EMF MEASUREMENT TASKS AND FREQUENCY SELECTIVE EVALUATION METHODS FOR RF-COMMUNICATION FACILITIES

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Abstract. In this paper we point out the most relevant content of the ICNIRP guidelines and derive from these standard EMF measurement tasks such as 'In Situ Measurements', 'Compliance Assessment Measurements' and 'RF-Monitoring'. Different requirements and background for these RF-field strength measurement tasks and their specific needs of technical equipment were discussed. Following that, we evaluate and compare up-to-date RF-measurement methods like field probes measurements or frequency selective methods using antennas. Here we consider point screening methods like the 'Isotropic Spatial Averaging Method' and the currently most popular 'Sweeping Method' for isotropic and frequency selective measurements as well as monitoring methods. Afterwards we focus on frequency selective, isotropic long-term EMF measurements performed with a 'Field Nose' system in the frequency range from 80 MHz up to 2.5 GHz and present effective methods for data reduction of such long-term measurements.

Introduction

Public concern about potential health effects of human exposure to the electromagnetic fields from modern RF-communication facilities augmented in the last years. Especially the number of base stations has grown up considerably within the recent years. Accurate measurements are necessary to determine the human exposure and they are a powerful instrument leading to an objective and factual discussion about that topic. Otherwise the physical characteristics of electromagnetic wave propagation and the wide differences in the today used communication technologies make EMF exposure measurements to a very challenging task.

Measurement Requirements

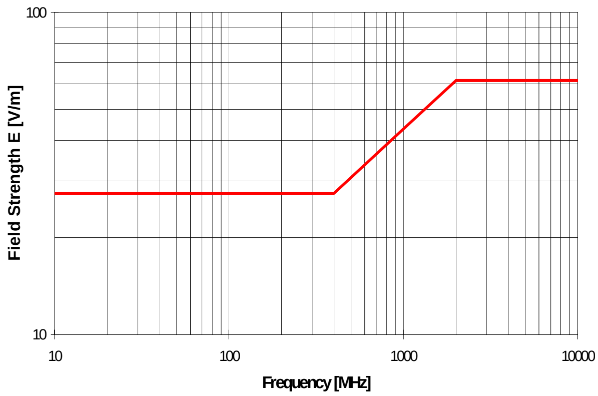
In most countries the limits for the exposure of the general public to electromagnetic fields are based on ICNIRP. In some other countries e.g. Switzerland or Italy more strict limits are valid. Table 1 gives the basic restrictions defined in ICNIRP guidelines [1] to protect the general public and workers from potential adverse health effects of exposure to EMF. The limits shown are SARs (Specific Absorption Rates), given in W/kg averaged over any 6 minutes time interval. The SAR

Table 1. Basic Restrictions of ICNIRP

Body Area	whole body	head, trunk	limbs
Public	0.08 W/kg	2 W/kg	4 W/kg
Workers	0.4 W/kg	10 W/kg	20 W/kg

averaging mass is any 10 grams of contiguous tissue of the human body. From these SAR values limits for the electromagnetic field strength were derived considering the thermoelectrical properties of human body tissue which is frequency dependent. Therefore also the limits have to be frequency dependent as shown in Figure 1, e.g. for the ICNIRP field strength limit for general public. Of course limits can be given either in electrical field strength E in [V/m] or in power flux density S, typically in [mW/m^2]. If measurements were done in the near field distance to an emitter, the power flux has to be calculated by independent measurements of the electric- and magnetic field strength.

Figure 1. ICNIRP limit for general public



In situations of simultaneous exposure to fields of different frequencies respectively channels, these exposures are additive in their effects. For thermal impact caused by RF, Formula (1) has to be considered to add contributions of multiple frequencies respectively the channels of different transmitters. Each channel has to be measured with appropriate bandwidth to yield the

$$\sum_{i>100kHz}^{300GHz} \left(\frac{E_i}{E_{Li}} \right)^2 \leq 1 \qquad (1)$$

E_i ..... electric field strength at channel centre frequency i
E_{Li}… electric field strength limit at frequency i [V/m]

whole power of that channel. To get an absolute value of the power flux, the contributions of all channels have to be added. In the case of the electrical field strength, this sum is corresponding to the equivalent field strength according Formula 2 on next page.

$$E_{equi} = \sqrt{\sum (S_i \cdot 120 \cdot \pi)} \qquad (2)$$

E_{equi} … equivalent electric field strength [V/m]
S_i ……. power flux density for channel i [W/m^2]

Following the requirements of ICNIRP guidelines, a lot of essential features for EMF measurement systems can be derived. Naturally they have to be frequency selective because of frequency dependent limits and to enable the classification of measured field strength to the different transmitters. Also it should be sensitive enough to detect field levels far below the limits to consider all technologies of interest for the user and especially also the public, even if some of them typically produce only negligible contributions to the equivalent field strength. On one hand it should be possible to average the values over any 6 minutes in time and on the other hand averaging in space considering the volume of the human body are required. It is also essential to use procedures allowing measurements with low uncertainty and good repeatability.

EMF Measurement Tasks

EMF measurements could be separated in three typical applications, which are 'In Situ Measurements', 'Compliance Assessment Measurements' and 'RF-Monitoring'.

'**In Situ Measurements**' are dealing with exposure evaluation of in situ locations mainly at sensitive areas like kindergartens or hospitals as well as at locations accessible for the public in close vicinity of transmitters, e.g. base stations. The compliance of the sum of the contributions of all relevant RF-transmitters at the place under investigation has to be checked in reference to national limits, protocols and standards. Often relevant sources, their frequencies, polarisation and direction of maximum signal strength are not known. Therefore an isotropic measurement instrument with root mean square detection and time averaging is the best suitable approach. For spatial averaging the sensor could be placed at corresponding positions. To evaluate the place of investigation broad band measurements can be additionally used.

'**Compliance Assessment Measurements**' are applicable for radio frequency (RF) safety compliance of products according the R&TTE-Directive 99/5/EC [2]. The main 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 this directive. The R&TTE directive has to be implemented by national authorities. Manufacturers and/or providers can demonstrate compliance of their products by applying harmonised standards. For base stations currently the drafts prEN50400 and prEN50401 are in the process of development. For compliance assessment procedures information on technical aspects of the device under test, e.g. frequency band, direction of maximum signal strength, polarisations, signal modulation and the total number of channels are usually known or can be determined. Moreover, in some cases it is possible to get information from the provider about the operating conditions of the considered base station. To perform Compliance Assessment Measurements, similar requirements on the method as described for In Situ Measurements have to be fulfilled. In the case of compliance assessment there is a need to make worst case estimation, e.g. the device under test has to be operated with maximum power during the test or extrapolation to the worst case situation is necessary.

'**RF-Monitoring**' is a topic becoming more and more essential, because the number of technologies using RF frequencies for communication purposes is rapidly increasing. To ensure transmission quality of communication services it is strictly determined, who is allowed to use specific parts of the frequency band and also the transmission power of such systems is limited. This should assure signal quality and coexistence of different services and technologies. Authorities being in charge of the inspection of the adherence to the requirements of the directive would benefit from monitoring systems. Such systems would allow them to monitor continuously the whole frequency range, looking for unexpected or unlicensed signals and transmitters exceeding allowed output power. Another use for such long term monitoring systems is to get information about the variation of the signal power of transmitters. This info could be used e.g. to determine long time exposure of the public within the frame of research studies or to define correction factors for in situ exposure estimation based on single time measurements considering typical exposure variations during a day. Monitoring systems have to be isotropic to detect unauthorised signals from all directions and they need sophisticated software to identify such events in a reliably way. They also should automatically perform detailed measurements over the interesting frequency range if some unexpected signals were found, save them and send an alarm to the responsible authority if this is desired.

EMF Measurement Methods

In this chapter we give a short overview of up-to-date methods for field strengths assessment in the RF- and microwave band and compare them to each other.

Measurements performed with '**RF Field Probes'** are very simple, fast and convenient. In general field probes have good isotropic radiation characteristics and a wide operating frequency range but unfortunate they are not frequency selective. Therefore measured values can not be assigned to specific emitters. Typically they are not sensitive enough to detect the small signals generated by modern communication transmitters. The field probe could be sensitive to 'out of band' signals and the calibration factor is only valid for sinusoidal signals and it is not constant over the whole operating range.

For frequency selective evaluation, the measurement system typically consists of an antenna and a frequency selective receiver or spectrum analyser operated in a sweeping mode over the frequency range of interest. The analyser settings, especially the RBW, the signal detector and the sweep time have to be suited for the technology which should be measured. In practise this is still a challenging task, because of the wide bandwidth and the very high dynamic in the time domain of most new technologies like UMTS, DVB or W-LAN systems. For such systems also individual measurement procedures like the decoding of the pilot for the exposure evaluation of UMTS base stations are recommended and will probable be required in the standards for compliance assessment measurements.

Regarding frequency selective methods, the '**Sweeping Method'** is currently in some countries very popular, because it can be done in short time and therefore it is very cost efficient. In order to determine the maximum field strength in a given volume, the receiving antenna is moved in this volume using a receiver 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 method is not fully corresponding to ICNIRP guidelines because it deals not with an isotropic radiation characteristic, averaging over time is not intended and it can lead to an overestimation as well as an underestimation of signals [3]. Also the repeatability and the uncertainty budget of this method are still debated. On the other hand, measurement results are quite good according to other, more extensive methods.

Due to the fact that no antenna has an isotropic radiation characteristic by itself, one solution consists in the addition of the contributions of three measurements of an antenna with a dipole like radiation pattern. A positioner can be used to realize these three orthogonal antenna orientations. ARC Seibersdorf research developed small RF-antennas with a dipole like radiation pattern and established the so-called 'Add3D Method' [4]. Other manufacturers offer systems dealing with 3 combined antennas and are switching between them. In that case there is the challenge to get an acceptable isotropic radiation pattern of the system because the three antennas interfere to each other. Using isotropic antenna systems in combination with a remote controlled spectrum analyser, fully automated measurements without influence of an engineer to the fields are possible. Repeatable measurements and time averaging methods with well known uncertainty estimation can be performed on one single point. Spatial averaging is possible by changing the antenna position. Therefore this procedure is called '**Isotropic Spatial Averaging Method'**. In principle this enables the user to realise ICNIRP conform RF-field strength measurements, however it is a very time consuming job if a volume representing a human being should be acquired. Therefore research work for harmonised European standardisation work is going to define a few measurement positions, 3 or 6 points are currently in discussion, which are representing adequate results for the whole human body.

For '**Monitoring Methods'** again isotropic systems are necessary to consider all sources around the system in equal measure. The main topic for such systems is long-term evaluation. Therefore spatial averaging is not as essential as to identify the variations of the signals in a very precise and reliable way. Fully automated data evaluation, their reduction, storage and transfer to a common data base are very important requirements for such measurement systems.

If EMF measurement methods are compared, all of them have their strength and weaknesses. It depends strongly on the individual needs of the user and legal requirements, which system and method is the best suited one. In Table 2 a rough comparison of described methods is presented.

Table 2. Comparison of Measurement Methods

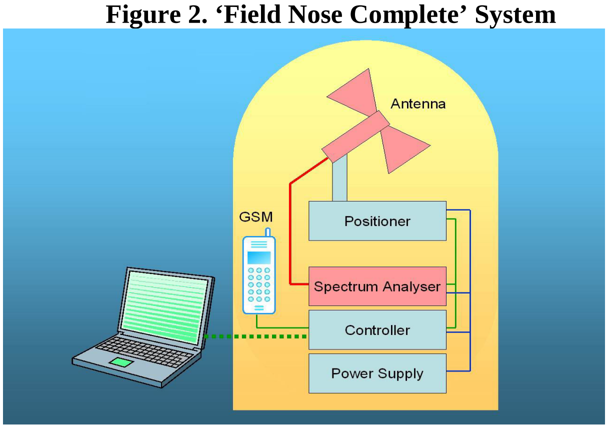
	FP	SM	SA	MM
frequency selective	- -	+ +	+ +	+ +
isotropic behaviour	+ +	-	+ +	+ +
time averaging	+ +	- -	+ +	+ +
spatial averaging	+	+ +	+	- -
high sensitivity	- -	+ +	+ +	+ +
repeatability	+ +	-	+ +	+ +
uncertainty	+	-	+	+
automatically	+ +	- -	+	+ +
simple and fast	+ +	+ +	-	+

FP RF Field Probes
SM Sweeping Methods
SA Isotropic Spatial Averaging Methods
MM Monitoring Methods

Measurement Examples and Data Reduction

Having a look at Table 2, it can be seen that isotropic antenna methods have most advantages for EMF measurement tasks. A block diagram for such a system developed in Seibersdorf with the name 'Field Nose Complete' is shown in Figure 2. It is based on the well known and tested Add3D method for isotropic measurements and works according the 'Monitoring Method'. The main components of the system are the precision conical dipole antenna 'PCD8250', a spectrum analyser, an automatic positioner, a microcontroller (PC) and the software package 'Nose Complete', which was especially developed for advanced EMF measurement applications. Measurement setup and data transfer is realised by a LAN-connection or a GSM-modem to external computers. With that system it is possible to perform advanced measurements like monitoring or continuous work with different measurement tasks. Also a lot of data evaluation procedures like field strength estimation for individual channels or technologies and providers are implemented as well as averaging methods and signal graphs in the time domain.

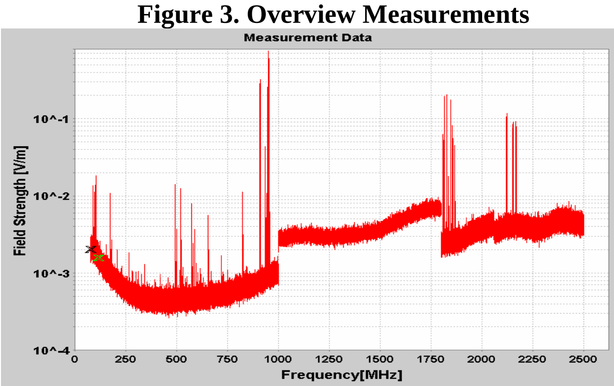
Figure 2. 'Field Nose Complete' System



In the frame of this work we like to introduce the data reduction functionality of the 'Nose' software because especially for long-term EMF measurements and monitoring this is an essential thing to avoid very huge amount of data which have to be transferred and stored.

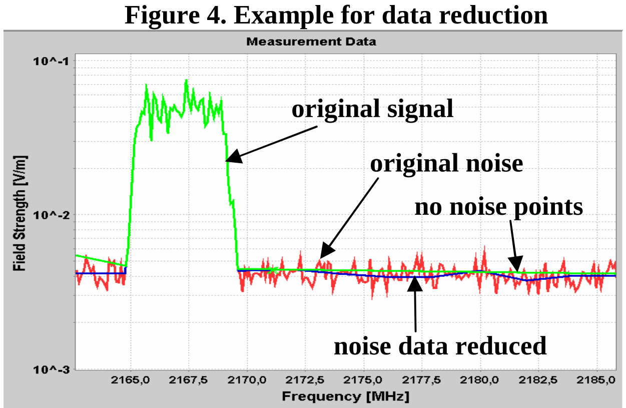
Figure 3 is showing 27 overview measurements from 80 MHz up to 2.5 GHz. They were performed in Ebreichsdorf, a small city 30 km in the south of Vienna, started on the 12th of October 2004. Each hour one of these measurements was automatically performed. In the

Figure 3. Overview Measurements



frequency range from 1 GHz up to 1.8 GHz we did not expect any signals. Therefore we used in this bandwidth a RBW of 1 MHz where at the other frequencies a RBW of 100 kHz was used. Caused by the selected RBW values and the large frequency range, each trace consists of exactly 17.000 measurement points. For the 27 measurements this gives a number of 459.000 measurement points and in a binary format we need about 4.4 MByte to store these 27 traces. Owing to different noise levels caused by RBW settings and frequency dependent antenna and cable factors, in principle a linear noise threshold can not be used. To solve this problem, we developed an intelligent signal detection algorithm, which differs between signals and noise. Using this feature, we can replace the noise points of the original measurement by only a few ones representing the frequency dependent noise floor, or to remove noise points at all. In Figure 4 we zoomed into the UMTS band from Figure 3 for one trace. For this measurement we built the noise data reduced trace and the trace with eliminated noise points. The UMTS signal is not effected in any way by this data reduction process, however the data amount have been reduced by a factor

Figure 4. Example for data reduction



of more than 10 for the noise data reduced traces and about 30 times less for the traces where we eliminated the noise. Although these factors depend on the signal to noise relation over the frequency band, the results can be seen as typical ones. Therefore this approach leads to very effective data reduction which is especially needed for EMF measurements over a wide frequency range and for long term measurements with plenty of repetitions like EMF monitoring.

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