MEASUREMENT METHODS AND LEGAL REQUIREMENTS FOR EXPOSURE ASSESSMENT NEXT TO GSM BASE STATIONS

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Abstract: The physical aspects of the electromagnetic field distribution in the complex environment next to GSM base stations and the necessary requirements on exposure assessment protocols are analysed in this paper. Homogeneity, impact of the environment and averaging procedures are analysed, the legal situation in the European Union and in the United States and existing exposure assessment protocols are discussed.

1. Introduction

The introduction of the digital GSM 900 / DCS 1800 systems in the 1990s led to a significant deployment of mobile phones. Today about 15 % of the population of the world are using mobile telephones, the penetration rate in Europe and the United States being much higher, e.g. about 80 % of the Austrian population are using mobile phones. This increased use of mobile phones triggered an important deployment of base stations. The number of base stations in a country depends on several factors as the number of network providers, the number of users and the topography. In Austria more than 14,000 GSM base stations are operated by four network providers, in Switzerland about 8,000 GSM base stations are operated by 3 providers. Such base stations are often situated close to dwellings or houses and have become the reason for concerns of parts of the population in recent years. Judgement of exposure of the population in the vicinity of mobile communication base stations is needed due to the requirements given in international and national directives, laws, regulations, decrees and other documents. Methods describing how to assess exposure levels are given in some guidelines and standards. On European level CENELEC and ETSI are currently developing adequate procedures. However, the methods described in the existing documents are not harmonised, they are partially based on different methodological principles. There is urgent need to make additional scientific investigations on physical properties of field distributions to give good scientific background for optimised assessment protocols. In this light the discussion on adequate ways to regulate exposure of the population living in the environment of such stations became increasingly intensive in the last years. The Salzburg model is a precautionary approach including assessment values for mobile communication base stations being several orders of magnitude below the limits recommended by the European Union and the World Health Organisation [1,2,3]. It became of interest in particular in Austria and Switzerland, e.g. the Salzburg model was referred to by various Swiss environmental organisations and authorities. In 2001 it was decided by Swiss authorities (OFCOM) to evaluate exposure in the city of Salzburg according to the requirements given in the ONIR regulation [4] to find out if the Salzburg assessment value could be complied with (see [5,6]). A detailed description of the applied methodology is given in [7]. Next to 8 of the 13 base stations examined the sum of the exposure values arising from the respective station exceeded the assessment value of 1 mW/m². The results also showed that there is no GSM net operated in the city of Salzburg that complies with the Salzburg model. The outcome of this measurement campaign was largely discussed in the last months and results were often compared with the outcome of other exposure campaigns performed in Austria and other countries in Europe that followed other assessment protocols. This led to several misunderstandings due to inadequate comparisons of results of different measurement campaigns.

2. Legal background

This chapter gives an overview on legal requirements and measurement recommendations for exposure assessment next to GSM base stations. It concentrates mainly on the European Union and the United States.

2.1 European Union

In the European Union the Council Recommendation 1999/519/EC [1] on the limitation of exposure of the general public to electromagnetic fields is the basic document which offers the European Union members a framework for exposure assessment. The member states are recommended to introduce a system of basic restrictions and reference levels. The ICNIRP guidelines of the year 1998 [2] which were developed in co-operation with the World Health Organisation (WHO) are the basis for this Council Recommendation.

For radio frequency (RF) safety compliance of products the R&TTE-Directive 1999/5/EC of the European Parliament and of the Council [8] is in use. It was published in the Official Journal of the European Communities in April 1999. R&TTE stands for radio equipment and telecommunications terminal equipment. The purpose of this directive is to establish a regulatory framework for the placing on the market, free movement and putting into service of radio equipment and telecommunications terminal equipment in the European Union. Health protection and the safety of the user and any other person is one of the essential requirements of the R&TTE-Directive. Products covered by the R&TTE-Directive can only be placed on the European market and put into service if they comply with the appropriate essential requirements. Member states shall ensure that the manufacturer or the person responsible for placing the product on the European market provides information for the user on the intended use, together with the declaration of conformity to the essential requirements. Products complying with all relevant essential requirements shall bear the CE mark. The European Commission mandated CEN, CENELEC and ETSI [9] to prepare and adopt harmonised standards covering the aspects of emission of electromagnetic fields (EMF) from 0 Hz to 300 GHz generated by equipment covered in the scope of either the Low Voltage Directive (LVD) 73/23/EEC [10] or the R&TTE Directive 1999/5/EC [8]. The standards are intended to become harmonised standards giving a presumption of conformity. These harmonised standards should describe test methods, test equipment and calculation methods needed in order to specify product requirements limiting the exposure to electromagnetic fields. It is stated in the mandate that the reference levels and basic restrictions of the European Council Recommendation 1999/519/EC [1] should be used. The compliance of a product with the emission limits given in the harmonised standards asked for in this mandate, will ensure that the measured EMF exposure of the human body originating from this apparatus will not under normal use exceed the limits given in the Council Recommendation 1999/519/EC. Up to now standards for mobile phones and electronic article surveillance devices have been harmonised for the R&TTE-Directive. For other products such as radio base stations CENELEC is in the process of developing adequate procedures. The Technical Committee TC 106x (former TC211) finalised the basic standard EN 50383 [11] and the product standards EN 50384 [12] and EN 50385 [13] related to radio base stations and fixed terminal stations for wireless telecommunication systems. These standards are defining compliance distances and volumes around base station antennas. For putting base station products into service in their operational environment, CENELEC TC 106x is currently working on a separate standard. In this standard the cumulative exposure from other sources has to be taken into account, too. Further information about the standardisation activities regarding base stations can be found in [14].

2.2 United States

In the United States the FCC (Federal Communications Commission) authorises and licenses devices, transmitters and facilities that generate RF and microwave radiation. It has jurisdiction over all transmitting services in the US except those specifically operated by the Federal Government. Under the National Environmental Policy Act (NEPA), the FCC has certain responsibilities to consider whether its actions will "significantly affect the quality of the human environment." Therefore, the FCC adopted guidelines developed by expert non-governmental organisations such as ANSI/IEEE and NCRP for the purpose of evaluating exposure due to RF transmitters licensed and authorised by the FCC. The FCC limits for maximum permissible exposure (MPE) are specified in terms of electric and magnetic field strength and power density for transmitters operating at frequencies between 300 kHz and 100 GHz. Limits are also specified for whole-body and partial-body absorption. The limits for localised (partial-body) exposure are used primarily for evaluating exposure due to transmitting devices such as hand-held portable telephones.

The FCC RF rules are published in volume 47 of the Code of Federal Regulations, Sections 1.1307(b), 1.1310, 2.1091 and 2.1093 [15]. Further information on evaluating compliance with these limits can be found in the FCC´s OET Bulletin 65 [16].

2.3 Measurement recommendations

Over the past years organisations in Europe, in the United States and in Canada issued many useful documents in order to provide guidance for evaluating compliance with legal requirements. Table 1 gives an overview.

The European Committee for Electrotechnical Standardisation (CENELEC) and the European Telecommunications Standards Institute (ETSI) are currently working on documents describing measurement methods for exposure assessment next to base stations and fixed radio transmitter sites. EN 50383 has been finalized and the ETSI TR 101 870 is available as draft version. The Standard EN 61566 about measurement of exposure to RF electromagnetic fields in the frequency range 100 kHz to 1 GHz already has existed since 1997.

In Germany the Electrotechnical Commission of DIN and VDE issued a standard about safety in electrical, magnetic and electromagnetic fields which contains methods for measurement and calculation. The French Frequency Agency issued a protocol for in situ measurements in 2001 aiming to provide methods to verify if exposure levels next to fixed electromagnetic transmitters operating in the frequency range from 9 kHz to 300 GHz comply with the limits given in the EU recommendation. The document includes both methodologies to analyse the examined site and exposure assessment. In summer 2002 the Swiss Agencies BUWAL (Swiss Agency for Environment, Forests and Landscape) and METAS (Swiss Federal Office of Metrology and Accreditation) published guidelines on the exposure assessment next to GSM base stations. Requirements on measurement personnel and equipment are given to make reliable estimations of exposure of future installations. Legal requirements relating to the protection from non-ionising radiation of people in Switzerland are discussed in [5,7].

In the United States documents containing practical guidelines and information for performing field measurements in broadcast and other environments are the OET Bulletin 65, the NCRP Report No. 119 and the ANSI/IEEE standards C95.1-1999 and C95.3-1992. The OET Bulletin 65 updates information and provides additional guidance for evaluating compliance with the new FCC policies, guidelines and measurement methods.

Table 1: Documents recommending measurement methods.

Document	Type	Organisation	Purpose
EN 61566:1997 [17]	Standard	CENELEC, Europe	Measurement of exposure to RF EM-fields
EN 50383:2002 [11]	Standard	CENELEC, Europe	Calculation and measuremen of EM-fields
Draft ETSI TR 101 870:2001 [18]	Guideline	ETSI, Europe	Methods for fixed radio transmitter sites characterization
DIN VDE 0848-1: 2000 [19]	Standard	DIN, VDE, Germany	Methods for measurement and calculation
ANFR/DR-15:2001 [20]	Guideline	ANFR, France	Measurement protocol for fixed radio transmitters
Measurement Recommendation: 2002 [21	Guideline	BUWAL, METAS, Switzerland	Measurement methods for GSM base stations
IEEE Std C95.1-1999 [22]	Standard	IEEE, USA	MPE limits and measuremen procedures
IEEE Std C95.3-1991 [23]	Standard	IEEE, USA	Measurement procedures and instrumentation
OET Bulletin 56: 1997 [24]	Guideline	FCC, USA	Measurement and prediction methods
NCRP Report No.119:1993 [25]	Guideline	NCRP, USA	Measurement methods
Safety Code 6:1999 [26]	Guideline	Health Canada, Canada	MPE limits and measuremen methods

3. Considerations on measurements

This chapter describes the basics of GSM signals and the requirements on measurement equipment and calibration. The variations of the electromagnetic field in time and space and the impact of these variations are discussed.
GSM uses RF-modulated, pulsed signals for communication. A Time Division Multiplex Access (TDMA) system is implemented and Gaussian Minimum Shift Keying (GMSK) modulation, a kind of phase modulation, is used for coding the digital base band information for RF transmission. The principles of TDMA, frame structure down to time slots containing the information bits, the parallel channels for downlink (base station to mobile) and uplink (mobile to base station) and additional functions of GSM systems e.g. Power Control or Frequency Hopping, are well described in the literature [27,28].
In the time domain each channel can be seen as a switched RF signal with constant amplitude for the time slots of the Broadcast Control Channel (BCCH) and varying amplitudes of the Traffic Channels (TCH) time slots (Figure 1). The bandwidth of each channel is 200 kHz. For GSM 900 124 channels for uplink (890 – 915 MHz) and for downlink (935 – 960 MHz) are typically implemented.

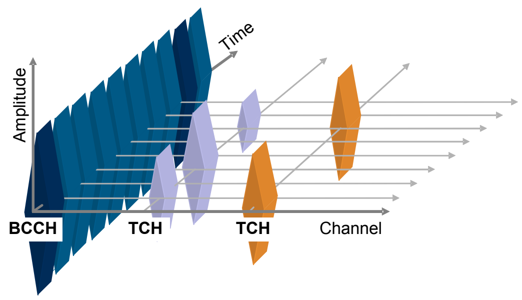


Fig. 1: Typical GSM downlink signal of three channels in the time domain

3.1 Measurement methods

Several methodologies to assess exposure are described in the literature. In the frame of this paper only methods for frequency selective exposure assessment will be discussed, procedures applying broadband meters are not covered.
One approach to assess exposure are scanning procedures. In principle, the engineer has to move a hand-held antenna slowly within the area of interest, e.g. a room, while the field levels are recorded on a spectrum analyser or a measurement receiver. Two variations of such procedures are described in detail in [21], in both cases it is essential to use the so-called max hold mode of the measuring device.
Another method is based on examinations of several points in areas of interest. Basically, an adequate antenna is mounted on a tripod and field levels can be assessed using isotropic systems or by making measurements in three orthogonal directions to obtain effective field values. A minimum distance between the engineer and other persons and the antenna of about 2 meters has to be kept to avoid field distortions due to their bodies. The antenna is connected to a spectrum analyser or a measurement receiver via a RF cable. Detailed descriptions of the methodology can be found in the literature, e.g. in [20].
The first method has the advantage not to be very time consuming and to give a good overview of the exposure scenario in the examined area. However, strong influence of the engineer's body on the results cannot be excluded and the summation of all maxima found in the whole examined area is problematic. The second approach guarantees reproducible results under controlled conditions, but only a limited number of positions can be examined in a reasonable period of time.
The measurement methodology described in [6,7] combines the advantages of both approaches.

3.2 Requirements on the measurement equipment

Necessary equipment for performing frequency selective measurements is a measurement receiver or a spectrum analyser, an antenna, a RF-cable and an evaluation software to allow efficient data management.
Important requirements on the analyser are high frequency accuracy to make the correlation of channels to measured peaks possible especially for wide frequency sweeps. For accurate measurements also the resolution bandwidth (RBW) has to be adjustable corresponding to the signal bandwidth (e.g. 200 kHz for GSM, optional 5 MHz for UMTS) respectively to the value recommended in standards or guidelines. The overall amplitude accuracy, the linearity of the RF components in the signal path and the Voltage Standing Wave Ratio (VSWR) of the input should be good because these characteristics are essential for uncertainty calculation. A low noise level allows high dynamic range and sensitive measurements. True RMS (Root Mean Square) detection is a basic requirement for correct results (but not always fulfilled) and max hold function is necessary for executing the measurements. Congenial features are fast frequency sweep time and a light portable instrument. This is very helpful to perform measurements at different locations. If mixer or preamplifier overload is caused by strong signals outside the measurement bandwidth is possible (e.g. in the frame of overview measurements), the use of a preselector or additional attenuator is necessary. Of course, an attenuator reduces also the GSM signal, therefore the impact on the sensitivity has to be taken into account.
For the antenna, a precise individual calibration including antenna factor (AF), antenna symmetry and VSWR (Voltage Standing Wave Ratio) over frequency is the most essential requirement. Especially with measurements in habitations coupling effects between the antenna, the environment and in some cases the measurement engineer have to be expected. They are caused by small distances between antenna and objects and lead to additional errors of the antenna e.g. in AF and VSWR. This part is unaccounted at calibration, but it can be considerably reduced by using antennas with fixed balun impedance. Good symmetry and VSWR is advantageous because they have direct effect on the uncertainty.
The cable should be flexible and robust for frequent use. Especially the cable loss has to be checked periodically, because this parameter is often changed by unintended stress of the cable.
Regular recalibration of the measurement equipment is highly recommended. One year is a typical calibration interval.

3.3 Field variations in time

According to the traffic density and transmission path a continuos variation of the number of used traffic channels and their amplitude can be observed according to the traffic density whereas the BCCH carrier is permanently switched on with constant power. This signal is commonly used for extrapolating the worst case exposure at the transmitting site. However, also the BCCH-carrier immissions are not time independent. Considerable variations are caused by the transmission path, multipath propagation, changes of the radiated power from the base station and uncertainties of the monitoring system. Deviations up to ± 3 dB were documented [29]. At

Seibersdorf 1,029 measurements of a BCCH carrier during a 6-day period in a room were made where no objects apart from the antenna were moved. Figure 2 shows that the field strength variation from the average value lays within +4.85 dB and –5.65 dB .

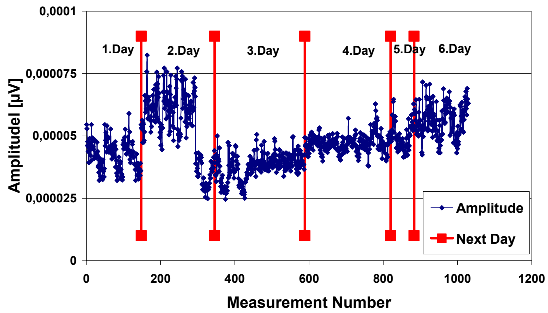
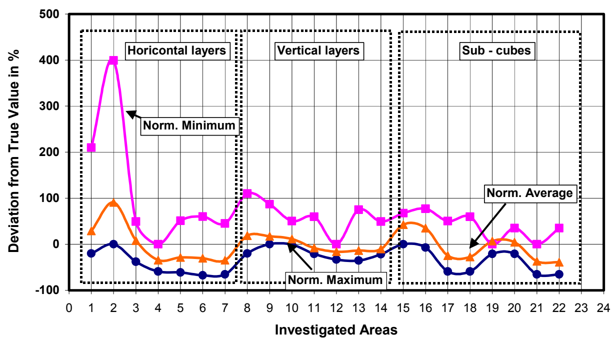


Fig. 2: Field strength variations of a BCCH carrier versus time

3.4 Field variations in space

Exposure assessment in the environment of base stations requires adequate measurement procedures. One approach is to search for the maximum of the exposure level in selected areas. If such a procedure is selected, it has to be taken into account that the variation of the field levels can be significant, e.g. measurements performed in Austria demonstrated that the variation of the field levels arising from a GSM 900 BCCH within a volume of about 1 m³ were within – 77 to 206 % from the average of about 340 values measured within this volume. This indicates that protocols based on maximum searches have to be further discussed [30,31].
Several guidelines and standards based on established, health-relevant effects, clearly indicate that measured field strengths should be averaged over an area or a volume corresponding to the dimensions of the human body before comparing the levels to the limits of such documents [2, 22]. In [22] additional peak limits for field strengths or power densities are given to avoid exposure above the local SAR limits. Some measurement guidelines [20,26] also describe methods how to average field strengths over volumes or areas similar to the human body, however, the rationale behind these averaging methods remains to be discussed.
A very important basic restriction given in such documents is the SAR that limits both whole body and local body exposure. However, the SAR is not easy to be determined, therefore so-called reference levels were established. If the reference levels given in terms of electric and magnetic field strengths and power densities are not exceeded the basic restrictions will not be exceeded in any case. Exposure above the reference levels does not have to imply that the basic restrictions are exceeded, however, additional investigations are necessary to show compliance with the basic restrictions. The relation between field strength and SAR are based on calculations and measurements performed under far field conditions. Additional investigations are needed to examine the correlation between field strength distributions and SAR distributions in areas with highly heterogeneous field distributions that can be found in the vicinity of base stations.
To investigate the impact of the amount of field values needed on averaging processes, the field values obtained within a cube in the frame of measurements at the ARCS already mentioned above where analysed in more detail. The maximum, minimum and the average field level of the cube of about 1 m³ were considered as "true values" (reference values). Several subareas of the cube were investigated to analyse the behaviour of the respective maximum, minimum and averaged field strengths of the subareas compared to the reference values representing the total investigated area. The subareas consisted of 7 horizontal layers of the whole cube and 7 vertical layers, each consisting of 49 measurement positions and 8 subcubes of the investigated area, each consisting of 64 measurement positions. The deviations from the maximum, minimum and average field value of the whole investigated cube compared to each subarea are given in diagram 1. The smallest local maximum was 68 % below the reference or true value, the highest local minimum was almost 400 % higher compared to the reference minimum. The highest local average was 91 % above and the lowest average value was 39 % below the reference value. 70 % of all examined local maxima were within –38 % of the reference maximum, the same number of local minima were not more than 60 % above the reference minimum. The deviations of 70 % of the local averages lay between +/- 29 % of the "true" average value from the whole investigated area.
These preliminary results show that the selected subareas may lead to underestimation of the existing field maximum of about 70 %, the averaged fields might be overestimated. However, in most cases variations of the local average were within about +/-30 % of the reference value, indicating that averaging over well selected subareas might lead to representative results.

Diagram 1: Deviations of normalised maximum, minimum and average of field values of local areas compared to the respective values of a larger reference area.



4. Measurement uncertainty and repeatability

4.1 Uncertainty of equipment

To obtain overall uncertainty several types of uncertainty have to be considered. The first type of the uncertainty consists of the contributions of the analyser, antenna, cable and additional attenuators. It is determined in standards [32,33,34] how to assess these parts. Documents containing calculation examples can be found in table 1.
It is often possible to reduce uncertainty by using calibrated attenuators of typical 6 dB between cable and antenna. This reduces mismatch, especially if the VSWR of the antenna is not that good. Another possibility is to reduce the frequency sweep range of the analyser as far as possible e.g. use only downlink frequency range. This narrows the frequency error. For the calculation itself all necessary information of the antenna, the cable and the attenuators should be a part of the calibration certificate. For the analyser the information is usually given in the technical description. Unfortunately this is not always part of the user's manuals.

4.2 Repeatability

Calculation of repeatability has to take into account reproducibility of the assembly (e.g. connectors), the operation of measurement equipment and the measurement procedure itself. Reproducibility can be checked by a careful test measurement of a well-known reference source. Values for overall uncertainty calculation can be obtained by statistics. The measurement procedure should be clearly defined, repeatable and on a well-founded scientific basis. An uncertainty calculation of the procedure e.g. by help of statistical methods and simulations is necessary. In principle, also the repeatability is a calculable part of the uncertainty if the procedure is well-selected and considerable effort is invested.

4.3 Environmental influence

The significant heterogeneity of the electromagnetic field distribution in the vicinity of base stations is caused by the influence of the environment leading to multipath propagation causing fading effects due to multiple reflections of the signals on different objects, e.g. buildings, ground or trees. Some objects are changing their position versus time leading to hardly predictable field distributions. Such moving scatterers can be persons, cars but also windows or doors to give some examples. Apart from the impact of such objects the influence of seasonal variations and the weather should also be considered. Field propagation can vary due to snow, rain and other ambient conditions, e.g. wet versus dry ground, snow, humidity. Pettersen et al 2001 [35] investigated the effects of different surfaces on field propagation at 1,625 MHz. They showed that water on grass increased reflection coefficients by 50 %, whereas water on asphalt had almost no impact on reflections. The different types of surfaces lead to various distributions of the signals in coherent and diffuse components, e.g. while investigating reflections on asphalt it was shown that the coherent component exceeded the diffuse component by 18 dB, in contrast the diffuse component exceeded the coherent component by 5 dB for ploughed fields [35].
Especially the fact that the measuring engineer has no possibility to control environmental influences, is the most difficult part of error calculation. In this area much additional research is needed to yield reliable estimations.

5. Discussion and conclusions

The success of mobile communication has led and will lead to an impressive deployment of base stations all over the world. However, the fact that possible hypothetical health effects arising from electromagnetic fields emitted by such installations are also discussed by parts of the population triggered the development of legal requirements in respect of exposure evaluation both on national and international levels. Exposure control needs adequate methodologies that are in the process of development at the international standardisation level, e.g. CENELEC is already preparing adequate standards that fulfil the requirements of the directives and recommendations set by the European Community. On national level, some countries already finalised documents including exposure assessment procedures, e.g. Switzerland and France. The most common methods are scanning procedures and procedures that are based on measurements of electromagnetic fields in three orthogonal directions.
Maximum search of field levels using scanning methods as recommended by [21] can lead to both under- and over- estimation of existing field levels. A maximum search using max hold function combined with scanning methodologies for measurements of more than one GSM channel leads to the summation of the maxima of all investigated channels that are distributed over the whole investigated area, e.g. a room. Summation of all these maxima can lead to unrealistic overestimation of their exposure. Apart from this, maxima might be more complicated to be reproduced compared to averaged values.
While scanning in areas of interest it has to be taken into account that the body of the engineer may influence the field distribution in a considerable way. Such effects can lead to both under– and over-estimation of real exposure. However, scanning methods seem to be well-suited to find the location for final measurements. The located place of a maximum might be used to indicate the area, where averaging processes can be performed to assure that such measurements are done where highest exposure levels can be expected. Taking into account that scanning methods are simple and very time efficient compared to averaging methods, determining if a link between these methods exists, and if so, quantifying it, remains to be investigated.
Overall, several scientific questions on physical aspects of electromagnetic field distributions in time and space remain to be solved, e.g. the impact of environmental factors or homogeneity. The outcome of ongoing and future investigations should be implemented in existing and future assessment methodologies developed by the responsible institutions, e.g. standardisation bodies.

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