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Uncertainty in Field Level Measurements of LTE Signals Associated with User Load

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***Abstract*—Recent modulation schemes in mobile communications, as long-term evolution (LTE), give rise to the question of how to properly asses the exposure to the electromagnetic fields generated by base station signals. This text examines the changes in the field strength associated with the user load variations in LTE signals. We have firstly generated a set of signals, with the same configuration parameters, modifying only the percentage of user load and simulating how it alters the field level. Then, a setup for measurements was defined and two electric field probes are exposed to the previous analyzed signals in a controlled environment. Field strength meter readings are recorded as in a real case of exposure evaluation. Uncertainties concerning probes performance and environmental conditions are also calculated to have an overall budget. Due to the user load changes, field level variations up to 11 dB have been found. The measurement uncertainty of the exposure level may be dramatically increased by these field fluctuations.**

***Index Terms*— Electromagnetic field exposure, electromagnetic measurements, long-term evolution, uncertainty.**

I. INTRODUCTION

THE interest in assessment of human exposure to electromagnetic fields has been continuously increasing due to the ongoing technological development. As an example, roll-out of long-term evolution (LTE) networks involves the deployment of new antennas for mobile communications.

Population is afraid of electromagnetic exposure as they cannot decide to be or not exposed to such energy. New network deployment carrying out new popping out antennas increases this fear, which measurements in actual scenarios try to mitigate. Experimental procedures evaluate the level of exposure to such equipment and check its compliance with the current legislation on the matter. When measuring field strength, broadband field probes emerge as a first option, as the overall contribution of all the signals present can be obtained simultaneously [1-2], exactly as human bodies receive the exposition.

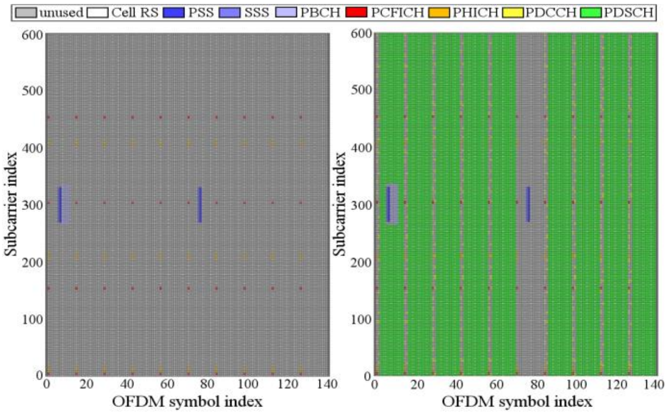
Such kind of probes perform precisely when measuring sinusoidal CW signals, as original designs focus on that kind of waveforms. However, several studies have shown that they may provide some errors when dealing with schemes with digitally modulated radio signals. Besides, these errors not only depend on the waveform to be measured but also on the probe selected [3-6]. This could be labelled as modulation uncertainty [4], and was the focus of previous works. Nevertheless, the signal received from a mobile phone base station depends also on other communication conditions, like temporal and spatial fluctuations [7-8]. Thus, uncertainty budget of exposure measurements may include additional effects that do not depend on probe performance.

Concentrating on cellular phone generations, the reduction of the active channels do not significantly affect error values at 3G UMTS systems [6]. The scope of this study is to analyze, whether in 4G LTE scheme, the amount of network resources demanded by the users have a meaningful contribution to the uncertainty in field level measurements. With this aim, we have generated a set of LTE signals where the number of occupied resource blocks change while keeping fixed the other parameters of the signal, which allows us to check possible variations in the received signal depending on the user load.

In an ideal situation, measurements to assess the exposure to electromagnetic fields should be accomplished with the system working at full load (worst-case scenario). In practice, the load varies in an uncontrolled way during the measurement, so the maximum field level may be underestimated. The impact of this component of uncertainty in the field strength assessment will be here studied. Measurement uncertainties related to the probes used and environmental conditions are also computed to have a complete budget for a real exposure analysis.

II. TESTED WAVEFORMS AND ERROR DEFINITION

We have programmed a function that uses the Matlab® LTE System Toolbox™ to generate LTE waveforms with a user load varying from 0% to 100%, in 1% steps (see Fig. 1).



a b

Fig. 1 a) 0% of channel occupation for the 10 MHz signal b) 100% of channel occupation for the 10 MHz signal.

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Configuration of downlink reference measurement channel (RMC) was as follows:

- Single-antenna transmission
- 16-QAM modulation
- 1.4 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz bandwidths
- Randomly generated input user data stream

The ICNIRP guidelines discuss about worst-case exposure conditions referring to the establishment of the reference levels for exposure. However, they do not give indications about the techniques used to measure the physical quantities that characterize electromagnetic fields or about the measurement conditions [9]. Although it is not expressly mentioned, to assure the full compliance of a transmitter with safety limits, the evaluation of field level should be performed for the worst-case scenario of exposure, i.e. where the maximum field level is expected.

Now, let us define the error accomplished in the worst-case exposure assessment due to not knowing the user load Δload_i, as the logarithmic ratio of the maximum field strength, E_{max}, to the field strength for a specific percentage of user load i, E_i.

$$\Delta\text{load}_i = 10\log\frac{E_{max}^2}{E_i^2} \tag{1}$$

The maximum error in the worst-case exposure assessment, Δload_{max}, would be then given by the ratio of the maximum field level to the minimum one.

Even in the case there are no users in the network (0% of user load), some reference signals (CRS), synchronization signals (PSS and SSS) and information in control channels (PBCH, PCFICH and PHICH) are still present (see Fig. 1a). For the 20 MHz RMC signal we have used [10] that represents a resource consumption from 6.61 to 6.73% (depending on the elements of the PDCCH) when compared to the full charged channel. That means a difference of power from 11.72 to 11.80 dB when load varies between 0% and 100%. The field strength related to user load will linearly increase from the lowest (0%) to full load.

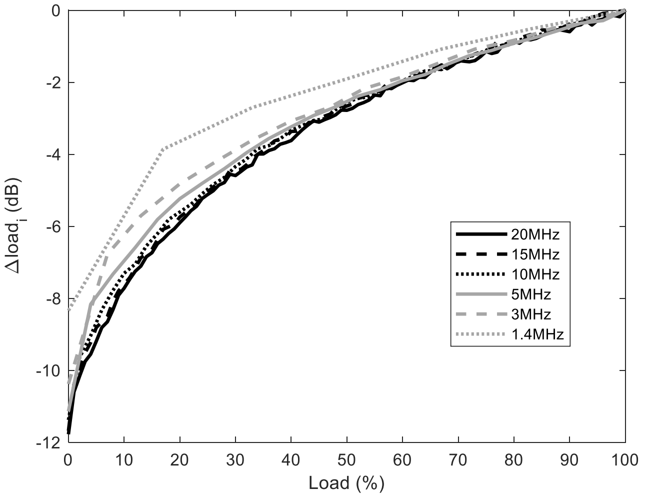

Fig. 2. Logarithmic ratio, $\Delta load_i$, of the maximum RMS field value to the RMS for each user load.

TABLE I
MAXIMUM EXPOSURE LEVEL ERROR $\Delta load_{max}$, DUE TO THE USER LOAD

BW (MHz)	Δload_{max} (dB)
20	11.77
15	11.68
10	11.38
5	11.14
3	10.37
1.4	8.34

III. SIMULATIONS

We have simulated a measurement event with an ideal probe (one able to measure the true RMS value of the signal) selecting from the waveforms generated in Matlab® as many samples as in a real case (measurements taken each 1 second over a 6 minute period as established in ICNIRP guidelines [9]).

Fig. 2 shows the ratio of the maximum RMS field value to the RMS for a given user load, for the different bandwidths. Table I summarizes the maximum error in the worst-case exposure level, Δload_{max}, for each bandwidth, as defined in the previous section. Values up to 11.77 dB are predicted.

In the simulations, the RMS field value increases with the user load, being the sharpest increment (in dB) in the first percentages of occupation. We have also to remark that the maximum error is larger the broader is the bandwidth.

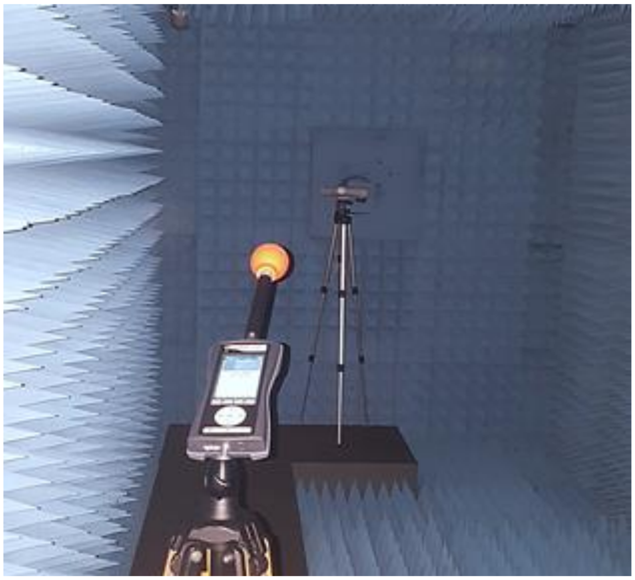

Fig. 3. Measurement setup.

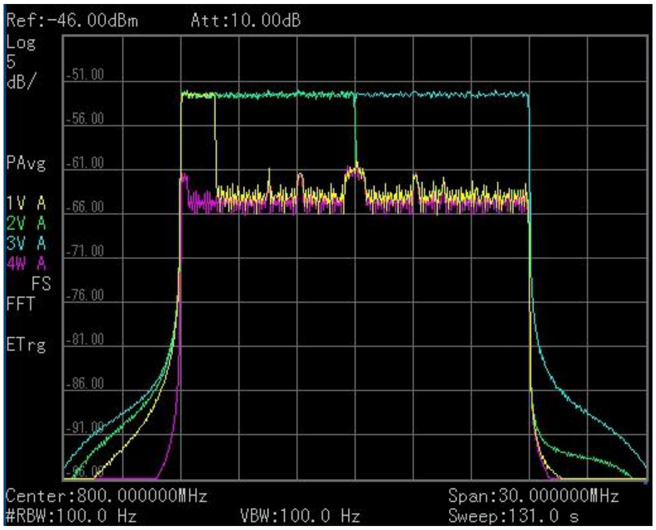

Fig. 4. Spectrum of the 0% (purple), 10% (yellow), 50% (green), and 100% (blue) load.

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IV. MEASUREMENTS

A. Setup and procedure

We defined the setup in Fig. 3, and implemented it in a full anechoic chamber, to evaluate the dependency of the signal level on the user load.

The chamber is a shielded room, coated by pyramidal absorber of 20 and 30 cm height at main reflection areas, which allow working from 500 MHz; and with an available volume of 5.5 m x 2.2 m x 1.8 m.

A signal generator SMJ100A from Rohde & Schwarz was used, setting its frequency to 800 MHz, as this correspond to the 'digital dividend' recently allocated in several countries for LTE [11]. The transmitted waveforms correspond to the ones with the different user load built in Matlab®, once converted to the signal generator compliant file. We have performed the measurements using the 20 MHz signals as the biggest error observed in the simulations occurred with this bandwidth. We also considered various user loads, separated in 10% steps, plus an additional point at 5% load. The spectrums with 0%, 10%, 50%, and 100% loads at the generator output depict Fig.4.

A 35 dB RF amplifier boosts the generator output before feeding an EM-6952 log periodic antenna.

On the receiver side, we have used two field probes located at the same position and connected to their proper readout unit:

- PMM EP300 with the 8053A reader
- Wavecontrol WPF3 with the SMP2 reader

Both probes make use of diode detectors and table II shows their main characteristics. They gathered the RMS value of the electric field for each transmitted signal measuring over 6 minutes [9], sampled at least each 1 second.

B. Results

Fig. 5 shows the measured RMS field strength at each user load normalized to the maximum RMS value recorded by each probe, $\Delta\text{load\_meas}_i$.

In the simulations, the more users in the network, the higher the received field. Performance observed at measurement results agrees with that previously computed (see maximum exposure level error in table III), exhibiting errors also around 11 dB. This is a tricky issue, as some legislations establish a lower fixed uncertainty level for these measurements. For instance, Spanish legislation sets a 6 dB margin [12].

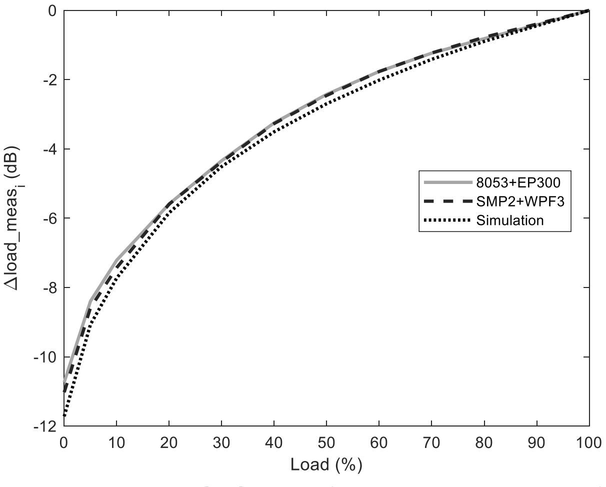

Fig. 5. Logarithmic ratio, $\Delta\text{load\_meas}_i$, of the maximum measured RMS field value to the measured RMS value for each user load.

Below 20% of user load, level differences with respect to the maximum load are above 6 dB. No substantial differences exist among instantaneous field values and the 6 minutes RMS. This could be due to the response of the probes that makes the measured value approach a fixed level as the modulation frequency grows [13]. Measurements taken with both probes are in good agreement, being 0.13V/m the maximum difference observed between them.

To that extent, we have studied the maximum error that could arise in worst-case exposure assessment due to not knowing the user load. In order to have a full uncertainty budget for a real assessment we should also to take into account another error sources (probe characteristics, environmental conditions, measurement repeatability), so the last step in this study was the estimation of the uncertainty of such components. Tables IV and V show the uncertainty budget related to each measurement case. Values in them represent the worst-case scenario where no corrections in the measurements are applied. Most of the components are systematic errors (type B evaluation), which contributions are extracted from the probe calibration certificates and datasheets [14]. Then, there is also a random component associated to the measurement repeatability. The coverage factor is k = 1.96 (level of confidence of approximately 95 percent), which is the recommended value for electromagnetic field strength measurements [15].

Thus, at this point if we put together the maximum error in worst-case exposure assessment due to an unknown user load, $\Delta\text{load\_meas}_{max}$, and the uncertainties associated to the probes and environment (Table VI), we can see that the first one represents the dominant contribution.

Correction of the measured values with the data given by probe calibration certificates (linearity and frequency response) will help to reduce uncertainty. Table VII presents the data in table VI after applying all the possible probe related corrections. However, uncertainty is still significantly high.

V. CONCLUSIONS

Results from this study reveal that errors when assessing the worst-case exposure to electromagnetic fields from LTE signals can happen due to uncontrolled variations in the channel occupation.

Simulation and measurements show that the signal level grows with the user load and that differences up to 11 dB can be found depending on the percentage of occupation. The uncertainty associated to other sources of error increases around 2.5 dB those induced by user load dependence.

TABLE II

CHARACTERISTICS OF FIELD PROBES

Probe	Detectors	Bandwidth	Dynamic range	Sensitivity
EP300	3	100 kHz – 3 GHz	0.1 - 300 V/m	0.15 V/m
WPF3	3	100 kHz – 3 GHz	0.2 - 130 V/m	0.2 V/m

TABLE III

MAXIMUM MEASURED EXPOSURE LEVEL ERROR $\Delta load\_meas_{max}$, DUE TO USER LOAD

Probe	$\Delta\text{load\_meas}_{max}$ (dB)
EP300	10.73
WPF3	11.02

TABLE IV

UNCERTAINTY BUDGET FOR THE FIRST MEASUREMENT CASE (EP300 PROBE)

Source	Reference	Value	Distribution	Divisor	Standard uncertainty (%)
Resolution	Datasheet	0.74%	Rectangular	1.732	0.42
Temperature	Datasheet	0.11 dB	Rectangular	1.732	0.74
Frequency response	Calibration Certificate	1.81 dB	Rectangular	1.732	13.38
Anisotropy	Calibration Certificate	0.21 dB	Rectangular	1.732	1.41.
Linearity	Calibration Certificate	0.34 dB	Rectangular	1.732	2.30
Calibration uncertainty	Calibration Certificate	2.10 dB	Normal (k=2)	2	13.68
Measurement repeatability	Measurement	3.24%	Normal (k=1)	1	3.24
			Combined standard uncertainty (%)		19.61
			Coverage factor		1.96
			Expanded uncertainty (%)		38.43
			Expanded uncertainty (dB)		**2.82**

TABLE V

UNCERTAINTY BUDGET FOR THE SECOND MEASUREMENT CASE (WPF3 PROBE)

Source	Reference	Value	Distribution	Divisor	Standard uncertainty (%)
Resolution	Datasheet	1.45%	Rectangular	1.732	0.84
Temperature	Datasheet	0,16 dB	Rectangular	1.732	1.06
Frequency response	Calibration Certificate	1,31 dB	Rectangular	1.732	9.40
Anisotropy	Datasheet	1.2 dB	Rectangular	1.732	8.55
Linearity	Calibration Certificate	0.26 dB	Rectangular	1.732	1.75
Calibration uncertainty	Calibration Certificate	1.46 dB	Normal (k=2)	2	9.15
Measurement repeatability	Measurement	3.24%	Normal (k=1)	1	3.24
			Combined standard uncertainty (%)		16.14
			Coverage factor		1.96
			Expanded uncertainty (%)		31.64
			Expanded uncertainty (dB)		**2.39**

TABLE VI

MAXIMUM MEASURED EXPOSURE LEVEL ERROR DUE TO THE USER LOAD AND MEASUREMENT UNCERTAINTY

Probe	Δload_meas$_{max}$ (dB)	Uncertainty (dB)	Δload_meas$_{max}$ + U
EP300	10.73	2.82	13.55
WPF3	11.02	2.39	13.41

TABLE VII

MAXIMUM MEASURED EXPOSURE LEVEL ERROR DUE TO THE USER LOAD AND MEASUREMENT UNCERTAINTY AFTER FIELD VALUES CORRECTIONS

Probe	Δload_meas$_{max}$ (dB)	Uncertainty (dB)	Δload_meas$_{max}$ + U
EP300	10.69	2.20	12.89
WPF3	10.82	2.09	12.91

The uncertainty in the assessment of the worst-case exposure coming from the fluctuations in the user load can be much higher than that provided by other factors, such as probe performance, environmental conditions or repeatability.

These results indicate that precise assessment measurements require to be done at periods of high occupancy or alternatively, to force the user load to 100%.

ACKNOWLEDGMENT

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