: Distribution of the electrical field strength over an area of 10 wavelengths

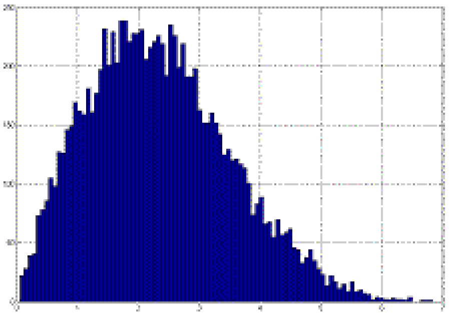


Figure A-19: Distribution of the amplitudes of the superimposed partial waves

In this simple case for approximately equal amplitudes of the single waves we can use a Rayleigh distribution to describe the situation.

In the next chapter we discuss more detailed the actually used models to describe the small scale fading effects. All these models have in common, that they are based on the bell shaped structure: the right side of the distribution is usually flatter than the left side.

Rayleigh Distribution

For mobile radiofrequency channels without a dominant spreading path the Rayleigh distribution is used to model the small scale fading losses. The arriving signals are in the same order of magnitude and are distributed uniformly in space in the direction of propagation (NLOS, Non Line of sight).

$$pdf_{Rayleigh} = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) \qquad 0 \le r \le \infty \tag{7.2.10}$$

The probability that the envelope of the received signal is lower than a defined value R is given by the corresponding *cumulative distribution function* (CDF)

$$cdf_{Rayleigh}(R) = P_r(r < R) = \int_0^R cdf(r)dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right) \tag{7.2.11}$$

where *r* is the envelope amplitude of the received signal, and $2\sigma^2$ is the predicted mean power of the multipath signal.

Ricean Distribution

In the case of a dominant signal component, as we can find for example in the situation of a direct line of sight (LOS), the spatial distribution can be described by the Rice distribution.

The Rice distribution is given by:

$$pdf_{Rice}(r) = \frac{r}{\sigma}\exp\left[-\frac{r^2 + A^2}{2\sigma^2}\right] I_0\left(\frac{Ar}{\sigma^2}\right) \tag{7.2.12}$$

where r is the amplitude of the signal envelope, and $2\sigma^2$ the mean signal power. A is the highest amplitude from the dominant signal, and $I_0(\bullet)$ is the modified Bessel function of the first kind and zero order (*Dirschmid, 1990*). The Rice distribution is often described by the k-factor:

$$k(dB) = 10 \cdot \log \frac{A^2}{2\sigma^2} \tag{7.2.13}$$

The numerical value 'k' is the so called *Rice factor* which describes the whole distribution completely.

Log-Normal Fading Model

This model is used when there are many reflections and diffractions between transmitter and receiver. The Log-Normal distribution is given by (see also 2.2-8):

$$pdf_{LogNormal} = \frac{1}{r\sqrt{2\pi\sigma^2}} \exp\left\{ -\frac{[\ln(r) - m]^2}{2\sigma^2} \right\} \tag{7.2.14}$$

where m is the median value, and σ is the standard deviation of the corresponding normal distribution, obtained by using the transformation

$$y = \ln(r) \tag{7.2.15}$$

To calculate the sum of every single Log-Normal component, methods like random Monte Carlo are used.

Suzuki Model

The Suzuki model combines the Log-Normal distribution with the Rayleigh distribution. This model allows a more flexible approximation of a wider kind of mobile channels.
Usually the Rayleigh distribution comes from the two independent normal distributed processes and with zero means $\mu_1(t)$ and $\mu_2(t)$

$$\xi(t) = \sqrt{\mu_1{}^2(t) + \mu_2{}^2(t)} \tag{7.2.16}$$

where $\xi(t)$ can be seen as the envelope from the complex normal distributed random process.
The Suzuki distribution is given by

$$pdf_{Suzuki}(r) = \int_0^\infty \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} \right) \cdot \frac{1}{\sqrt{2\pi} \cdot s\sigma} \exp\left[-\frac{(\ln\sigma - m)^2}{2s^2} \right] d\sigma \tag{7.2.17}$$

where σ is the standard deviation and r the amplitude. This Model is a wide accepted model for mobile channels with no direct line of sight (NLOS).

Nakagami Model

The Nakagami model was developed in the early 40s by Nakagami (*Nakagami, 1960*). The probability density function (PDF) can be written as:

$$pdf_{Nakagami} = \frac{2m^m r^{2m-1} \exp\left(-\frac{m}{\Omega} r^2 \right)}{\Gamma(m)\Omega^m} \tag{7.2.18}$$

The parameter r is the envelope amplitude of he received signal (the brackets $\langle\rangle$ describe the time averaging process).

$$\Omega = \left\langle r^2 \right\rangle \tag{7.2.19}$$

is the time averaged power of the received signal and

$$m = \frac{\langle r \rangle^2}{\left\langle \left(r^2 - \langle r \rangle^2 \right)^2 \right\rangle} \tag{7.2.20}$$

is the inverse of the normalized variance of r^2. The factor $\Gamma(\bullet)$ is the Gamma function (*Dirschmid, 1990*):

$$\Gamma(\alpha) = \int_0^\infty \mathrm{e}^{-\mathrm{t}} \mathrm{t}^{\alpha-1} \mathrm{dt} \tag{7.2.21}$$

and for integer and positive values we have the simple relation:

$$\Gamma(\mathrm{n}+1) = \mathrm{n}! = \prod_{\mathrm{i}=1}^{\mathrm{n}} (\mathrm{i}) \tag{7.2.22}$$

The Nakagami distribution is more general as other known distributions and allows a maximum of variability. For m = 1 the distribution becomes the Rayleigh distribution. The Nakagami model is suitable for urban multipath propagation with many scattered field components.

Weibull Model

The model is defined by

$$pdf_{Weibull}(r) = \frac{\alpha b}{r_0} \left(\frac{br}{r_0} \right)^{\alpha-1} \exp\left[-\left(\frac{br}{r_0} \right)^{\alpha} \right] \tag{7.2.23}$$

where α is a shape parameter, that has to be chosen - to fit best with the measured values. The value r_0 is the effective value from r, and

$$b = \sqrt{\frac{2}{\alpha} \cdot \Gamma\left(\frac{2}{\alpha} \right)} \tag{7.2.24}$$

is a normalization factor. In the special case α = 1/2, the Weibull distribution becomes a Rayleigh distribution. The Weibull distribution allows a similar flexibility as the Nakagami distribution. In the literature it has been shown (*Kaltenbach, 1998*, *Hashemi, 1993*) that this distribution is suited well for indoor distributions.

Apart from these 6 here listed small scale fading models also others were developed like the *Rice Log-Normal model* (*Vatalaro, 1995*) or the *Nakagami Log-Normal model* (*Tjhung, 1999*). The difficulty consists in how to assign to an exposure situation the corresponding best fitting probability density function with the matching parameters. One possible way to solve this question is the use of numerical tools.

8 References

Altpeter ES, Krebs T, Pfluger DH, von Känel J, Blattmann R, Emmenegger D, Cloetta B, Rogger U, Gerber H, Manz B, Coray R, Baumann R, Staerk K, Griot C, Abelin T. 1995. Study on health effects of the shortwave transmitter station of Schwarzenburg, Berne, Switzerland (Major Report). BEW Publication Series No. 55. Bern, Federal Office of Energy. Ref Type: Report

Altpeter E, Battaglia M, Bader A, Pfluger D, Minder CE, Abelin T. 2000. 10 Jahre epidemiologische Forschung im Umfeld des Kurzwellensenders Schwarzenburg: Was haben wir gelernt?. Institut für Sozial- und Präventivmedizin, Universität Bern, Finkenhubelweg 11, CH-3012 Bern, Schweiz. (www.land-sbg.gv.at/celltower).

ANFR. 2004. PROTOCOLE DE MESURE IN SITU, Visant à vérifier pour les stations émettrices fixes, le respect des limitations, en terme de niveaux de référence, de l'exposition du public aux champs électromagnétiques prévues par le décret n° 2002-775 du 3 mai 2002. Agence Nationale des Fréquences, Edition 2004.

Arai N, Enomoto H, Okabe S, Yuasa K, Kamimura Y, Ugawa Y. 2003. Thirty minutes mobile phone use has no short-term adverse effects on central auditory pathways. Clin Neurophysiol 114, 1390-1394.

Auvinen A, Hietanen M, Luukkonen R, Koskela RS. 2002. Brain tumors and salivary gland cancers among cellular telephone users. Epidemiology 13, 356-9.

Bak M, Sliwinska-Kowalska M, Zmyslony M, Dudarewicz A. 2003. No effects of acute exposure to the electromagnetic field emitted by mobile phones on brainstem auditory potentials in young volunteers. Int J Occup Med Environ Health 16, 201-208.

Bakom. 2001. Faktenblatt TETRA http://www.bakom.ch, [1665.pdf], April 2001.

Bakom 2002. Coray R, Krähenbühl P, Riederer M, Stoll D, Neubauer G, Szentkuti, B. NIS – Immissionen in Salzburg, Study of the Swiss Federal Office for Communication, February, 2002.

Bayerisches Landesamt für Arbeitsschutz: Elektromagnetische Felder am Arbeitsplatz – Ergebnisse einer Messreihe des LfAS. http://www.lfas.bayern.de -[emf.pdf].

Beale LA. 2004. Personal Communication.

Bergqvist U, Vogel E. 1997. Possible health implication of subjective symptoms and electromagnetic fields: a report by a European group of experts for the European Commission DG V. 1997. Sona (Sweden), National Instiute for Working Life, Arbete och Hälsa, 19. Ref Type: Report

Berkson J. 1950. Are there two regressions? Journal of American State Association 45, 164-180.

Bernardi P, Cavagnaro M, Pisa S, Piuzzi E. 2002. Evaluation of human exposure in the vicinity of a base-station antenna using the multiple-region/FDTD hybrid method Microwave Symposium Digest, 2002 IEEE MTT-S International , Volume: 3 , 2-7 June 2002 Pages:1747 – 1750.

Bini M, Checcucci A, Ignesti A, Millanta L, Olmi R, Rubino N, Vanni R. 1986. Exposure of workers to intense RF electric fields that leak from plastic sealers. J Microw Power Electromagn Energy.;21(1):33-40.

BIPT, the Belgian regulatory body for postal services and telecommunication. http://www.bipt.be/bipt_E.htm

Bonek E, Molisch A. 2000. Mobilkommunikation. Vorlesungsskriptum der TU Wien. Institut für Hochfrequenztechnik, 6. Auflage, Februar.

Borbely AA, Huber R, Graf T, Fuchs B, Gallmann E, Achermann P. 1999. Pulsed high-frequency electromagnetic field affects human sleep and sleep electroencephalogram. Neuroscience Letters 275, 207-210.

Bornkessel C, Schubert M. 2004. Entwicklung von Mess- und Berechnungsverfahren zur Ermittlung der Exposition der Bevölkerung durch elektromagnetische Felder in der Umgebung von Mobilfunk Basisstationen Zwischenbericht ´Analyse der Immissionsverteilung´", IMST GmbH, July 2004.

Bortkiewicz A, Gadzicka E, Zmyslony M. 1996. Heart rate variability in workers exposed to medium-frequency electromagnetic fields. J Auton Nerv Syst 59, 91-97.

Bortkiewicz A, Pilacik B, Gadzicka E, Szymczak W 2002. The excretion of 6-hydroxymelatonin sulfate in healthy young men exposed to electromagnetic fields emitted by cellular phone -- an experimental study. Neuroendocrinol Lett 23 Suppl 1, 88-91.

Bortkiewicz A, Zmyslony M, Gadzicka E, Palczynski C, Szmigielski S. 1997. Ambulatory ECG monitoring in workers exposed to electromagnetic fields. J Med Eng Technol 21, 41-46.

Boscolo P, Di Sciascio MB, D'Ostilio S, Del Signore A, Reale M, Conti P, Gavazzano P, Paganelli R, Di Gioacchino M. 2001. Effects of electromagnetic fields produced by radiotelevision broadcasting stations on the immune system of women. Science of the Total Environment 273, 1-10.

Braune S, Riedel A, Schulte-Monting J, Raczek J. 2002. Influence of a radiofrequency electromagnetic field on cardiovascular and hormonal parameters of the autonomic nervous system in healthy individuals. Radiat Res 158, 352-356.

Braune S, Wrocklage C, Raczek J, Gailus T, Lucking CH. 1998. Resting blood pressure increase during exposure to a radio- frequency electromagnetic field. Lancet 351, 1857-1858.

Breckenkamp J, Berg G, Blettner M. 2003. Biological effects on human health due to radiofrequency/microwave exposure: a synopsis of cohort studies. Radiat Environ Biophys 42, 141-154.

Burch JB, Reif JS, Noonan CW, Ichinose T, Bachand AM, Koleber TL, Yost MG. 2002. Melatonin metabolite excretion among cellular telephone users. Int J Radiat Biol 78, 1029-1036.

Catney D, Gavin A. 2004. Investigation of Cancer Incidence in the Vicinity of Cranlome Telecommunications Mast. Northern Ireland Cancer Registry Department of Epidemiology & Public Health, Queen's University Belfast. (http://www.qub.ac.uk/nicr/cranlome.htm)

Cano MI, Pollan M. 2001. Non-Hodgkin's lymphomas and occupation in Sweden. International Archives of Occupational and Environmental Health 74, 443-449.

Chia SE, Chia HP, Tan JS. 2000. Prevalence of headache among handheld cellular telephone users in Singapore: A community study. Environmental Health Perspectives 108, 1059-1062.

Christensen HC, Schuz J, Kosteljanetz M, Poulsen HS, Thomsen J, Johansen C. 2004. Cellular telephone use and risk of acoustic neuroma. Am J Epidemiol. 2004 Feb 1;159(3):277-83.

Collatz Christensen H, Schüz J, Kosteljanetz M, Poulsen HS, Thomsen J, Johansen C. 2004. Cellular telephone use and risk of acoustic neuroma. Am J Epidemiol 159, 277-283.

Cook A, Woodward A, Pearce N, Marshall C. 2003. Cellular telephone use and time trends for brain, head and neck tumours. N Z Med J 116, U457.

Cook CM, Thomas AW, Prato FS. 2002. Human electrophysiological and cognitive effects of exposure to ELF magnetic and ELF modulated RF and microwave fields: a review of recent studies. Bioelectromagnetics 23, 144-157.

Cooper D, Hemmings K, Saunders P. 2001. Cancer incidence near radio and television transmitters in Great Britain. I. Sutton Coldfield transmitter; II. All high power transmitters. American Journal of Epidemiology 153, 202-204.

Croft RJ, Chandler JS, Burgess AP, Barry RJ, Williams JD, Clarke AR. 2002. Acute mobile phone operation affects neural function in humans. Clin Neurophysiol 113, 1623-1632.

Curcio G, Ferrara M, De Gennaro L, Cristiani R, D'Inzeo G, Bertini M. 2004. Time-course of electromagnetic field effects on human performance and tympanic temperature. Neuroreport 15, 161-164.

Dale C, Wiart J. 2004. Exposure comparison between a mobile phone and a base station at 900 MHz, 1800 MHz & 2100 MHz. 26th annual meeting, Washington , DC June 20-24, 2004, Bioelectromagnetics Society.

Danestig J. 2004. Analysis of RF exposure from radio base station antennas in operating environments. Department of Electromagnetics. Chalmers University of Technology, Göteborg, Sweden.

Dasdag S, Balci K, Kaya H, Celik MS. 1999. Hormone levels of people occupationally exposed to radio frequencies. Biochemical Archives 15, 255-260.

David E, Reissenweber J, Wotjysiak A, Pfotenhauer M. 2002. On the phenomena of electromagnetic hypersensitivity. Umweltmed Forsch Prax 7, 7-16.

Davis RL, Mostofi FK. 1993. Cluster of testicular cancer in police officers exposed to hand-held radar. Am J Ind Med 24, 231-3.

DCA. 1994. Department of Communications and the Arts. Radio and Television Broadcasting Stations. Canberra: AGPS, 1994.

De Roos AJ, Teschke K, Savitz DA, Poole C, Grufferman S, Pollock BH, Olshan AF. 2001. Parental occupational exposures to electromagnetic fields and radiation and the incidence of neuroblastoma in offspring. Epidemiology 12, 508-517.

de Seze R, Fabbro-Peray P, Miro L. 1998. GSM radiocellular telephones do not disturb the secretion of antepituitary hormones in humans. Bioelectromagnetics 19, 271-278.

Del Signore A, Boscolo P, Kouri S, Di Martino G, Giuliano G. 2000. Combined effects of traffic and electromagnetic fields on the immune system of fertile atopic women. Industrial Health 38, 294-300.

Diener E, Diener C. 1996. Most people are happy. Psychological Science 7, 304-324.

Dirschmid HJ. 1990. Mathematische Grundlagen der Elektrotechnik. 4te Auflage, Vieweg Verlag, Braunschweig.

Dolk H, Elliott P, Shaddick G, Walls P, Thakrar B. 1997a. Cancer incidence near radio and television transmitters in Great Britain .2. All high power transmitters. American Journal of Epidemiology 145, 10-17.

Dolk H, Shaddick G, Walls P, Grundy C, Thakrar B, Kleinschmidt I, Elliott P. 1997b. Cancer incidence near radio and television transmitters in Great Britain .1. Sutton Coldfield transmitter. American Journal of Epidemiology 145, 1-9.

Döttling M., Becker T., Wiesbeck W.,: Modeling of the DECT outdoor radio channel. Universität Karlsruhe, IEEE Xplore Online, [00605898.pdf] 1997.

Dreyer NA, Loughlin JE, Rothman KJ. 1999. Cause-specific mortality in cellular telephone users. Journal of the American Medical Association 282, 1814-1816.

Eddelbüttel, Doris: Es hat gefunkt - Test WLAN-Hotspots; in: ÖKO-TEST-Magazin Nr. 11, November 2002, ÖKO-TEST-Verlag GmbH Frankfurt/Main; S. 129-129. www.baubiologie.net/

Edelstyn N, Oldershaw A. 2002. The acute effects of exposure to the electromagnetic field emitted by mobile phones on human attention. Neuroreport 13, 119-121.

Elwood JM. 1999. A critical review of epidemiologic studies of radiofrequency exposure and human cancers. Environmental Health Perspectives 107, 155-168.

Elwood JM. 2003. Epidemiological studies of radio frequency exposures and human cancer. Bioelectromagnetics Suppl 6, S63-S73.

Eulitz C, Ullsperger P, Freude G, Elbert T. 1998. Mobile phones modulate response patterns of human brain activity. Neuroreport 9, 3229-3232.

Fabbro-Peray P, Daures JP, Rossi JF. 2001. Environmental risk factors for non-Hodgkin's lymphoma: a population-based case-control study in Languedoc-Roussillon, France. Cancer Causes & Control 12, 201-212.

Flodin U, Seneby A, Tegenfeldt C. 2000. Provocation of electric hypersensitivity under everyday conditions. Scandinavian Journal of Work Environment & Health 26, 93-98.

Freude G, Ullsperger P, Eggert S, Ruppe I. 1998. Effects of microwaves emitted by cellular phones on human slow brain potentials. Bioelectromagnetics 19, 384-387.

Freude G, Ullsperger P, Eggert S, Ruppe I. 2000. Microwaves emitted by cellular telephones affect human slow brain potentials. European Journal of Applied Physiology and Occupational Physiology 81, 18-27.

Frick U, Rehm J, Eichhammer P. 2002. Risk perception, somatization, and self report of complaints related to electromagnetic fields - A randomized survey study. International Journal of Hygiene and Environmental Health 205, 353-360.

Fucic A, Garaj-Vrhovac V, Skara M, Dimitrovic B. 1992. X-rays, microwaves and vinyl chloride monomer: their clastogenic and aneugenic activity, using the micronucleus assay on human lymphocytes. Mutat Res 282, 265-271.

Funch DP, Rothman KJ, Loughlin JE, et al. 1996. Utility of telephone company records for epidemiologic studies of cellular telephones. Epidemiology; 7:299-302.

Garland FC, ED Gorham, CF Garland. 1987. Hodgkin's disease in the US navy. Epidemiol., Vol. 16, No. 3, pp. 367-372.

Garland, F.C., E.D. Gorham, C.F. Garland, and J.A. Ferns. 1988a . Non Hodgkin's disease in the US navy personnel. Arch. Environ. Health, Vol. 43, No. 6, pp. 425-429.

Garland, F.C., E.D. Gorham, C.F. Garland, and A.M. Ducatman. 1988b. Testicular Cancer in US navy personnel. Am. J. Epidemiol., Vol. 127, No. 2, pp. 411-414.

Garland FC, E Shaw, ED Gorham, CF Garland, MR White, PJ Sinsheimer. 1990. Incidence of Leukaemia in occupations with potential electromagnetic field exposure in US navy personnel. Am. J. Epidemiol., Vol. 132, No. 2, pp. 293-303.

Garn H, Neubauer G. 1998. Elektromagnetische Felder in Salzburg, ARCS Gutachten Nr. EE - EMV - S 55/98

Garson OM, McRobert TL, Campbell LJ, Hocking BA, Gordon I. 1991. A chromosomal study of workers with long-term exposure to radio-frequency radiation. Med J Aust 155, 289-292.

Goldsmith JR. 1995. Epidemiologic Evidence of Radiofrequency Radiation (Microwave) Effects on Health in Military, Broadcasting, and Occupational Studies. Int J Occup Environ Health 1, 47-57.

Goldsmith JR. 1997. Epidemiologic evidence relevant to radar (microwave) effects. Environmental Health Perspectives 105, 1579-1587.

Grajewski B, Cox C, Schrader SM, Murray WE, Edwards RM, Turner TW, Smith JM, Shekar SS, Evenson DP, Simon SD, Conover DL. 2000. Semen quality and hormone levels among radiofrequency heater operators. Journal of Occupational and Environmental Medicine 42, 993-1005.

Grayson JK, 1996. Radiation exposure, socioeconomic status, and brain tumor risk in the US Air Force: a nested case-control study. American Journal of Epidemiology 143, 480-486.

Groves FD, Page WF, Gridley G, Lisimaque L, Stewart, A, Tarone RE, Gail MH, Boice JD Jr, Beebe GW. 2002. Cancer in Korean war navy technicians:Mortality survey after 40 years. Am J Epidemiol 155:810–818.

Guberan E, Campana A, Faval P, Guberan M, Sweetnam PM, Tuyn JW, Usel M. 1994. Gender ratio of offspring and exposure to shortwave radiation among female physiotherapists. Scand J Work Environ Health 20, 345-8.

Haarala C, Aalto S, Hautzel H, Julkunen L, Rinne JO, Laine M, Krause B, Hamalainen H. 2003a. Effects of a 902 MHz mobile phone on cerebral blood flow in humans: a PET study. Neuroreport 14, 2019-2023.

Haarala C, Bjornberg L, Ek M, Laine M, Revonsuo A, Koivisto M, Hamalainen H. 2003b. Effect of a 902 MHz electromagnetic field emitted by mobile phones on human cognitive function: A replication study. Bioelectromagnetics 24, 283-288.

Haas H. 2001.Numerische Simulationsverfahren in der Elektrotechnik. Institut für Theoretische Elektrotechnik, Vorlesungsskriptum TU Wien.

Haider H, Kriz A, Müllner W. 2002. Frequenzselektive Analyse des Isotropieverhaltens und der Messunsicherheit für das Feldstärke Messverfahren Add3D. EMV 2002, 10. Internationale Fachmesse und Kongress für Elektromagnetische Verträglichkeit, 9.-11. April 2002 Düsseldorf.

Hallberg O, Johansson O. 2002. Melanoma incidence and frequency modulation (FM) broadcasting. Arch Environ Health 57, 32-40.

Hamblin DL, Wood AW, Croft RJ, Stough C. 2004. Examining the effects of electromagnetic fields emitted by GSM mobile phones on human event-related potentials and performance during an auditory task. Clin Neurophysiol 115, 171-178.

Hanson Mild, K, Oftedal, G, Sandstrom, M, Wilen, J, Tynes, T, Haugsdal, B, Hauger E, 1998: Comparison of symptoms experienced by users of analogue and digital mobile phones: a Swedish-Norwegian epidemiological study. Arbetslivsrapport 23.

Hardell L, Hallquist A, Mild KH, Carlberg M, Pahlson A, Lilja A. 2002a. Cellular and cordless telephones and the risk for brain tumours. Eur J Cancer Prev 11, 377-386.

Hardell L, Mild KH, Carlberg M. 2002b. Case-control study on the use of cellular and cordless phones and the risk for malignant brain tumours. Int J Radiat Biol 78, 931-936.

Hardell L, Nasman A, Pahlson A, Hallquist A, Mild KH. 1999. Use of cellular telephones and the risk for brain tumours: A case-control study. International Journal of Oncology 15, 113-116.

Hardell L, Hansson Mild K, Sandstrom M, Carlberg M, Hallquist A, Pahlson A. 2003. Vestibular schwannoma, tinnitus and cellular telephones. Neuroepidemiology. 2003 Mar-Apr; 22(2):124-9.

Harrington RF. 1968. Field Computation by Moment Method. MacMillan.

Hashemi H. 1993. The Indoor Radio Propagation Channel. Proceedings of the IEEE, Vol. 81, pp. 943-968, July 1993.

Hayes RB, Brown LM, Pottern LM, Gomez M, Kardaun JW, Hoover RN, O'Connell KJ, Sutzman RE, Javadpour N. 1990. Occupation and risk for testicular cancer: a case-control study. Int J Epidemiol 19, 825-31.

Heath CW Jr. 1996. Electromagnetic field exposure and cancer: a review of epidemiologic evidence. CA Cancer J Clin 46, 29-44.

Heynick L. 1998. Independent Consultant. Radiofrequency electromagnetic fields and cancer: a comprehensive review of the literature pertient to air force operations.

Hietanen M, Hamalainen A M, Husman T. 2002. Hypersensitivity symptoms associated with exposure to cellular telephones: no causal link. Bioelectromagnetics 23, 264-270.

Hietanen M, Kovala T, Hamalainen AM. 2000. Human brain activity during exposure to radiofrequency fields emitted by cellular phones. Scandinavian Journal of Work Environment & Health 26, 87-92.

Hillert L, Berglind N, Arnetz BB, Bellander T. 2002. Prevalence of self-reported hypersensitivity to electric or magnetic fields in a population-based questionnaire survey. Scand J Work Environ Health 28, 33-41.

Hladky A, Musil J, Roth Z, Urban P, Blazkova V. 1999. Acute effects of using a mobile phone on CNS functions. Cent Eur J Public Health 7, 165-7.

Hocking B. 1998. Symptoms associated with mobile phone use. Occupational Medicine-London 48, 357-360.

Hocking B, Gordon IR, Grain HL, Hatfield GE. 1996. Cancer incidence and mortality and proximity to TV towers. Medical Journal of Australia 165, 601-605.

Hocking, B, Westerman, R. 2000. Neurological abnormalities associated with mobile phone use. Occupational Medicine Oxford, 50, 366-368.

Hocking, B, Westerman, R. 2001.Neurological abnormalities associated with CDMA exposure. Occupational Medicine Oxford, 51, 410-413.

Huber R, Graf T, Cote KA, Wittmann L, Gallmann E, Matter D, Schuderer J, Kuster N, Borbely AA, Achermann P. 2000. Exposure to pulsed high-frequency electromagnetic field during waking affects human sleep EEG. Neuroreport 11, 3321-3325.

Huber R, Schuderer J, Graf T, Jutz K, Borbely AA, Kuster N, Achermann P. 2003. Radio frequency electromagnetic field exposure in humans: Estimation of SAR distribution in the brain, effects on sleep and heart rate. Bioelectromagnetics 24, 262-276.

Huber R, Treyer V, Borbely AA, Schuderer J, Gottselig JM, Landolt HP, Werth E, Berthold T, Kuster N, Buck A, Achermann P. 2002. Electromagnetic fields, such as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG. J Sleep Res 11, 289-295.

Hutter H, Moshammer H, and Kundi M. 2002. Mobile telephone base stations: effects on health and wellbeing. Workshop on Biological Effects of EMFs. Kostarakis P. Vol 2, 344-352. Rhodes.

Hyland GJ. 2000. Physics and biology of mobile telephony. Lancet 356, 1833-1836.

Inskip PD, Tarone RE, Hatch EE, Wilcosky TC, Shapiro WR, Selker RG, Fine HA, Black PM, Loeffler JS, Linet MS. 2001. Cellular-telephone use and brain tumors. New England Journal of Medicine 344, 79-86.

Ishimaru A.1997. Wave Propagation and Scattering in Random Medi. University of Washington, IEEE Press, The Institute of Electrical and Electronic Engineers, Inc. New York .

ITUR 2001. Recommendation ITU-R p.676-5 Attenuation by Atmospheric Gases. International Telecommunication Union 2001.

Jahn O. 2000. Electromagnetic fields: low dose exposure, current update. Int Arch Occup Environ Health 73 Suppl, S1-S3.

Jarupat S, Kawabata A, Tokura H, Borkiewicz A. 2003. Effects of the 1900 MHz electromagnetic field emitted from cellular phone on nocturnal melatonin secretion. J Physiol Anthropol Appl Human Sci 22, 61-63.

Jech R, Sonka K, Ruzicka E, Nebuzelsky A, Bohm J, Juklickova M, Nevsimalova S. 2001. Electromagnetic field of mobile phones affects visual event related potential in patients with narcolepsy. Bioelectromagnetics 22, 519-528.

Johansen C, Boice JD, McLaughlin JK, Olsen JH. 2001. Cellular telephones and cancer - A nationwide cohort study in Denmark. Journal of the National Cancer Institute 93, 203-207.

Johansen C, Boice JD Jr, McLaughlin JK, Christensen HC, Olsen JH. 2002. Mobile phones and malignant melanoma of the eye. Br J Cancer. 2002 Feb 1;86(3):348-9.

Kallen B, Malmquist G, Moritz U. 1982. Delivery outcome among physiotherapists in Sweden: is non-ionizing radiation a fetal hazard? Arch Environ Health 37, 81-5.

Kaltenbach R. 1998. Statistical Distribution of Path Interarrival times in Indoor Environment. RF Dep. University of Kassel, IEEE 1998, VTC, pp. 548-551.

Kliukiene J, Tynes T, Andersen A. 2003. Follow-up of radio and telegraph operators with exposure to electromagnetic fields and risk of breast cancer. Eur J Cancer Prev. 2003 Aug;12(4):301-7.

Koivisto M, Haarala C, Krause CM, Revonsuo A, Laine M, Hamalainen H. 2001. GSM phone signal does not produce subjective symptoms. Bioelectromagnetics 22, 212-215.

Koivisto M, Krause CM, Revonsuo A, Laine M, Hamalainen H. 2000a. The effects of electromagnetic field emitted by GSM phones on working memory. Neuroreport 11, 1641-1643.

Koivisto M, Revonsuo A, Krause C, Haarala C, Sillanmaki L, Laine M, Hamalainen H. 2000b. Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans. Neuroreport 11, 413-415.

Kolosowski W., Wnuk M., Rozanski G.: Analysis and measurement of EM field distributions in area where DECT systems work. Military University of Technology, Electronics Fculty, Poland, IEEE Xplore Online [00944890.pdf], 2001

Krause CM, Haarala C, Sillanmaki L, Koivisto M, Alanko K, Revonsuo A, Laine M, Hamalainen H. 2004. Effects of electromagnetic field emitted by cellular phones on the EEG during an auditory memory task: a double blind replication study. Bioelectromagnetics 25, 33-40.

Krause CM, Sillanmaki L, Koivisto M, Haggqvist A, Saarela C, Revonsuo A, Laine M, Hamalainen H. 2000. Effects of electromagnetic fields emitted by cellular phones on the electroencephalogram during a visual working memory task. International Journal of Radiation Biology 76, 1659-1667.

Kurt F, Rreithofer F, Koroschetz F. 2003. Erhebung der HF-Belastung im Speziellen durch die Mobilfunktelefonie Zusammenfassender Bericht, 09. November 2000 – 31. December 2003, Umwelt Steiermark.

Lagorio S, Rossi S, Vecchia P, De Santis M, Bastianini L, Fusilli M, Ferrucci A, Desideri E, Comba P. 1997. Mortality of plastic-ware workers exposed to radiofrequencies. Bioelectromagnetics 18, 418-421.

Lalic H, Lekic A, Radosevic-Stasic B. 2001. Comparison of chromosome aberrations in peripheral blood lymphocytes from people occupationally exposed to ionizing and radiofrequency radiation. Acta Medica Okayama 55, 117-127.

Langholz B. 2001. Factors that explain the power line configuration wiring code-childhood leukemia association: what would they look like?. Bioelectromagnetics Suppl 5, S19-S31.

Larcheveque E, Dale C, Wong MF, Wiart J. 2005. Analysis of Electric Field Averaging for In Situ Radiofrequency Exposure Assessment IEEE VTC to be published 2005

Larsen AI. 1991. Congenital malformations and exposure to high-frequency electromagnetic radiation among Danish physiotherapists. Scand J Work Environ Health 17, 318-23.

Lass J, Tuulik V, Ferenets R, Riisalo R, Hinrikus H. 2002. Effects of 7 Hz-modulated 450 MHz electromagnetic radiation on human performance in visual memory tasks. Int J Radiat Biol 78, 937-944.

Lautru D, Wiart J, Tabbara W, Mittra R. 2000. A MoMTD/FDTD hybrid method to calculate the SAR induced by a base station antenna. Antennas and Propagation Society International Symposium, 2000. IEEE , Volume: 2 , 16-21 July 2000 Pages:757 - 760 vol.2.

Le Pennec F. 2001. Analyse de champ proche et de couverture radioélectrique, September 2001, École Nationale Supérieure des Télécommunications de Bretagne Département Microondes.

Lebedeva NN, Sulimov AV, Sulimova OP, Korotkovskaya TI, Gailus T. 2001. Investigation of brain potentials in sleeping humans exposed to the electromagnetic field of mobile phones. Critical Reviews in Biomedical Engineering 29, 125-133.

Lebedeva NN, Sulimov AV, Sulimova OP, Kotrovskaya TI, Gailus T. 2000. Cellular phone electromagnetic field effects on bioelectric activity of human brain. Critical Reviews in Biomedical Engineering 28, 323-337.

Lee TMC, Ho SMY, Tsang LYH, Yang SYC, Li LSW, Chan CCH. 2001. Effect on human attention of exposure to the electromagnetic field emitted by mobile phones. Neuroreport 12, 729-731.

Leitgeb N, Schrottner J. 2003. Electrosensibility and electromagnetic hypersensitivity. Bioelectromagnetics 24, 387-394.

Lerman Y, Jacubovich R, Green MS. 2001. Pregnancy outcome following exposure to shortwaves among female physiotherapists in Israel. Am J Ind Med 39, 499-504.

Levallois P, Neutra R, Lee G, Hristova L. 2002. Study of self-reported hypersensitivity to electromagnetic fields in California. Environ Health Perspect 110 Suppl 4, 619-623.

Lilienfeld AM , Tonascia J,Tonascia S, Libauer CA, Cauthern GM. 1978. Foreign Service health status study – evaluation of health status of foreign service and other employees from selected eastern European spots. Final Report.

Lönn S, Forssen U, Vecchia P, Ahlbom A, Feychting M. 2004. Output power levels from mobile phones in different geographical areas; implications for exposure assessment. Occup Environ Med 61, 769-772.

Lönn S, Klaeboe L, Hall P, Mathiesen T, Auvinen A, Christensen HC, Johansen C, Salminen T, Tynes T, Feychting M. 2004. Incidence trends of adult primary intracerebral tumors in four Nordic countries. Int J Cancer 108, 450-455.

Lonne-Rahm S, Andersson B, Melin L, Schultzberg M, Arnetz B, Berg M. 2000. Provocation with stress and electricity of patients with "sensitivity to electricity". J Occup Environ Med 42, 512-6.

Lotz WG, Rinsky RA, Edwards RD. 1995. Occupational exposure of police officers to microwave radiation from traffic radar devices. National Institute for Occupational Safety and Health, Division of Biomedical and Behavioral Science and Division of Surveillance, Hazard Evaluations, and Field Studies. (http://infoventures.com/EMF/FEDERAL/NIOSH/POLICE/PL-RDR1.HTML)

Maes A, Collier M, Slaets D, Verschaeve L. 1995. Cytogenetic Effects of Microwaves From Mobile Communication Frequencies (954 Mhz). Electro- and Magnetobiology 14, 91-98.

Mann K, Röschke J. 1996. Effects of pulsed high-frequency electromagnetic fields on human sleep. Neuropsychobiology 33, 41-47.

Mann K, Wagner P, Brunn G, Hassan F, Hiemke C, Röschke J. 1998. Effects of pulsed high-frequency electromagnetic fields on the neuroendocrine system. Neuroendocrinology 67, 139-144.

Mann SM, cooperTG, Allen SG, Blackwell RP, Lowe AJ. 2000. Exposure to radio waves near mobile phone base stations, NRPB – R321, www.nrpb.org.uk , National Radiological Protection Board, 2000.

Maskarinec G, Cooper J, Swygert L. 1994. Investigation of increased incidence in childhood leukemia near radio towers in Hawaii: preliminary observations. J Environ Pathol Toxicol Oncol 13, 33-7.

McKenzie DR, Yin Y, Morrel S. 1998. Childhood incidence of acute lymphoblastic leukaemia and exposure to broadcast radiation in Sydney--a second look. Aust N Z J Public Health 22:360-367.

Michel G. 2004. Symptom reporting: Exploration of situational and individual predictors. PhD thesis. University of Fribourg, Switzerland.

Michelozzi P, Capon A, Kirchmayer U, Forestiere F, Buggeri A, Barca A, Peducci CA. 2002. Adult and childhood leukemia near a high-power radio station in Rome, Italy. Am J Epidemiol 155, 1096-1103.

Milham S. 1985. Silent keys: Leukaemia mortality in amateur radio operators. Lancet, No. 8432, 6 April 1985, p. 812.

Milham S Jr. 1988a. Increased mortality in amateur radio operators due to lymphatic and hematopoietic malignancies. Am J Epidemiol 127, 50-4.

Milham S Jr. 1988b. Mortality by license class in amateur radio operators. Am J Epidemiol 128, 1175-6.

Mochizuki S, Watanabe S, Taki M, Yamanaka Y, Shirai H. 2003. Novel iteration procedures of a hybrid method combining MoM and scattered-field FDTD method for electromagnetic dosimetry Wireless Communication Technology, 2003. IEEE Topical Conference on , 15-17 Oct. 2003 Pages:200 – 201.

Monfrecola G, Moffa G, Procaccini EM. 2003. Non-ionizing electromagnetic radiations, emitted by a cellular phone, modify cutaneous blood flow. Dermatology 207, 10-14.

Morgan RW, Kelsh MA, Zhao K, Exuzides KA, Heringer S, Negrete W. 2000. Radiofrequency exposure and mortality from cancer of the brain and lymphatic/hematopoietic systems. Epidemiology 11, 118-127.

Mueller CH, Krueger H, Schierz C. 2002. Project NEMESIS: Perception of a 50 Hz electric and magnetic field at low intensities (laboratory experiment). Bioelectromagnetics 23, 26-36.

Muscat JE, Malkin MC, Thompson S, Shore RE, Stellman SD, McRee D, Neugut AI, Wynder EL. 2000. Handheld cellular telephone use and risk of brain cancer. Jama-Journal of the American Medical Association 284, 3001-3007.

Muscat JE, Malkin MG, Shore RE, Thompson S, Neugut AI, Stellman SD, Bruce J. 2002. Handheld cellular telephones and risk of acoustic neuroma. Neurology 58, 1304-1306.

Nakagami M. 1960. The m-distribution – A General Formula of Intensity Distribution of Rapid Fading. in W.G Hoffman, Statistical Methods in Radio Wave Propagation, Pergamon, 1960.
National Council on Radiation Protection and Measurement.1993. A practical guide to the determination of human exposure to radiofrequency fields. Bethesda, Md: NCRP. (NCRP Report No. 119).

Navarro EA, Segura J, Gómez-Perretta C, Portolés M, Maestu C, Bardasano JL. 2001 About the effects of microwave exposure from cellular phone base stations: A first approach. Department of Applied Physics, Universitat de València.

Navarro EA, Segura J, Portoles M, Gomez-Perretta de Mateo C. 2003. The microwave syndrome: a prelinimary study in Spain. Electromagnetic Biology and Medicine 22, 161-169.

Neubauer G. Elektromagnetische Felder in Salzburg 3, ARCS Gutachten Nr. EE - EMV - S 72/99

Neubauer G, Schmid G, Elektromagnetische Felder in Salzburg 2, ARCS Gutachten Nr. EE - EMV - S 55-2/98

Neubauer G, Bergqvist U, Hamnerius Y, Martens L, Thuroczy G, Vogel E, Wiart J, Friedrich G. 20001. Exposure next to GSM base stations in several countries in Europe, 5th International Congress of the European Bioelectromagnetics Association (EBEA), Helsinki, Finland, 6-8 September 2001 p. 118 – 119.

Neubauer G, Haider H, Lamedschwandner K, Riederer M, Coray R. 2003. Measurment methods and legal requirements for exposure assessment next to GSM Base stations, International Zurich Symposium on EMC, Proceeding Book, 27 F1, pp 143 – 148, February 2003.

Neubauer G, Röösli M, Feychting M, Hamnerius Y, Kheifets L, Kuster N, Schüz J, Wiart J. 2004. Feasibility of Future Epidemiological Studies on Possible Health Effects of Mobile Phone Base Stations. Platform Presentation at the 26th annual meeting of the Bioelectromagnetics Society, June 20-24, Washington DC, USA, Abstract Book pp. 16-17.

Oftedal G, Vistnes AI, Rygge K. 1995. Skin symptoms after the reduction of electric fields from visual display units. Scand J Work Environ Health 21, 335-44.

Oftedal G, Wilen J, Sandstrom M, Mild KH. 2000. Symptoms experienced in connection with mobile phone use. Occup Med Lond 50, 237-45.

Olsson M. 2004. Impacts of Meteorological Conditions on Field Propagation in the Frequency Range 0.8-3 GHz. Master Thesis, Depart. of Electromagnetics, Chalmers University of Technology, Gothenburg, Sweden.

Ozturan O, Erdem T, Miman MC, Kalcioglu MT, Oncel S. 2002. Effects of the electromagnetic field of mobile telephones on hearing. Acta Otolaryngol 122, 289-293.

Parsons JD. 2000.The Mobile Radio Propagation Channel. John Wiley & Sons LTD, Chinchester - New York- Weinheim - Brisbane-Singapore – Toronto, Second Edition .

Pätzold M. 1999. Mobilfunkkanäle – Modellierung, Analyse und Simulation, Vieweg Verlag, Braunschweig/Wiesbaden.

Perez-Gomez B, Pollan M, Gustavsson P, Plato N, Aragones N, Lopez-Abente G. 2004. Cutaneous melanoma: hints from occupational risks by anatomic site in Swedish men. Occup Environ Med 61, 117-126.

Preece AW, Iwi G, Davies-Smith A, Wesnes K, Butler S , Lim E, Varey A. 1999. Effect of a 915-MHz simulated mobile phone signal on cognitive function in man. International Journal of Radiation Biology 75, 447-456.

Prentice RL, Sheppard L. 1995. Aggregate data studies of disease risk factors. Biometrika 82, 113-126.

Radon K, Maschke C. 1998. Gibt es Elektrosensibilität im D-Netzbereich? Umweltmed Forsch Prax 3, 125-129.

Radon K, Parera D, Rose DM, Jung D, Vollrath L. 2001. No effects of pulsed radio frequency electromagnetic fields on melatonin, cortisol, and selected markers of the immune system in man. Bioelectromagnetics 22, 280-287.

Ramsdale PA, Wiener A. 1999. Cellular phone base stations: Technology and Exposures, Radiation Protection Dosimetry, Vol. 83, Nos 1-2, pp 125-130, 1999.

Rea WJ, Pan Y, Fenyves EJ, Sujisawa I, Suyama H, Samadi N, Ross GH.1991. Electromagnetic-Field Sensitivity. Journal of Bioelectricity 10, 241-256.

Reiser H, Dimpfel W, Schober F. 1995. The influence of electromagnetic fields on human brain activity. Eur J Med Res 1, 27-32.

Repacholi MH. 1998. Low-level exposure to radiofrequency electromagnetic fields: Health effects and research needs. Bioelectromagnetics 19, 1-19.

Robinette, CD, C Silverman, S Jablon. 1980. Effects upon health of occupational exposure to microwave radiation (Radar). Am. J. Epidemiol., Vol. 112, No. 1, pp. 39-53.

Röösli M, Baldinini Y, Egger M, Braun-Fahrländer, C. 2003a. Sleeping disorders and mobile phone base stations: A pilot study. Thuroczy G. 81-71. 15-5-2003a. Budapest, European Bioelectromagnetics Association (EBEA). 6th International Congress.

Röösli M, Baldinini Y, Egger M, Braun-Fahrländer C. 2003b. Sleeping disorders associated with mobile phone base stations: A pilot study. 15-5-2003b. COST 281 MCM and Workshop in Dublin, May 15th and 16th, 2003: Mobile Phone Base Stations and Health.

Röösli M, Moser M, Baldinini Y, Meier M, Braun-Fahrländer C. 2004. Symptoms of ill health ascribed to electromagnetic field exposure - a questionnaire survey. International Journal of Hygiene and Environmental Health 207, 141-150.

Röösli M, Rapp R. Braun-Fahrländer C. 2003c. Radio and microwave frequency radiation and health - an analysis of the literature. Gesundheitswesen 65, 378-392.

Röösli M, Wanner M, Braun-Fahrländer C. 2002a. Comparison of measurements and calculations of electromagnetic radiation from GSM mobile phone base stations. Epidemiology 13, S196.

Röschke J, Mann K. 1997. No short-term effects of digital mobile radio telephone on the awake human electroencephalogram. Bioelectromagnetics 18, 172-176.

Rothman KJ. 1986. Modern Epidemiology. Little, Brown and Company, Boston, MA.

Rothman KJ. 2000. Epidemiological evidence on health risks of cellular telephones. Lancet 356, 1837-1840.

Rothman KJ, Greenland S. 1998. Modern Epidemiology, Second Edition Ed. Little, Brown and Company, Boston, MA.

Rothman KJ, Loughlin JE, Funch DP, Dreyer NA. 1996. Overall mortality of cellular telephone customers. Epidemiology 7, 303-305.

Rousseau PR, Burkholder RJ. 1995. A hybrid approach for calculating the scattering from obstacles within large, open cavities. Antennas and Propagation, IEEE Transactions on , Volume: 43 , Issue: 10, Oct. 1995, Pages:1068 – 1075.

Salvatore JR. 1993. Radar guns. J Natl Cancer Inst 85, 67-8.

Sandstrom M, Wilen J, Oftedal G, Mild KH. 2001. Mobile phone use and subjective symptoms. Comparison of symptoms experienced by users of analogue and digital mobile phones. Occupational Medicine-Oxford 51, 25-35.

Santini R, Le Ruz P, Danze JM, Santini P, Seigne M. 2002. Preliminary study on symptoms experienced by people living in vicinity of cellular phone base stations. Bioelectromagnetics 24th Meeting Abstract Book. June. Québec Canada.

Santini R, Santini P, Danze JM, Le Ruz P, Seigne M. 2002. Symptoms experienced by people in vicinity of base station : I/ Incidences of distances and sex. Pathol. Biol.

Santini R, Santini P, Santini P, Danze JM, Le Ruz P, Seigne M. 2003a. Survey study of people living in the vicinity of cellular phone base stations. Electromagnetic Biology and Medicine 22, 41-49.

Santini R, Santini P, Santini P, Danze JM, Le Ruz P, Seigne M. 2003b. Symptoms experienced by people in vicinity of base stations: II/ Incidences of age, duration of exposure, location of subjects in relation to the antennas and other electromagnetic factors. Pathol Biol 51, 412-415.

Santini R, Santini P, Seigne M, Danze JM. 2001a. Symptomes exprimés par des riverains de station relais de téléphonie mobile. La Presse Medicale 30, 1594.

Santini R, Santini P, Danze JM, Le Ruz P, Seigne M. 2002. Investigation on the health of people living near mobile telephone relay stations: I/Incidence according to distance and sex. Pathol Biol (Paris) 50, 369-373.

Santini R, Seigne M, Bonhomme-Faivre L. 2000. Danger of cellular telephones and their relay stations. Pathol Biol (Paris) 48, 525-528.

Santini R, Seigne M, Bonhomme-Faivre L, Bouffet S, Defrasne E, Sage M. 2001b. Symptoms experienced by users of digital cellular phones. Pathologie Biologie 49, 222-226.

Schilling CJ. 1997. Effects of acute exposure to ultrahigh radiofrequency radiation on three antenna engineers. Occup Environ Med; 54 :281 -284.

Schüz J, Mann S. 2000. A discussion of potential exposure metrics for use in epidemiological studies on human exposure to radio waves from mobile phone base stations. Journal of Exposure Analysis and Environmental Epidemiology 10, 600-605.

Selvin S, Schulman J, Merrill DW. 1992. Distance and risk measures for the analysis of spatial data: a study of childhood cancers. Soc Sci Med 34, 769-77.

Sheppard L, Prentice RL, Rossing MA. 1996. Design considerations for estimation of exposure effects on disease risk, using aggregate data studies. Stat Med 15, 1849-1858.

Silny J. 1999. Electrical hypersensitivity in humans - Fact or fiction? Zentralblatt für Hygiene und Umweltmedizin 202, 219-233.

Silvester PP, Ferrari RF. 1996. Finite Elements for Electrical Engineers. Cambridge University Press, Cambridge UK.

Stang A, Anastassiou G, Ahrens W, Bromen K, Bornfeld N, Jockel KH. 2001. The possible role of radiofrequency radiation in the development of uveal melanoma. Epidemiology 12, 7-12.

Stenberg B, Eriksson N, Mild KH, Hoog J, Sandstrom M, Sundell J, Wall S. 1995. Facial skin symptoms in visual display terminal (VDT) workers. A case-referent study of personal, psychosocial, building- and VDT-related risk indicators. Int J Epidemiol 24, 796-803.

Szmigielski S. 1996. Cancer morbidity in subjects occupationally exposed to high frequency (radiofrequency and microwave) electromagnetic radiation. Science of the Total Environment 180, 9-17.

Taflove A. 1995. Computational Electrodynamics: The Finite-Difference Time-Domain Method. Boston MA, Artech House.

Tahvanainen K, Nino J, Halonen P, Kuusela T, Laitinen T, Lansimies E, Hartikainen J, Hietanen M, Lindholm H. 2004. Cellular phone use does not acutely affect blood pressure or heart rate of humans. Bioelectromagnetics 25, 73-83.

Taskinen H, Kyyronen P, Hemminki K. 1990. Effects of ultrasound, shortwaves, and physical exertion on pregnancy outcome in physiotherapists. J Epidemiol Community Health 44, 196-201.

Thomas TL, Stolley PD, Stemhagen A, Fontham ETH, Bleecker ML, Stewart PA, Hoover RN. 1987. Brain tumor mortality risk among men with electrical and electronics jobs: A case-control study. J. Nat. Cancer Inst., Vol. 79, No. 2, pp. 233-238.

Tjhung TT, Chai CC. 1999. Fade statistics in Nakagami-lognormal channels. Communications, IEEE Transactions on , Volume: 47 , Issue: 12 , Dec. 1999 Pages:1769 – 1772.

Tuschl H, Neubauer G, Garn H, Duftschmid K, Winker N, Brusl H. 1999. Occupational exposure to high frequency electromagnetic fields and its effect on human immune parameters. Int J Occup Med Environ Health 12, 239-251.

Tworoger SS, Davis S, Emerson SS, Mirick DK, Lentz MJ, McTiernan A. 2004. Effect of a nighttime magnetic field exposure on sleep patterns in young women. Am J Epidemiol 160, 224-229.

Tynes M, Hannevik A, Andersen A, Vistnes, Haldorsen T. 1996. Incidence of breast cancer in Norwegian female radio and telegraph operators. Cancer Causes Control, Vol. 7, No. 6, pp. 197-204.

Uddmar T, Hamnerius Y. RF Exposure from Wireless Communication, Master Thesis in Electrical Engineering, Chalmers University of Technology, Department of Electromagnetics, Göteborg , 1999.

Uni Bremen 2001: Gutachten zur EMVU-Belastung durch das WLAN; Universität Bremen, Arbeitsgruppe WLAN-Infrastruktur, Postfach 33 04 40, 28334 Bremen; www.dmn.tzi.org/wlan/wlan-emvu-gutachten-bremen.pdf

Urban P, Lukas E, Roth Z. 1998. Does acute exposure to the electromagnetic field emitted by a mobile phone influence visual evoked potentials? A pilot study. Cent Eur J Public Health 6, 288-290.

Vangelova K, Israel M, Mihaylov S. 2002. The effect of low level radiofrequency electromagnetic radiation on the excretion rates of stress hormones in operators during 24-hour shifts. Cent Eur J Public Health 10, 24-28.

Vatalaro F. 1995. Generalised Rice-lognormal channel model for wireless communications. Electronics Letters , Volume: 31 , Issue: 22 , 26 Oct. 1995 Pages:1899 – 1900.

Volkers N. 1992. Speed kills--but what about radar guns? J Natl Cancer Inst 84, 1310-1.

Wagner P, Röschke J, Mann K, Fell J, Hiller W, Frank C, Grozinger M. 2000. Human sleep EEG under the influence of pulsed radio frequency electromagnetic fields. Results from polysomnographies using submaximal high power flux densities. Neuropsychobiology 42, 207-212.

Wagner P, Röschke J, Mann K, Hiller W, Frank C. 1998. Human sleep under the influence of pulsed radiofrequency electromagnetic fields: A polysomnographic study using standardized conditions. Bioelectromagnetics 19, 199-202.

Wanner M. 2001. Hochfrequenzstrahlung und Mobilfunkbasisstationen. Thesis. Basel.

Warman GR, Tripp HM, Warman VL, Arendt J. 2003. Circadian neuroendocrine physiology and electromagnetic field studies: precautions and complexities. Radiat Prot Dosimetry 106, 369-373.

Warren HG, Prevatt AA, Daly KA, Antonelli PJ. 2003. Cellular telephone use and risk of intratemporal facial nerve tumor. Laryngoscope. 2003 Apr;113(4):663-7.

Wilen J, Hornsten R, Sandstrom M, Bjerle P, Wiklund U, Stensson O, Lyskov E, Mild KH. 2004. Electromagnetic field exposure and health among RF plastic sealer operators. Bioelectromagnetics 25, 5-15.

Wölfle G, Bevot C, Hahn M, Landsdorfer FM. 1998a. Berechnung der Empfangsfeldstärke in Gebäuden mit empirischen, neuronalen und strahlenoptischen Prognosemodellen. ITG Workshop Wellenausbreitung bei Funksystemen und Mikrowellensystemen. DLR Wessling Mai 1998, S. 109-115, http://www.ihf.uni-stuttgart.de .

Wuschek M. 2001. Bericht über die Messung hochfrequenter elektromagnetischer Felder im Fürstentum Liechtenstein. Erstellt im Auftrag des Amtes für Kommunikation, Vaduz von der Ingenieurgemeinschaft für Geowissenschaften und Umwelttechnik, Regensburg, March, 2001.

Yee KS. 1966. Numerical Solution of Initial Boundary Value Problems Involving Maxwell' s Equations in Isotropic Media. IEEE Trans. Ant. & Prop., Vol. 14, 1966.

Young WB, Silberstein SD. 1992. Transcranial Doppler: technique and application to headache. Headache*. 32(3):136-42.*

Zwamborn APM, Vossen SHJA, van Leersum BJAM, Ouwens MA, Mäkel WN. 2003. Effects of global communication system radio-frequency fields on well being and cognitive functions of human subjects with and without subjective complaints. FEL-03-C148. Niederlande, TNO Physics and Electronics Laboratory.