Statistical Analysis of Real Radiofrequencies Exposure in a Realistic Environment

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***Abstract*—In this paper, the general public daily exposure to radiofrequencies in indoor areas is investigated. The considered signals are FM, TV, and GSM over one day. The study focus on the determination of the distribution of FM, TV, and GSM signals in a realistic electromagnetic environment in Indoor distinguishing Urban and Rural locations. The goal is to analyze the real exposure compared to maximum assessment imposed by radio protection standards. 17 measurements in Urban and 6 measurements in Rural areas have been performed. A total of 145690 time samples per signal for Urban and 51420 time samples per signal for Rural were obtained from the measurement campaign.**

Keywords: statistics; electromagnetic field; exposure; radiofrequency

I. INTRODUCTION

THE public is exposed to radiofrequency electromagnetic fields emitted by wireless communication systems (cellular network, Wireless LAN as well as broadcast) and the total exposure has to be assessed in accordance with international guidelines. The exposure is assessed on the one hand to check the compliance to safety standards such as those from the Institute of Electronics and Electrical Engineers [2], and the International Commission on Non Ionizing Radiation Protection [1], and on the other hand to estimate the daily exposure.

The fundamental limits are recommended by ICNIRP and IEEE; these standards give the basic restrictions in order of limiting the whole body and local absorption. The Specific Absorption Rate (SAR), expressed in watts per kilograms is used to quantify the exposure. Previous works have investigated the relationship between the incident field and the whole body averaged SAR that allows establishing the reference levels under some assumptions.

More recently, the relationship between the Whole Body SAR and an incident plane wave has been investigated [3, 4] showing the absorbed power depending on the frequencies. However, the exposure in real environment is induced by multiple plane waves, therefore, the relationship between WBSAR and multiple plane waves or non uniform exposure has been investigated statistically [5, 6]. But in all the case, it is missed the comprehensive characterization of the real exposure facing the time variation of emissions.

Usually, electromagnetic-field measurements are performed in a real environment with a spectrum analyzer and an electromagnetic-field probe over a short period of time (typically less than one hour) because they are time and cost consuming. In practice, compliance tests are performed with "instantaneous" measurement which could be extrapolated to "worst-case". For example, for GSM, the extrapolation is based on the measurement of the BCCH (Broadcast Control Channel) and the TRX.

Compliance tests which have been performed so far don't take into consideration the fluctuations induced by different services i.e. Broadcast, Cellular Network and Wireless LAN e.g. the variation over time depends on the amount of traffic in Cellular Network contrary to broadcast where the signal remain relatively constant.

In this paper, temporal measurements and distribution of the exposure to FM, TV, DTV, and GSM during a day at different indoor sites (Urban/Rural) are presented. The purpose of this paper is to show the distribution of the exposure to FM, TV, DTV, and GSM in indoor distinguishing Urban and Rural locations and to give the Probability density function (PDF) for extrapolation of measurements made during shorter periods of time in the day instead of one or more days.

II. STATISTICAL ANALYSIS OF SIGNAL VARIATIONS

The measurement have been done every 10s for each signal in a real indoor environment, we made 17 measurements in 8 different sites in Urban and 6 measurements in 3 different sites in Rural. Performing each of these measurements during one day results in a total of 8570 measured samples per signal. The total number of samples is 145690 time samples per signal for Urban and 51420 time samples per signal for Rural. Special software has been developed for automatic measurement, using a spectrum analyzer, and a isotropic tri-axial probe according to EN50492 standard.

The frequency center and the span defined in the software are given in the Table I.

ANR MULTIPASS PROJECT, http://multipass.elibel.tm.fr/

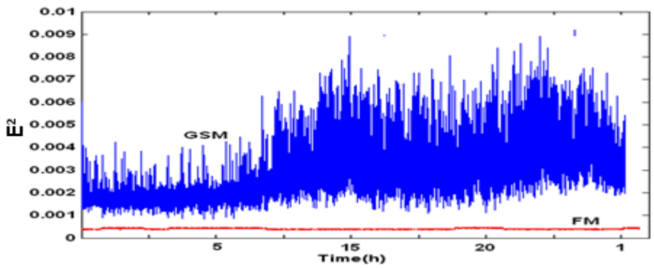

Figure 1. Variation of the electric field for FM and GSM during one day

TABLE I
Description of the frequency center and the span used during the measurement

Band	frequency center (MHz)	Span (MHz)	Description
FM	97,5	21	FM radio broadcasting
TV1	199	50	TV broadcasting
TV2	670	400	Digital TV broadcasting
GSM900 downlink (RX)	945	40	Transmission from base station to handset

In Joseph et al. [7], it is stated that the variation of GSM is much higher than the variation of the FM signal. In fact, GSM delivers the highest field variability and their variation over time depends on the traffic demand. Physicals changes in the environment and traffic cause variations in time of the electric field's amplitude. The FM and the TV signals remain relatively constant. The fields of GSM are higher during daytime than at night. Therefore, we distinguish Broadcast networks from wireless communication networks because of the traffic load in GSM.

A. Broadcasting emissions (FM and TV distribution)

Fig. 2 shows the Normal distribution fit of all the measured electric field values for FM (same conclusion for TV1 and TV2) in Urban and in Rural. We normalize the square field E by the mean E^2 for each measure in order to merge all the measurements and to establish a global distribution of the signal variation.

The results show that FM, TV1, and TV2 have been found to follow a Normal distribution in both Urban and Rural using the log-likelihood test.

The Normal distribution has a PDF as

$$P(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}. \qquad (1)$$

The μ is the mean, the parameter σ^2 is called the variance, as for any real-valued random variable, it describes how concentrated the distribution is around its mean.
The parameter a = σ/μ is called the coefficient of variability. This parameter is important to show the variability around the mean, it represents the time variation of the considered signal. The coefficients of variability are given in the Fig. 3 for the different sources.
The coefficient of variability in Urban is bigger than in Rural due to the presence of the fading which produce high variability of the field. The variability is around 20% in Urban and 5% in Rural.

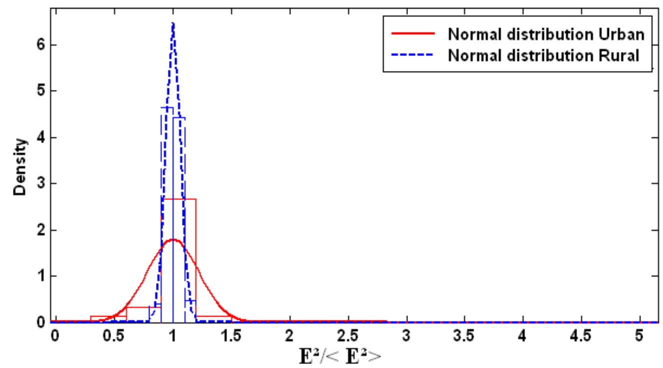

Figure 2. Distribution of FM in Urban and in Rural (dotted line)

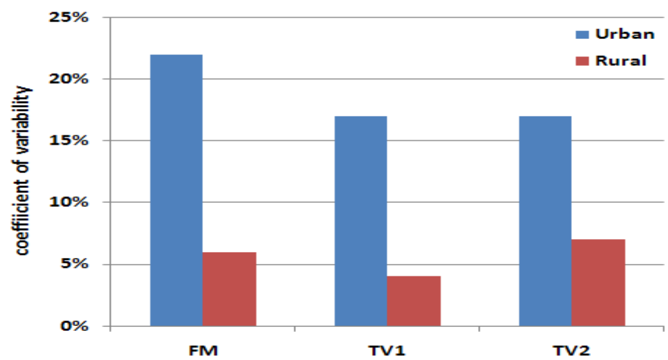

Figure 3. Coefficient of variability for FM, TV1 and TV2 (Urban and Rural)

If one performs short-period measurements, one should use the mean μ for this measurement, the coefficient of variability in the Fig. 3 and the equation (1) in order to obtain the true distribution during a longer period (a day).

- *Influence of the rolling average*

All the measurements have been done every 10s as mentioned above, we performed a rolling average for these measurements in order to see the influence on the mean and on the deviation of one day. In addition, one measurement every 0.20s was performed for GSM during one day results in a total of 65536 measured samples to see if there is any change if the measurement would have done with smallest time sampling. We took different rolling average values (30s, 1min, 2min30s, 6min, and 8min) for all the measurements taken every 10s (measure 1) and for the GSM measurement (measure 2) which have taken every 0.20s; the results are given in the Fig.4 which shows that the calculation of the mean of E^2 over 24h is not influenced by using different rolling average values, the mean over 24h remains constant. Hence, the sampling rate has no influence on the mean value over 24 h. Contrariwise, the deviation decreases with the increasing of the rolling average value, it is sensitive with a small time sampling (presence of the Fading).
Our study is focused on the real measurement taken every 10s with no rolling average.

B. Wireless signals (GSM)

Fig. 5 shows the distribution (in gray) of one measurement of the measured electric field values for GSMRX. This Figure demonstrates that GSM received signal (noted GSMRX)

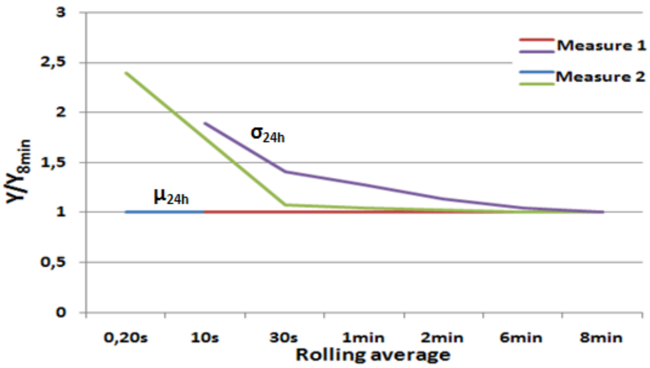

Figure 4. Influence rolling average values on the mean (μ) and standard variation (σ)

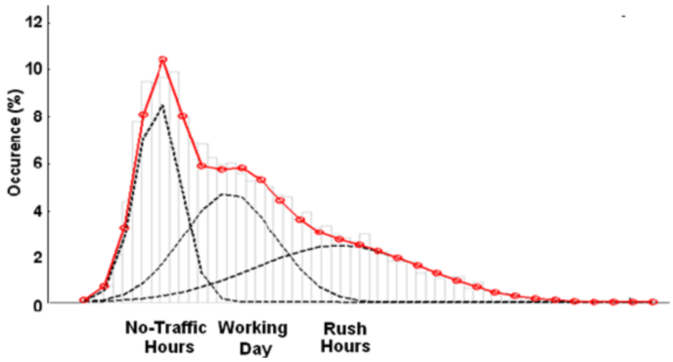

Figure 5. Distribution of GSMRX (gray bars). The line marked by circles is the sum of the three Gaussians.

doesn't fit a Normal distribution or any other known (lognormal, gamma, Rayleigh, Rician, exponential law, Beta, Weibull) distribution. It shows different peaks during the day depending on the traffic demand.

The electric field amplitude increase with the traffic, and as shown in the Fig. 5, the distribution could be a mix of different Gaussian (dotted line Gaussian); therefore we can predict that GSM should have a Multi-Gaussian distribution.

A Gaussian mixture decomposition model is constructed based on the EM algorithm (Expectation Maximization).

The Gaussian mixture decomposition was tested using 2, 3, 4 and 5 Gaussians. We found that only 2 or 3 (depend on the measurement and so on the location) for all the measurements is the optimum to characterize the daily variation of the GSMRX signals (see Fig. 6). We found that 50% of all the measurements in Urban and 100% of all the measurements in Rural have a mixture of three Gaussians. Therefore, three mixture Gaussian distribution model is the most representative model for a GSM distribution.

The Probability density function for GSMRX is a mix of a three Gaussian so it could be given as

$$P(x) = p_1.P_1(x,\mu_1,a_1) + p_2.P_2(x,\mu_2,a_2) + p_3.P_3(x,\mu_3,a_3). \qquad (2)$$

With $P_i(x,\mu_i,a_i)$ is given by the (1), the parameters $a_i = \sigma_i/\mu_i$ are the coefficient of variability and p_i are the class membership probability estimates of the ith Gaussian (i = 1, 2 and 3).

We should find the relation between μ_1, μ_2, and μ_3, the coefficient of variability a_1, a_2, and a_3 and the values of p_i to determine the Probability density function of the GSMRX.

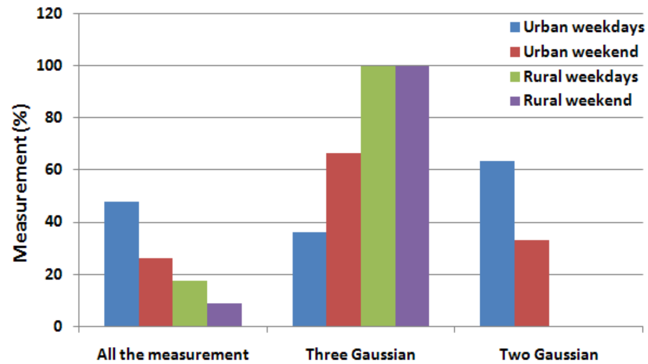

Figure 6. Number of Gaussian found for all the measurement (Urban and Rural)

We added 9 measurements performing in Poland during 9 days in two different locations to compare the results, the measurement have been done every one minute, 1440 measurements per one day.

The average values of the different ratio are given in the Fig. 8.

The results in France (Urban) compared with Poland show that the distributions are almost the same and equivalent behavior is observed.

Fig. 7 shows the three Gaussian models for the GSMRX in Urban and in Rural.

The first Gaussian is probably represents the Electric field distribution when there is no (or few) traffic. This was verified comparing the first Gaussian to samples during the night (from 1am to 5am) and a very good agreement was observed (see Fig. 9).

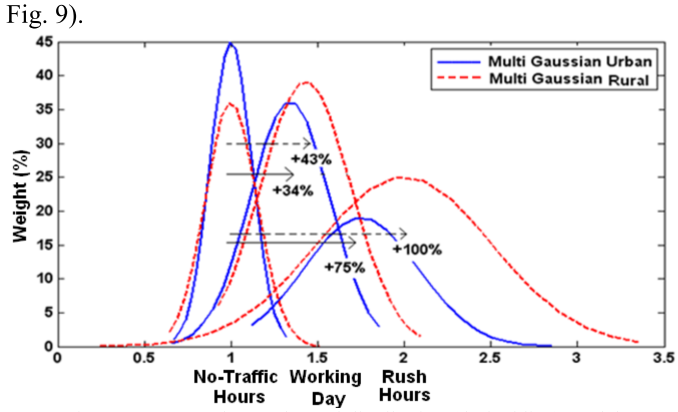

Figure 7. GSM Urban and Rural distribution (dashed line) model

Therefore, the first Gaussian represents the distribution of the Electric field when there is either no traffic or a little of ongoing communication (No-Traffic Hours). The second one represents the Electric field when there is communications (Working Day) with an increase in traffic of 40% compared to the No-traffic Hours. The last Gaussian correspond to a maximum of traffic which can be reachable mostly at the Rush Hours (12am-2pm and 6pm-10pm) with an increase in traffic of 100% compared to the No-Traffic Hours. The coefficient of variability is roughly the same (around 20%) for the three Gaussians in Urban and in Rural.

Urban and Rural results in France show that the ratio of Gaussian means in Rural is higher than in Urban due to high power transmitting in Rural (large cellular coverage) and because of the propagation path loss.

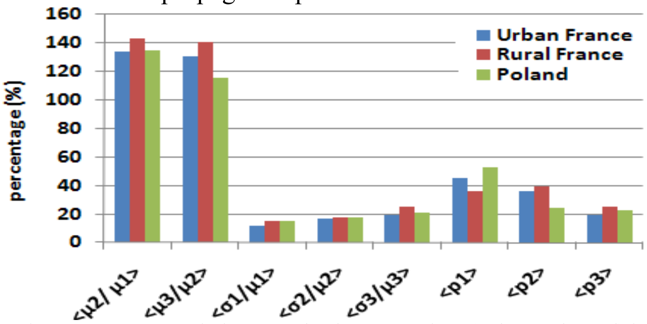

Figure 8. Average ratio between the three Gaussians (Urban and Rural) in France and Poland

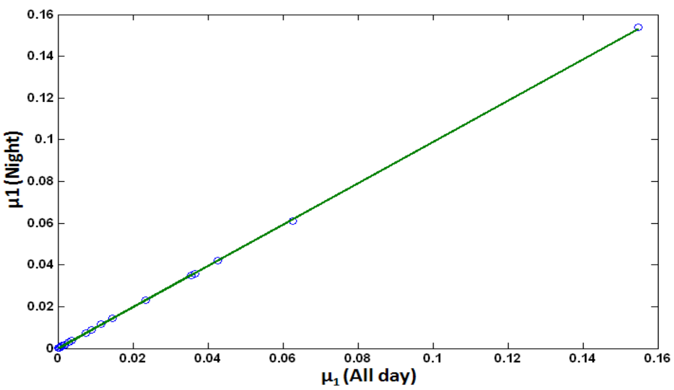

Figure 9. Comparing μ (First Gaussian) during all the day with the night

III. SYNTHESIS

FM, TV1, and TV2 have a Normal distribution in both Urban and Rural areas, the PDF for these signals are:

$$P_{FM,TV1,TV2} = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}.$$

The coefficient of variability in Urban (around 20%) is bigger than in Rural (around 5%) due to the presence of the fading which produce high variability of the field.

GSMRX have a three mixture Gaussian distribution model, the PDF is:

$$P_{GSMRX} = 0.45\ P_1(x,\mu,a) + 0.35\ P_2(x,1.4\ \mu,a) + 0.20\ P_3(x,2\ \mu,a).$$

With $a = \sigma/\mu = 20\%$.

The first Gaussian represents the Electric field distribution when there is no traffic that means mostly during the No-Traffic Hours and especially in the night from 1am to 5am, the second one represents the Electric field during the working day and the last Gaussian when there is a maximum of traffic which can be reachable at the Rush Hours (12am-2pm and 6pm-10pm).

The model given in (2) shows that the traffic variation follows a mixture Gaussian decomposition corresponding to three different usages: No-Traffic Hours, Working Day and Rush Hours (three levels).

It is found that a maximum realistic traffic induce a low rise of the received power between the maximal (Rush hours) and the minimal (No-Traffic hours).

The number of TRX is shown to have no influence on the average received power in real environment. Hence, full traffic situation is never reached even if instantaneously (Time slot scall) this can happen.

IV. CONCLUSION

Temporal RF exposure of the general public in indoor during a period of one day is investigated in this paper. Physicals changes in the environment and varying amount of traffic cause variations in time of the electric field's amplitude. The FM and the TV signals remain relatively constant so that these signals fit a Normal distribution while GSM field values are variable and higher during daytime than at night due to the traffic presented during the day. GSM fit a three Gaussian distribution model.

The main conclusion is that an instantaneous measurement of the received power is stable and reproducible metric assuming a $\pm$ 1.5dB uncertainty over the day.

This study will be continued to assess real exposure and to characterize the ratio between daily and maximum theoretical values.

This work is of interest for elaborating standards of exposure based on measurements in operating systems.

V. ACKNOWLEDGMENT

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