Reproducibility of GSM and UMTS EMF Measurements

P. Fritschi, B. Eicher, H. Lehmann

Swisscom Ltd., Innovations, Environment and Electromagnetic Compatibility, CH-3050 Berne, Switzerland

peter.fritschi@swisscom.com

***Abstract*— This contribution discusses the basic concepts of EMF measurements for compliance tests of mobile phone base stations in Switzerland. The employed maximum search method is explained and details of frequency selective field strength measurements of GSM and code domain power measurements of UMTS signals are investigated.**

After the discussion of the main influence factors on the reproducibility, the test set-up for the analysis is described. The use of a robot for a reproducible spatial positioning of the receiving antenna allows for comparison of GSM and UMTS signals under almost identical conditions. The results indicate that GSM 1800 as well as UMTS signals show a good reproducibility with deviations of 0.1-1.8 dB.

I. Introduction

In Switzerland, all new built or refurbished base stations (BS) for mobile communication have to pass a stringent acceptance test to prove their compliance with the respective national limits regarding the exposure to electromagnetic fields (EMF). This contribution deals primarily with compliance tests for the Swiss specific EMF regulation, notably one of the most restrictive regulations in the world.

A. Acceptance Tests

The EMF acceptance tests in Switzerland are based on the "Ordinance relating to Protection from Non-Ionising Radiation" (ONIR) [1] where, beside other requirements, a recommendation describes the in-situ measurement procedure for EMF generated by mobile phone BS. For the last five years, two different measurement recommendations were mainly applied: one for the Global System for Mobile communication (GSM) [2] and one for the Universal Mobile Telecommunication System (UMTS) [3].

Both recommendations follow the same basic concept: Based on free field calculations made during the application process for the building permit, the maximum field strength at the locations with the highest field strengths calculated has to be verified by measurement. To be independent of field strength variations from traffic on the BS, a traffic-independent part of the RF-Signal has to be recorded. For GSM these conditions are fulfilled by the power of the Broadcast Control Channel (BCCH) of a cell. For UMTS the corresponding traffic-independent part of the signal is the transmitting power of the Primary Common Pilot Channel (P-CPICH).

During the acceptance tests, the maximum electric field strength at the examined location has to be searched by a manual displacement of the measurement antenna. This maximum search method is applied, because the level of the field strength in a room usually varies considerably due to reflection, absorption and diffraction in the room, depending on the geometry and the construction materials of the building.

In order to measure the above-mentioned signals, compliance tests of GSM BS were commonly carried out with spectrum analysers by measuring the BCCH signal. For UMTS, measurement instruments for Code Domain Power (CDP) are used to measure the field strength of the P-CPICH.

B. Considerations of the measurement recommendation for UMTS

Especially after the publication of the draft of the measurement recommendation for acceptance tests for UMTS [3], several attempts have been made to validate all parts of this measurement method. Based on a first round robin test [4], doubts among the applicability of the measurement recommendation, particularly concerning the reproducibility of the measurement results came up. The criticism focussed on the uncertainty induced by the CDP measurement. Presumably, this was the reason to perform a measurement campaign applying the measurement recommendation, in which the results from different CDP measurement instruments have been compared. This campaign [5], again designed as a round robin test, showed that the recommendation for acceptance tests for UMTS [3] provides indeed valid results. However, no information was gathered on the origin of the remaining measurement tolerances. Independent from the above mentioned validations Swisscom Ltd. as a leading and responsible provider for mobile communication has made additional investigations using a somewhat different approach. The results of this work provide not only some answers about the reliability of the recommendations but, in addition delivers more insight in the properties of field strength distributions under real life conditions in general.

Our approach differs in two points from the approach used in [4] and [5]. First of all, it seemed essential to have also some information about the reproducibility of the GSM measurements. Secondly, we aimed to reduce or control the external influence factors on the measurements to a minimum in order to find out, how different results of CDP and spectral measurements - under nearly identical conditions - behave.

Regarding the factors which potentially affect the reproducibility of the results in the above-mentioned EMF measurements the following 4 sources can be identified:

1) Measurement uncertainty: The combined measurement uncertainty of all instruments in the measurement chain.

2) Sample taking: There are always variations due to the sample taking in space and time. This derives mainly from the manual and therefore arbitrary maximum search sequence.

3) Spectral vs. CDP measurements: The difference between the frequency domain measurement (for GSM) and the CDP measurement method (for UMTS).

4) Spatial distribution: The individual spatial distribution of the electromagnetic field at the location of interest has to be considered.

It was the goal of this investigation to separate out the importance of factor *3)* on the overall measurement tolerance.

II. METHODS

From the discussion above, the main requirement for the test set-up is to keep the influence of the factors *1)*, *2)* and *4)* as small or as constant as possible.

A. Test set-up

The biggest challenge was to provide a well controlled repetition of the sample taking. This requirement was solved by using a robot, intended for education purposes (Fig. 1). The structure of the robot was mainly realised without metallic elements.

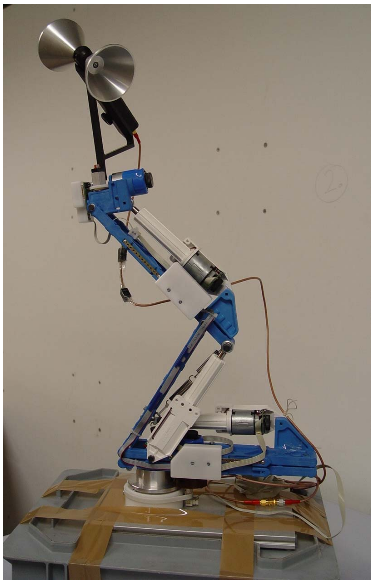


Fig. 1 Education robot for displacing the biconical receiving antenna

With this device, the spatial track of the antenna could be repeated with a tolerance of approximately 1 or 2 cm. In order to allow the analysers to gather enough readings per antenna position, the possibility to perform the spatial displacement of the antenna with a very low speed was an additional advantage of the robot. The unfolded track of the antenna in all reachable directions has a length of approx. 20 m and took 1 hour and 4 minutes to run. Circa 18'500 readings for GSM 1800 and 37'000 readings for UMTS were stored for each track. The antenna polarisation was changed for several sections of the movement track but was identical for all measurements. The curve, which the antenna follows, looks like the shape of the frame of an umbrella.

In order to keep the other influence factors small, the measurement equipment used was the same for all measurements. In a given room all measurements were made with the robot remaining in the same position during the movement of its arms.

In addition, to eliminate the influence on the electric field distribution of human beings all persons were kept out of the vicinity of the receiving antenna.

B. Comparison of the UMTS (CDP) and GSM 1800 (spectral) methods

Since the intention was to compare the reproducibility of measurements of GSM in the frequency domain with UMTS in the code domain under closely comparable conditions, we measured only GSM 1800 signals with its smaller frequency shift to UMTS than GSM 900.

C. Measurement instruments

The measurements were made with the following devices:

- Spectrum Analyser, Rohde&Schwarz, FSU for the spectral measurement of GSM 1800
- Radio Network Analyser, Rohde&Schwarz, TSMU with RFEX V4.10 for the CDP measurement of UMTS
- Biconical Antenna, Austrian Research Centers Seibersdorf, PCD 8250 for GSM 1800 and UMTS measurements

The measurement uncertainty of the Spectrum Analyser (FSU) is ±0.5 dB. According to the technical data sheet, the measurement uncertainty of the Radio Network Analyser (TSMU) is ±1.5 dB.

The antenna was moved with a Teach-Robot from Edutec.

The antenna from above is used exclusively as a biconical antenna. The Add3D system was not applied.

III. RESULTS

Measurements were carried out in four different buildings in the vicinity of four different base stations. Table I gives information about the measurements performed.

All measurements were made in rooms located within the main coverage area of the measured cell. However, line of sight (LOS) conditions have not been fulfilled in all cases, as the direct view to the antenna of the BS was more or less covered by construction elements of the building itself or other obstructions like trees and roofs of nearby buildings. Ranking the locations in terms of LOS, location B fulfills quite well this condition, whereas for the locations C, D and A the LOS condition gradually diminishes.

The results in Table I show deviations of the maximum values in the range of 0.01 to 1.82 dB between the different tracks. The reproducibility of the measurements was better for GSM than for UMTS at locations A, B and D whereas for location C the results for UMTS show smaller deviations than GSM data.

TABLE I
DESCRIPTION OF THE DIFFERENT MEASUREMENT TRACKS AND OBSERVED DEVIATION OF THE RECORDED ANTENNA SIGNAL MAXIMUM.

Lo-cation	Measurement Tracks	Deviation of the recorded maximum [dB] UMTS	GSM	Remarks
A	3 x UMTS (Initial measurement and first repetition the same day, the third track has been recorded five days later)	0.55	-	Test sequence of the robot*
A	3 x UMTS, 3 x GSM 1800 (Initial measurement and first repetition the same day, the third track has been recorded two days later)	1.82	1	Improved motion sequence of the robot
B	2 x UMTS, 2 x GSM 1800 (One initial and a repetition measurement the same day)	0.1	0.01	
C	5 x UMTS, 5 x GSM 1800 (One initial and four repetition measurements the same day)	0.72	1.46	
D	2 x UMTS, 2 x GSM 1800 (One initial and a repetition measurement the same day	0.36	0.16	

*In order to avoid intermittent malfunction of the robot, parts of the motion sequence had to be slowed down after the start of the campaign.

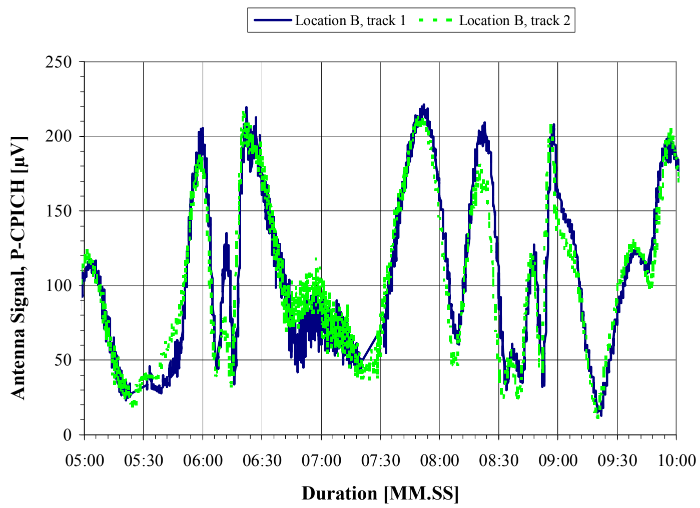


Fig. 2 Extract from the two measurements tracks for UMTS performed at location B. The results are plotted over time.

Fig. 2 shows an extract from the two UMTS measurements at location B. One observes that minima and maxima were found at the same points of the sequence and the deviations are quite small. The deviation of the means values of these two tracks is 2%. Table II lists the different field parameters in terms of the mean, median and maximum values over the entire recorded tracks.

TABLE II
MEASUREMENT RESULTS IN TERMS OF THE RECORDED ANTENNA SIGNAL. UNLESS SPECIFIED DIFFERENTLY THE VALUES ARE GIVEN IN [µV].

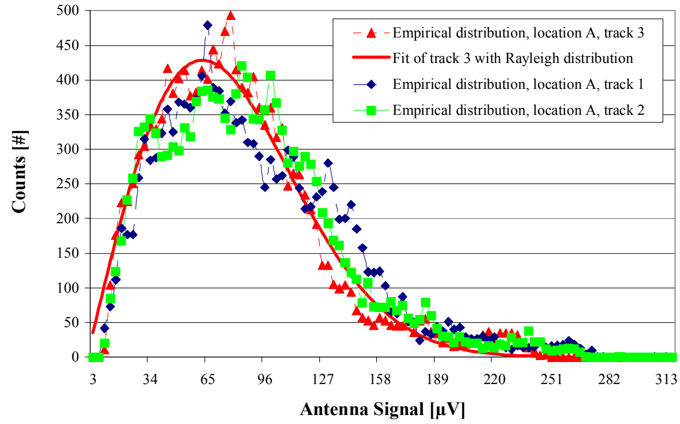
Location	GSM				
	Observable	Track [#] 1	2	3	Deviation of the observable [% of average over the tracks]
A	Mean	86	83	77	10.9
	Median	77	78	71	9.7
	Maximum	310	283	282	9.9
	Max./Mean	3.61	3.40	3.66	
B	Mean	438	427		2.5
	Median	350	339		3.3
	Maximum	1818	1821		0.1
	Max./Mean	4.15	4.26		
C	Mean	1326	1310		1.2
	Median	1123	1079		4.0
	Maximum	4581	4278		6.8
	Max./Mean	3.46	3.27		
D	Mean	537	537		0.1
	Median	512	508		0.8
	Maximum	1555	1583		1.8
	Max./Mean	2.89	2.95		

Location	UMTS				
	Observable	Track [#] 1	2	3	Deviation of the observable [% of average over the tracks]
A	Mean	18	21	17	21.3
	Median	15	18	14	25.1
	Maximum	53	65	56	21.2
	Max./Mean	2.91	3.15	3.38	
B	Mean	170	167		2.0
	Median	135	130		3.5
	Maximum	660	667		1.1
	Max./Mean	3.87	3.99		
C	Mean	196	193		1.9
	Median	166	161		3.3
	Maximum	580	570		1.8
	Max./Mean	2.95	2.96		
D	Mean	55	54		3.1
	Median	50	47		4.8
	Maximum	170	164		4.1
	Max./Mean	3.08	3.05		

In Fig. 3 the empirical antenna signal distributions of the tracks from two different locations are shown. The subsequent tracks at a given location are quite similar. As already observed earlier [6] the field strength distributions of the recorded data are right skewed and can be fitted in first approximation with the Rayleigh distribution. For situation A the fit is better than for situation B. The fits tend to be worse for LOS situations.

IV. DISCUSSION

The results obtained with the measurement set-up described above point towards quite good reproducibility of the measurements. The use of a robot permits the reproducible scanning of a volume of interest.



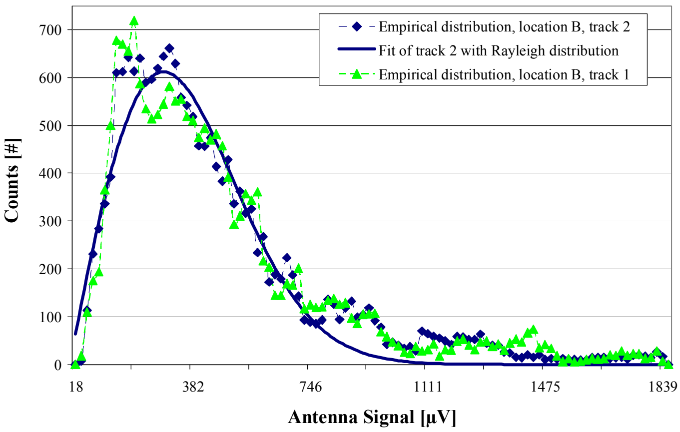


Fig. 3 Distribution of the antenna signal for different GSM measurements performed at location A (top) and B (bottom). The Rayleigh distribution fitted to one track is also shown (solid line).

Compared to the reproducibility of results gathered with the maximum search method as prescribed by the Swiss legislation the differences of the maximum values are considerable smaller by using a defined set of points slowly scanned by the robot. In a recent round robin test [5] extended standard deviations in the range from 25% to 54% have been observed for a situation in which a static, simulated UMTS signal has been used. The data presented here - showing maximum deviations in the range from 1.1% to 21.2% - was obtained by measurements on four different real life UMTS BS. The sample taking method combined with the spatial variations of the EMF are thus two of the most important contributions to the variability in the different measurement results. More stable results can only be obtained by standardizing the sampling of the volume.

Comparing the results for the two different mobile phone standards, one has to consider the fact that the instrument used for the UMTS measurements has a three times higher measurement uncertainty than the spectrum analyser used for GSM. Even though, the differences in terms of reproducibility are small. Therefore, it can be assumed that the reproducibility of UMTS measurements (CDP) is comparable to the one for spectral GSM measurements.

One observes that neither the maximum value nor the mean values show a clear advantage in terms of reproducibility of the measurement results. This conclusion is, however, based on the data recorded for the here described automated sample taking. If the sample taking is realised by an operator who can hardly repeat twice an identical scan sequence, this conclusion might be altered (see for instance [6]). Moreover, the person itself has a non negligible influence on the EMF. Persons moving around the idle robot in a distance of approx. 1m causes signal variations up to 18dB. Furthermore, the data recorded show that a small antenna displacement can lead to important changes in the measured intensity. On the other hand, the measurement tracks with a smoother shape in the region of the maximum values seem to deliver more reproducible results.

The observation that the fit of the data with the Rayleigh distribution leads to the better results for non LOS conditions, relies on the fact that the Rayleigh distribution assume a number of statistically independent propagation paths which superpose to the total received signal.

Finally, the data shows that the maximum value recorded is more than 3 times higher (see Table 2) than the average exposure to the ambient EMF. As a biconical antenna has been used for the measurements, this overestimation will be reduced in isotropic measurements. Nevertheless, the maximum value as assessed according to the Swiss measurement recommendation will still overestimate to an important degree typical exposure levels.

V. Conclusions

By keeping the external influence factors as low as technically feasible, it can be shown that measurements of EMF generated by mobile phone BS show a good reproducibility. The deviations of the maximum recorded value and the mean value are usually much smaller than the measurement error, independent whether a GSM or a UMTS signal has to be evaluated.

References

[1] Swiss Federal Council (1. Feb. 2000): *Ordinance relating to Protection from Non-Ionising Radiation (ONIR)*, SR814.710, www.admin.ch/ch/d/sr/c814_710.html

[2] Federal Office for the Environment (FOEN) and Federal Office of Metrology (METAS), *Measurement recommendation for Base Stations (GSM)*, published June 28, 2002, www.bafu.admin.ch/elektrosmog/01100/01108/01110/index.html?lang=de#srungmarke0_13

[3] Federal Office for the Environment (FOEN) and Federal Office of Metrology (METAS), *Draft measurement recommendation for Base Stations (UMTS-FDD)*, published Sept. 17, 2003, www.bafu.admin.ch/elektrosmog/01100/01108/01110/index.html?lang=de#srungmarke0_13

[4] Federal Office of Metrology (METAS), *Comparison of measurements with UMTS Code Domain Power measurement instruments*, 2005-255-575, Nov. 10, 2005, www.metas.ch/de/labors/2/25.html

[5] Federal Office of Metrology (METAS), C*omparison of UMTS measurements, Summer 2006*, 2006-218-598, Jan. 10, 2007, www.metas.ch/de/labors/2/25.html

[6] H. Lehmann, B. Eicher, P. Fritschi, *Indoor measurements of the electrical field close to mobile phone base stations*, INTERNATIONAL UNION OF RADIO SCIENCE (URSI), 2002, www.swisscom.com/Innovations/content/Labs/Testlab_STS121