Field Nose, a Frequency Selective and Isotropic System for Long-Term EMF Measurements and Monitoring

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Abstract - Field Nose, a frequency selective and isotropic measurement system designed for short- and long-term EMF measurements as well as for monitoring and scientific studies is presented. The measurement procedure of the Field Nose system is described and an overview to rigorous, frequency selective uncertainty analysis is given. The system is compared to other EMF-measurement devices and procedures like broadband field probes, directive antenna measurement systems and the sweeping method. Furthermore an example of a measurement campaign using Field Nose with 6 antennas is presented.

I. INTRODUCTION

The judgement on possible hazards from human exposure to radio frequency electromagnetic fields is done according to EMF limits derived from scientific investigations of biological effects. To ensure that the limits for the general public are not exceeded, a permanent monitoring functionality of field levels could be useful, especially nearby potential emitters or at critical locations like schools or hospitals. In opposite to classical environmental pollution of water or air, the total exposure due to EMF may become more essential because of new respectively more intensive use of EMF-based communication equipment like GSM, UMTS, DECT, W-LAN or Bluetooth. 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. From a theoretical point of view electromagnetic wave propagation is well understood in electrodynamics study. However caused by wave propagation mechanism like reflection, absorption and interference precise determination of high frequency electromagnetic fields in complex environment is still a difficult task. To verify compliance with frequency dependent limits and observe the progression of RF-emitters with their signals, technically suited and reproducible measurement methods and instruments have to be established.

II. MEASUREMENT REQUIREMENTS

II.1 General Requirements

Table I 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 SAR (Specific Absorption Rate) given in W/kg averaged over any 6 minutes time interval. The localized SAR averaging mass is any 10 grams of contiguous tissue of the human body. In situations of simultaneous exposure to fields of

Table I – Basic Restrictions

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

different frequencies, these exposures are additive in their effects. For thermal impact caused by RF, formulas (1) and (2) have to be considered to add contributions of multiple frequencies respectively different transmitters. These reference levels for the electric and magnetic field strength were derived from the basic SAR restrictions.

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

E_i …….. electric field strength at frequency i
E_{Li} ……. electric field strength limit at frequency i

$$\sum_{j>100kHz}^{300GHz} \left(\frac{H_j}{H_{Lj}} \right)^2 \leq 1 \qquad (2)$$

H_j …. magnetic field strength at frequency j
H_{Lj} … magnetic field strength limit at frequency j

Following the requirements of ICNIRP guidelines, a lot of essential features for EMF measurement systems can be derived. Of course 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 or the public, even if some of them typically produce only negligible amounts to the summed field strength. On one hand it should be possible to average the values over any 6 minutes in time and on the other hand average in space considering the volume of the human body respectively the interesting areas of it. It is essential to use procedures that allow measurements with low uncertainty and good reproducibility.

II.2 Typical EMF Measurement Tasks

In the following paragraphs three very typical applications of EMF measurements are described in a short way and their specific needs for the measurement system are given.

II.2.1 In Situ Measurements

This kind of measurements deals with exposure evaluation of in situ locations mainly at very 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 used in addition.

II.2.2 Compliance Assessment Measurements

For radio frequency (RF) safety compliance of products the R&TTE-Directive 99/5/EC [2] is in force. 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 this directive. The national implementation of the R&TTE-Directive is assured in harmonised national and European standards [3]. For base stations currently the drafts prEN50400 and prEN50401 are in the process of development. For compliance assessment procedures, differing to in situ measurements, 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 (well) known or can be determined. Moreover, sometimes it is also possible to get information of the providers themselves about the operating condition of the considered base station. While performing compliance assessments next to base stations, the same requirements on the method as described in Chapter II.2.1 have to be fulfilled, except for the isotropic behaviour and the bandwidth if there are no relevant contributions from other sources and secondary field propagation paths can be excluded. In the case of compliance assessment there is need to make worst case estimation, e.g. the d.u.t. has to be operated with maximum power during the test or mathematical extrapolation to worst case operation can be performed.

II.2.3 RF-Monitoring

The number of technologies using RF frequencies for communication purposes is rapidly increasing. Many companies paid a lot of money to get licences for their systems which are operating at exclusive bandwidth or to develop systems working in ISM frequency bandwidth where they have to share available frequency bandwidths with other companies or technologies. To ensure transmission quality of such communication services it is very strictly determined, who is allowed to use any parts of the frequency band. And the transmission power of such systems is limited. Regulations are based on the R&TTE-Directive 99/5/EC. This should assure signal quality and coexistence of different services and technologies starting from radio stations up to TV, GSM, UMTS, Wireless LAN, Bluetooth and many others. 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 (monitoring mode) for unexpected or unlicensed signals or transmitters exceeding allowed power limits. These monitoring systems have to be isotropic to detect unauthorised signals from all directions and they need sophisticated software to identify such events in an automatic way, make detailed measurements over the frequency area of interest, save the data and send an alarm to the responsible authority if this is desired.

III. EMF MEASUREMENT METHODS

In this chapter we give an overview of actually used methods for field strengths assessment in the RF and microwave band and compare them.

III.1 Field Probes

Measurements done with RF field probes are very simple, fast and convenient. They have good isotropic radiation characteristics and a wide operating frequency range. They are not frequency selective but newest types offer possibility to give the total result in per cent of a selected limit even if the limit is frequency dependent. Therefore measured values can not be assigned to specific emitters. Unfortunately they are not sensitive enough to detect the typical 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.

III.2 Directive Antenna Methods

III.2.1 Single Point with Directive Antenna

The measurement system consists of an antenna and a frequency selective receiver or spectrum analyser. Typical directive antennas are log. periodic or horn antennas. The measurements are done in a sweeping mode or at discrete frequencies, with a certain bandwidth of the receiver. In principle a precision measurement is possible, if the interesting frequencies, the range of maximum field strength and the polarisation are known. For in situ measurements this method becomes an extremely time consuming job due to the small beam width of the antenna because of the exact area, direction and polarisation have to be analysed by manual search for each interesting frequency.

III.2.2 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 method is not corresponding to ICNIRP guidelines because it deals not with an isotropic radiation characteristic, averaging over time is not really possible and can lead to an overestimation as well as an underestimation of signals [4]. The reproducibility and the uncertainty budget of this method are still debated.

III.3 Isotropic Antenna Methods

III.3.1 Single Point with Isotropic Characteristic

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 [5]. Details to that method will be given in chapter IV. Other manufacturers offer systems dealing with 3 antennas instead of the rotation of one and are switching between them or combine the signals of three sensors to one signal. In both cases there is the challenge of an acceptable isotropic radiation pattern over the whole frequency range of the system which is typical from 80 MHz to 3 GHz. Using isotropic antenna systems in combination with remote controlled spectrum analyser, fully automated measurements without influence of an engineer are possible. Reproducible time averaging methods with well known uncertainty estimation can be performed on one single point in the interesting area. A field probe or the measurement antenna in a sweeping mode can be used to determine this measurement point.

III.3.2 Spatial Averaging Methods

Spatial Averaging methods are dealing with the Isotropic Antenna method using additional manual or automatic positioning units for spatial averaging. This enables this method to overcome last difficulties to realise ICNIRP conform RF-field strength measurements.

III.4 Monitoring Methods

For Monitoring Methods again isotropic systems are necessary but 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 save (e.g. if the analyser is sending not valid data or some devices have a total error), weather proved, air-conditioned and the systems should be working 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.

III.5 Comparing EMF Measurement Methods

Of course all EMF measurement methods have their strength and weaknesses and it depends strongly on the individual customers needs which system and method is the best suited one for his applications. In Table II a comparison of described methods is given.

IV. FIELD NOSE

Having a look at Table II, it can be seen that isotropic antenna methods have clear advantages in EMF measurement tasks. The system we used for our long-term measurements is cold "Field Nose Basic" and therefore this system will be described closer within this chapter.

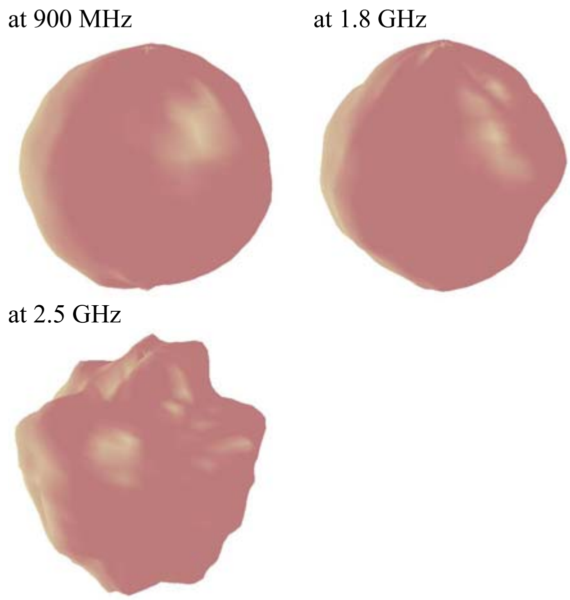
IV.1 Measurement Principle and Uncertaint

The measurement system of Field Nose is based on the so-called Add3D method developed by the Austrian Research Centre Seibersdorf [5]. It is based on frequency selective measurements with a receiver or spectrum analyser and a broadband receiving antenna. This antenna, the PCD 8250, covers the frequency range from 80 MHz up to 2.5 GHz and has a dipole like radiation pattern. Therefore the effective field strength E [dBµV/m] can be obtained from three voltage measurements U_i [µV] with orthogonal orientation of the antenna, one after the other and application of the antenna factor AF_{Add3D} [dB/m] according to formula (3).

$$E = AF_{Add\,3D} + 20\log\left(\sqrt{U_x^2 + U_y^2 + U_z^2}\right) \qquad (3)$$

The over all radiation characteristic of the components would yield to perfect sphere-shaped radiation pattern if each antenna measurement would have perfect dipole like radiation pattern. Therefore, each received signal is evaluated in the same kind, independent of the direction or polarisation of the incident field. Of course the radiation characteristic of a real antenna is frequency dependent and therefore a deviation of the sphere-shaped over-all radiation characteristic is inevitable. In Figure I measurement results of the isotropic behaviour of a PCD 8250 antenna including the antenna positioner for different frequencies are given. The isotropy increases with higher frequencies due to pattern degeneration at these frequencies.

Figure I – Isotropy of Field Nose



The isotropy uncertainty contribution $Iso_{(AF,.Add3D)}$ [dB] for the Add3D measurement method with the PCD8250 antenna and the results of an expanded uncertainty calculation for the Field Nose system according GUM (Guide to the Expression of Uncertainty in Measurement) are presented in Table III.

Table II – Comparison of EMF Measurement Methods

Features/Measurements	*Field Probe*	*Dir. Ant.*	*Sweeping*	*Single P. Iso.*	*Spat.Av*	*Monitoring*
Frequency selective	- -	+ +	+ +	+ +	+ +	+ +
Isotropic behaviour	+ +	- -	- -	+ +	+ +	+ +
Time averaging	+ +	+	- -	+ +	+ +	+ +
Spatial averaging	+	-	+	-	+ +	-
Sensitivity	-	+ +	+ +	+ +	+ +	+ +
Reproducible	+	+	-	+ +	+ +	+ +
Uncertainty calculation	+	+	-	+ +	+	+ +
Out of band signals	-	+ +	+ +	+ +	+ +	+ +
Simple and fast	+ +	-	+ +	+	-	+
Remote control	+ +	- -	- -	+ +	+	+ +

Table III – Uncertainty of Field Nose

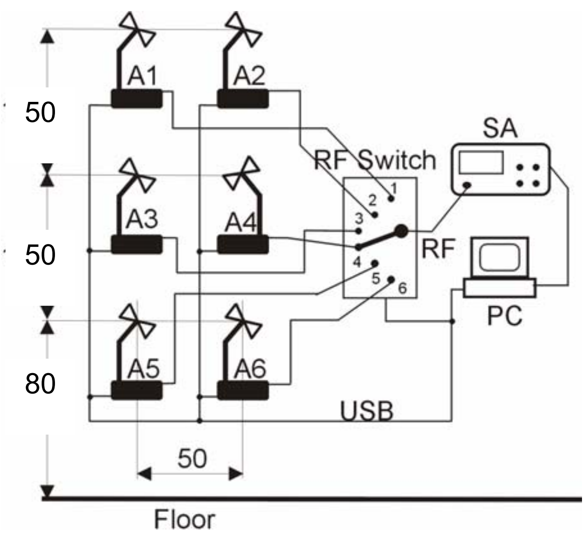
Frequency [MHz]	Iso($_{AF, Add3D}$) [dB]	Exp. Uncertainty [dB]
900	0.28	1.84
1800	0.44	1.90
2500	0.79	2.55

To calculate the expanded measurement uncertainty of the Field Nose system the uncertainty of AF- and cable calibration, the isotropy of the method, the three voltage measurements of the receiver, mismatch between antenna and receiver, temperature effects and positioning uncertainties of the antenna in combination with the antenna rotator are considered [6].

IV.2 Long-Term Measurements

To demonstrate the application of Field Nose Basic for long-term measurements we placed 6 systems (antenna PCD8250 and automatic rotator) in a room at Seibersdorf with direct sight to the local base station at a distance of approximately 60 meters. The antennas were placed in a grid given in Figure II on a construction of styrofoam. A distance of 50 cm between the

Figure II – Assembly for Long-Term Measurements



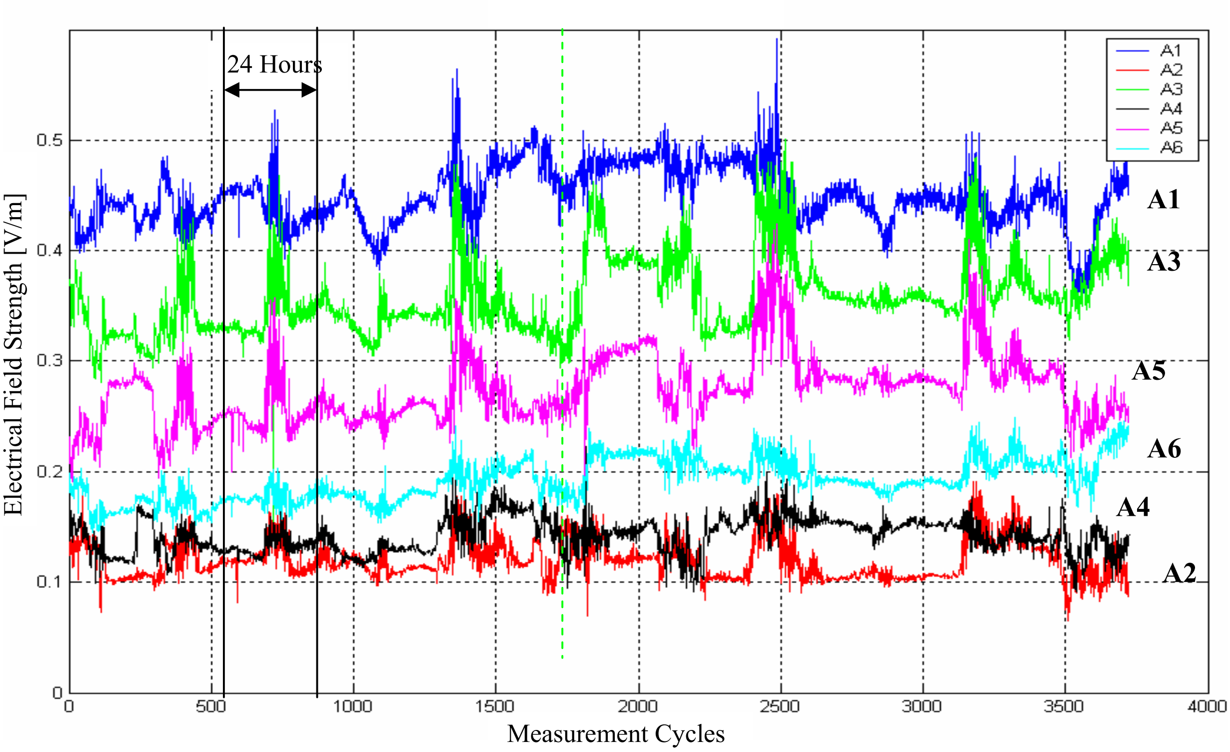
antennas were chosen to represent a volume similar to the human body on the one hand and to avoid coupling effects between the antennas on the other hand. The antennas on the left side (A1, A3, and A5) have direct sight to the base station whereas the other three ones have some shadow effects caused by a column of the building. The measurements were performed according to the Add3D method with a spectrum analyser (HP 8563E) and a software controlled RF-switch to actuate one antenna after another. Measurements were continuously done in the GSM downlink range from 940 MHz to 960 MHz with a RBW of 100 kHz and max-hold over 20 sweeps at each antenna orientation. Time required for one full measurement cycle with all 6 antennas was about 4.5 minutes. In Figure III the signals of the BCCH of the viewed base station at 946.6 MHz are presented for about 3750 measurement cycles which are corresponding to about 12 days. Considering the measured BCCH-signals over the time period of almost two weeks, the good correlation between them is remarkable. All of them are showing periods with a flat run interrupted by sections with much higher fluctuations. This characteristic seems very likely to be caused by causal changes in the propagation conditions of the electromagnetic field probably due to different weather conditions. Detailed results about the average values and maximum deviation during the measurement period are given in Table IV.

Table IV – Average Values of A1 – A6

Antenna	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*
Average [V/m]	0.45	0.12	0.36	0.14	0.27	0.19
+Variation [%]	32.6	61.0	48.5	44.8	57.9	32
- Variation [%]	20.6	45.2	21.3	40.1	29.0	23

The differences in the absolute values of the field strength levels are supposed by the 'sight' of the antennas to the base station. The antennas A1, A3 and A5 have the highest signals and they have also direct sight through the window to the base station. The antennas A6, A4 and A2 are shaded by a column of the building and therefore the signals are much smaller.

Figure III – Measured BCCH-Signals at 946.6 MHz of Antennas A1 – A6



V. SUMMARY

Based on the ICNIRP guidelines typical EMF measurement tasks are described and their individual requirements are given. Measurement methods used nowadays are discussed and compared. We noticed the advantages of frequency selective, isotropic systems in respect of the other methods however also this methods have their limitations especially in spatial averaging. As demonstrated in the long-term measurement example, the well performed EMF measurement system Field Nose has the possibility to perform isotropic, frequency selective investigations with spatial resolution considering the volume of a human body. Such measurements could be an essential contribution to the discussions around harmonized, European standards or assisting EMF exposure studies in the future.

VI. REFERENCES

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