ADD3D, A NEW TECHNIQUE FOR PRECISE POWER FLUX DENSITY MEASUREMENTS AT MOBILE COMMUNICATIONS BASE STATIONS

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ABSTRACT

The new method Add3D we have developed is based on the frequency selective measurement method with a receiver or spectrum analyser and uses a broadband omnidirectional receive antenna. Add3D is a precision measurement method that combines the advantages of the field probe (isotropic behaviour) with that of frequency selective measurements.

Frequency selective field-strength measurement with PBA 10200

INTRODUCTION

With the recent rapid increase in the use of mobile phones, public concerns and queries regarding the health and safety aspects of mobile telecommunications equipment have been growing. Safety guidelines for protecting human beings from radio frequency exposure exist in various countries.

The basic limits are defined commonly in terms of specific absorption rate (SAR). The SAR is a term which is practically not accessible for routine evaluations of the exposure situation in real life. It is determined in expensive investigations by simulations, measurements in phantoms and measurements in tissue in the laboratories. The only quantities that can be measured for routine evaluations of the exposure situation more or less easily are the electric and magnetic field strengths. Therefore the standards also show the derived limits for electric and magnetic field strength.

STANDARDS

The derived limits are given in terms of power flux density S (W/m^2), or/and electric field strength E (V/m) respectively magnetic field strength H (A/m). At operating frequencies of mobile communication base stations in far field conditions the measurement of the electric field strength is sufficient. There the simple Eq. 1 describes the correlation to power flux density:

$$E\,[V/m] = \sqrt{S\,[W/m^2] \cdot 377\,[\Omega]} \qquad (1)$$

The limits are frequency dependent as shown as example in Fig.1 for the ICNIRP limit. This fact requires a frequency selective measurement system to evaluate the measurement results with the corresponding limit values. If the measurement system is not frequency selective then the lowest limit within the measurement range has to be chosen.

International and National Standards and Recommendations Overview

Example of the field-strength limit values E_{Lim} for mobile communication frequencies at far field conditions for the general public and continuous exposure:

Country	**Standard**	**E_{Lim} 950 MHz**	**E_{Lim} 1850 MHz**
International	Council Recommendation 1999/519/EG	42 V/m	59 V/m
International	ICNIRP Guidelines, April 1998	42 V/m	59 V/m
Austria	ÖNORM S1120	49 V/m	61 V/m
Germany	26. Deutsche Verordnung	42 V/m	59 V/m
Italy	Decreto n. 381, 1998	6 (20) V/m	6 (20) V/m
The Netherlands	Health Council	51 V/m	83 V/m
Switzerland	Verordnung 1999	4 V/m	6 V/m
USA	IEEE C95.1	49 V/m	68 V/m
China	Draft: National Quality Technology Monitoring Bureau	49 V/m	61 V/m
Japan	Radio-Radiation Protection Guidelines, 1990	49 V/m	61 V/m

General Guidelines:

Council Recommendation July 1999 (1999/519/EG)
ICNIRP Guidelines (April 1998)

Frequency	S
10 MHz - 400 MHz	2000 mW/m²
400 MHz - 2 GHz	f [MHz] / 0,2 mW/m²
2 GHz - 40 GHz	10000 mW/m²

Therefore the limit at 950 MHz is 4750 mW/m² and at 1,85 GHz is 9250 mW/m².

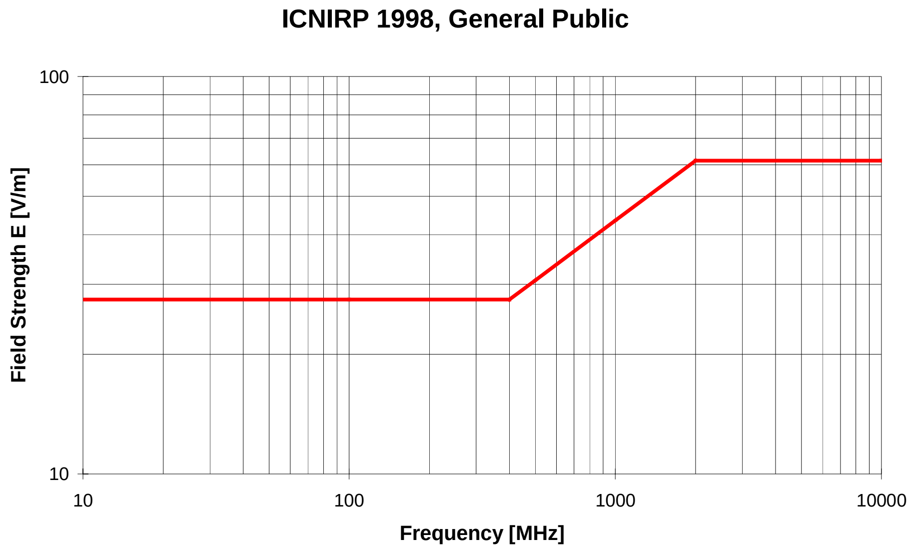


Figure 1: Frequency dependent field-strength limit

It is important to determine whether, in situations of simultaneous exposure to fields of different frequencies, these exposures are additive in their effects. Additivity should be examined separately for the effects of thermal and electrical stimulation, and the basic restrictions below should be met. The formula applies to relevant frequencies for thermal considerations under practical exposure situations:

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

where E_i = the electric field strength at frequency i
E_{Li}= the electric field strength limit at frequency i

The summation formula 2 assume worst-case conditions among the fields from multiple sources. As a result, typical exposure situations may in practice require less restrictive exposure levels than indicated by Eq. 2 for the reference levels.

Country specific standards

Austrian Pre-Standard ÖNORM S1120, 1992

Frequency	S
30 MHz - 300 MHz	2000 mW/m²
300 MHz - 1,5 GHz	6,66666 x (f, MHz) mW/m²
1,5 GHz - 40 GHz	10000 mW/m²

Therefore the limit at 950 MHz is 6333,3 mW/m² and at 1,85 GHz is 10000 mW/m².

26. Deutsche Verordnung (1996)

Frequency	S
10 MHz - 400 MHz	2000 mW/m²
400 MHz - 2 GHz	f [MHz] / 0,2 mW/m²
2 GHz - 40 GHz	10000 mW/m²

Therefore the limit at 950 MHz is 4750 mW/m² and at 1,85 GHz is 9250 mW/m².

Italian Decreto n. 381, September 1998

Frequency	S
0,1 – 3 MHz	-
> 3 – 3000 MHz	1000 mW/m²
> 3 – 300 GHz	4000 mW/m²

Therefore the limit at 950 MHz as well as at 1850 MHz is 1000 mW/m².

In buildings, used for more than 4 hours the compliance with precaution limits of 6 V/m for the electrical field strength and of 0.016 A/m for the magnetic field strength is required. The equivalent power flux density is 0.1 W/m^2 at frequencies above 3 MHz.

The precaution limit at 950 MHz as well as at 1850 MHz is 100 mW/m².

Schweizer Verordnung über den Schutz vor nichtionisierender Strahlung, Dezember 1999

The ICNIRP limits are valid generally. Additionally in sensitive areas (residential areas, hospitals, ...) the compliance with emission limits is required. This limit is 4 V/m (42,4 mW/m²) for base stations operating at around 900 MHz, 6 V/m (95,5 mW/m²) at 1800 MHz and 5 V/m (66,3 mW/m²) at stations operating both frequencies.

Health Council of the Netherlands, 1997

Frequency	E
10 MHz - 400 MHz	28 V/m
400 MHz – 2 GHz	53 x f [GHz] $^{0.72}$
2 GHz - 10 GHz	87 V/m

Limits only for field strength given

Therefore the limit at 950 MHz is 6920 mW/m² and at 1,85 GHz is 18069,1 mW/m².

USA: IEEE C95.1 1991

Frequency	S
100 MHz - 300 MHz	2000 mW/m²
300 MHz - 15 GHz	6,66666 x (f [MHz]) mW/m²
15 GHz - 300 GHz	100000 mW/m²

Therefore the limit at 950 MHz is 6333,3 mW/m² and at 1,85 GHz is 12333 mW/m².

China: Draft National Quality Technology Monitoring Bureau

Frequency	S
30 MHz – 300 MHz	2000 mW/m²
300 MHz – 1,5 GHz	6,66666 x (f, MHz) mW/m²
1,5 GHz – 40 GHz	10000 mW/m²

Therefore the limit at 950 MHz is 6333,3 mW/m² and at 1,85 GHz is 10000 mW/m².

Japan: Radio-Radiation Protection Guidelines for Human Exposure to Electromagnetic Fields, TCC, MPT 25.6.1990

Frequency	S
30 MHz - 300 MHz	2000 mW/m²
300 MHz - 1,5 GHz	6,66666 x (f, MHz) mW/m²
1,5 GHz - 40 GHz	10000 mW/m²

Therefore the limit at 950 MHz is 6333,3 mW/m² and at 1,85 GHz is 10000 mW/m².

MEASUREMENT METHODS

Using a mobile communication base stations as example we describe the state of the art for measuring the field strength demonstrating pros and cons of the methods.

<u>Situation:</u> The field strength of a dual band GSM base station at 900 MHz and at 1,8 GHz in urban area has to be measured at several locations with different distance from the antenna mast.

<u>Information available:</u>
- relevant frequencies
- type of modulation

<u>Information not available:</u>
- direction of maximum signal strength
- polarisation at measurement point
- frequencies and amplitude of ambient signals
- duty cycle (has effect on the signal envelope shape)

Measurement with Field Probe

Measurement of the field strength is done with a field probe specified for 80 MHz to 40 GHz in this example.

+ The measurement can be done very simple, convenient and fast.
+ Due to the isotropic characteristic of the field probe the unknown direction of maximum field and the unknown polarisation are not of importance.
+ Measurement of the signal sum

But the question arises if this is really a measurement of the field strength generated by the base station?

- The instrument is not built to distinguish between emissions of different frequencies like radio and TV broadcast stations or GSM mobile phones or the base station we want to measure.
- Therefore we have no information if the reading on the meter corresponds with the base station's emission or with any signal within the probes measurement range. In fact the reading will correspond with the strongest signal or the sum of several signals.
- The probe can be sensitive even to signals 'out of band'. The frequency range in the probe specification is not necessarily correlated with its real sensitive range.
- Furthermore the lowest limit of 2000 mW/m^2 at 80 MHz has to be applied for the whole frequency range because the meter reading can not be correlated to a certain frequency. Then the measurement result could be charged too severe.
- The calibration factor of the probe is usually valid for sinusoidal signals. The waveform of the measured signal(s) is unknown. This is because the duty cycle (which is responsible for the waveform) of many mobile communication signals

depend on the load (number of simultaneously connected people). The load is variable and generally unknown – therefore additional errors can result.
- The calibration factor of the probe is generally not constant over the whole frequency range. A frequency specific application of the calibration factor is not possible.
- The sensitivity of the probe is low: 0,1 V/m maximum

For this kind of measurement the use of a field probe is not applicable and should be avoided. A field probe can only be used when it is assured by additional frequency selective measurements that the signal of interest is much stronger than the other signals at the measurement location.

Measurement with Directive Antenna

The measurement system consists of an antenna and a frequency selective receiver or spectrum analyser. Antennas available up to now and covering the frequency range of mobile communication are either directive or narrowband. 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.

+ For each reading the measurement frequency is known
+ The frequency dependent antenna factor can be applied
+ The appropriate frequency dependent limit values can be applied
+ Out of band signals play no role if the receiver is well designed.
+ Modulation and duty cycle of the signal are not important when the measurement is done with a maxhold scan for a certain time period.

The disadvantages this method has result from the kind of antenna used:

- due to the directivity of the antenna the measurement has to be repeated at numerous orientations of the antenna to get an overview. The number of orientations depend on the directivity. For a beam width of e.g. 45° a minimum of 18 directions are required (45 degree steps in 3 axes) for each polarisation (2). Depending on the directivity of the antenna an additional scanning for the maximum in the expected direction has to be done.
- Different frequencies might require a fine scanning in different directions
- It is a very time consuming measurement

The frequency selective measurement with the directive antenna is a precision measurement when it is done carefully but then it is a very time consuming job.

NEW MEASUREMENT METHOD: Add3D

The new method **Add3D** we have developed is based on the **frequency selective** measurement method with a receiver or spectrum analyser and uses a **broadband omnidirectional receive antenna**. The antenna **PBA 10200** covers the frequency range 100 MHz up to 2,1 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: U_x, U_y and U_z [V].

The field-strengths are calculated in linear quantities:

$$E_i = U_i \cdot AF, \quad i = \{x, y, z\} \qquad (3)$$

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

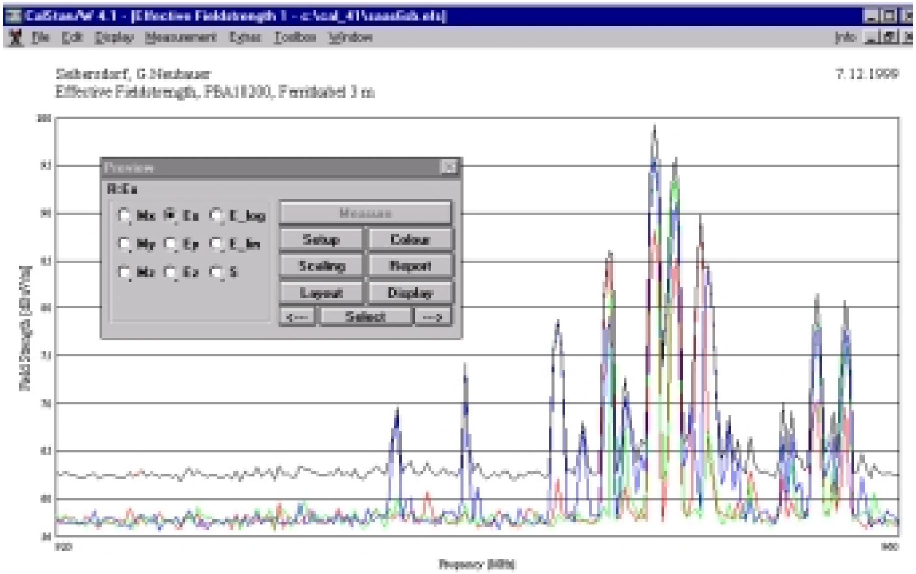
$$E_{eff} = \sqrt{E_x^2 + E_y^2 + E_z^2} \quad = \quad \sqrt{U_x^2 + U_y^2 + U_z^2} \cdot AF \qquad (4)$$

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

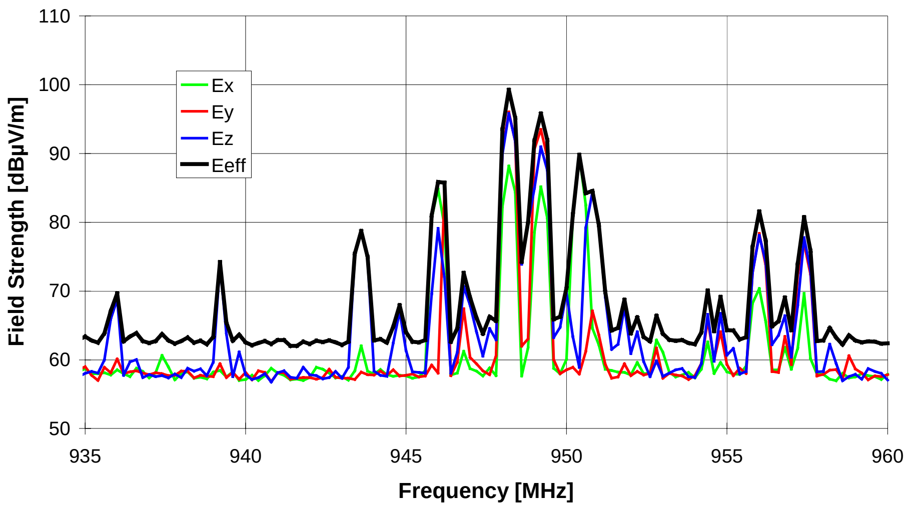
The measurements in 3 orthogonal directions are done with one antenna. Therefore the only problem that remains is that the readings do not happen at the same time. To avoid measurement errors due to rapidly changing signals sufficiently long measurement times with max-hold acquisition have to be chosen at each direction.

The acronym **Add3D** stands for **Add**ition of **3 D**imensional Field Components according to Eq 4.

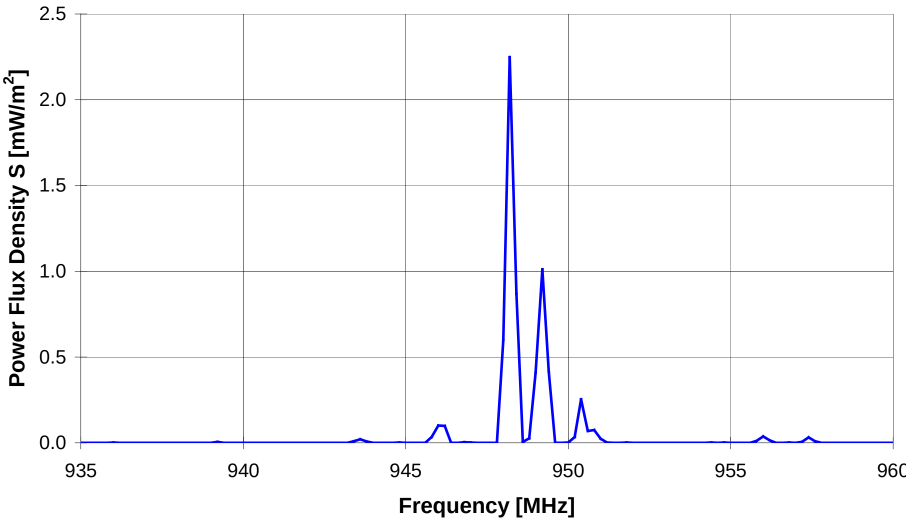
- **+** The measurement procedure is simple and time efficient as it is controlled by software. The operator positions the antenna in the three different orientations, the software sets the receiver bandwidth and the frequency range and stores the measured data.
- **+** The measurements are done in the frequency range of interest, the appropriate limit values can be applied
- **+** Out of band signals play no role if the receiver is well designed.
- **+** With one set of measurements (3 directions) the effective field strength’s of all neighbouring base stations (operating at different frequencies) can be determined. This is a great time saving advantage for mapping the field distribution.
- **+** The **Add3D** is a precision measurement method that combines the advantages of the field probe (isotropic behaviour) with that of frequency selective measurements.



Screen-shot of the measurement software CalStan/W 4.1



Result showing the 3 orthogonal E-field components obtained by multiplying the voltage readings with the antenna factor and the effective field strength E_{eff} according to Eq. 4 in logarithmic quantities (20 $\log_{10}(E)$) as function of frequency.



Result showing the power flux density S in mW/cm^2 as function of frequency S= E_{eff}^2 /377