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Measurement and analysis of human exposure to electromagnetic fields in the GSM band

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ABSTRACT

The paper presents the results of an experimental activity aimed at investigating the statistical properties of the exposure to electromagnetic radiation generated by the GSM cellular system. Many channels radiated by sources at different distance from the measurement point were monitored for seven days to obtain long-term samples of the peak and average *rms* strength over six minutes. The purpose of the research is to shed new light on the time patterns and amplitude distribution of the exposure level, with the intent to study: (1) the relationship between peak and average strength so that the worst case exposure can related to the average exposure, which is the quantity that measurement standards focus on; (2) variations of exposure with traffic conditions.

1. Introduction

Human exposure to electromagnetic radiation (EMR) has been a recurrent research topic over the past decades for the alleged hazard to human health for both occupational and general public exposure. Medical research, experimental evidence and epidemiology studies resulted in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines published in 1998 [1] (and revised in 2003 [2] and 2009 [3] for the low and high frequency range, respectively) that the European Council has adopted as the main reference for its Recommendation published in July 1999 to establish the maximum field strength of EMR between 0 Hz and 300 GHz for general public exposure [4]. Although it is only a recommendation and not a directive [5], the document has been promptly considered by many International and National guidelines or regulations as the reference to rely upon for limiting exposure. Technical bodies have then issued specific measurement standards [6–8] indicating the most appropriate procedure to assess exposure levels, usually suggesting a 6-min average although an extrapolation procedure is often suggested to assess the worst-case exposure. For the GSM system, such procedure relies upon the measurement of the Broadcast Control Channel (BCCH) strength which is then multiplied by $k = \sqrt{1 + n_{TCH}}$, where n_{TCH} is the total number of Traffic Channels (TCH) associated to the measured (BCCH).

Because of the pervasive presence of wireless networks over the territory, population is mostly concerned with high frequency radiation exposure, which has therefore gained quite a large interest in the scientific community. More specifically, GSM, UMTS and LTE mobile systems and, although to a lower extent, wifi systems are the sources that are most frequently studied. The European Union itself is deeply involved in research programs dedicated to electromagnetic fields exposure and has recently funded the *Low EMF Exposure Future Networks (LEXNET)* project [9] under the FP7 program, to reduce by 50% at least the exposure of population to (EMR) without compromising the quality of service.

An extremely extensive study conducted on health effects is *The Interphone Study* [10] by the WHO/International Agency for Research on Cancer(IARC), the main results of which can be found in [11,12] and are briefly summarized in [13]: *A reduced odds ratio*[2] *for glioma and meningioma related to ever having been a regular mobile phone user possibly reflects participation bias or other methodological limitations. No elevated odds ratio for glioma or meningioma was observed more than 10 years after first phone use. There were suggestions of an increased risk of glioma, and much less so meningioma, in the highest decile of cumulative call time, in subjects who reported usual phone use on the same side of the head as their tumor and, for glioma, for tumors in the temporal lobe. Biases and errors limit the strength of the conclusions that can be drawn from these analyses and prevent a causal interpretation.* More informally, there is no evidence of a link

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[2] *The odds ratio is a measure of relative risk. In other terms, an odds ratio of x means that people exposed have x times the risk of non-exposed people.*

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between long-term mobile telephone use and increased risk of cancer, based on the results of the Interphone study. Also for this reason, in 2011 IARC has classified radiofrequency electromagnetic fields (EMF) as *possibly carcinogenic to humans* (Group 2B) [14]. According to the definition provided by IARC, Group 2B is used for *agents for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals. It may also be used when there is inadequate evidence of carcinogenicity in humans but there is sufficient evidence of carcinogenicity in experimental animals* and includes about 250 substances, mostly chemical compounds but also many familiar items like coffee, pickled vegetables, carbon paper, gasoline exhaust, talcum powder, and nickel (coins).

Because of the concern about health effects (e.g., [15, Table 1] shows that in Italy 69% of the population is sensitive to the topic), a wide range of studies about exposure levels is available in the scientific literature. In [16–18] the field strength in the vicinity of GSM/UMTS base stations installed indoor or on buildings and in the vicinity of stations' mast is investigated, respectively. Measurement data are processed to obtain the main summary statistics (minimum, maximum, median, mean) of wideband exposure at increasing distance from the source. In [19] an extensive measurement campaign was carried out in response to residents' complaints of over-exposure. Compliance with the ICNIRP guidelines and Chinese environmental EMF safety standards was assessed and the results forwarded to citizens to promote correct public perception of the radio-frequency (RF) EMF exposure from base stations. In [20] a two-step procedure is proposed that, after building a preliminary regression map using *kriging* [21], makes use of an iterative sampling strategy that selects new measurement locations based on the prediction uncertainty of the model. Narrowband measurements at hotspots were also made to extract the frequencies with the most relevant contribution to the overall exposure. In [15], samples of electric and magnetic field strength and electromagnetic power density taken at increasing distance from a base transceiver station (BTS) are analyzed. One interesting outcome is that the actual radiation pattern of a GSM base station is very close to the theoretical one when the propagation occurs in the absence of reflectors along the line-of-sight path. Paper [22] presents a mobile measurement system to assess the effect of power control algorithm on the Specific Absorption Rate (SAR) in a real exposure scenario. It focuses on the change in the radiation level between the initiation of a call and its handover between cells, comparing results from different mobile devices and propagation channels (i.e., urban and rural areas).

Measurement methods are also of great interest in the international research community because of the impact that the measurement procedure and instrument configuration has on the measured exposure. In [23] we have investigated the effect of the measurement methodology on the maximum exposure E_{pk} and found that a conservative value depends on the specific type of channel (i.e., BCCH or TCH) and its traffic load. In [24] a comparison between the 6-min averaging time stipulated by standards to other averaging times is provided. It is shown that the averaging time can be reduced at the cost of a small increase in measurement accuracy and uncertainty. Time variability of exposure is also studied in [25], where it is investigated how short-period measurements can be representative for the actual maximal and average exposure during longer periods. Also, factors that correlate short- and long-period measurements are introduced. In [26] a method is proposed to estimate the field strength in a point in time by using exposure from another instant. The proposed method, however, makes use of the Erlang data (i.e., network traffic intensity data) that are usually not disclosed by service operators. Amplitude fluctuations of the GSM-generated EMR are assessed in [27] by means of standard deviation and Allan variance [28] in order to obtain information about the type of noise, drift and stability of samples [29,30]. Measurement architectures for long-term exposure in four different bands and distributed systems for large area monitoring are proposed in [31,32], respectively.

Statistical characterization of exposure over time is the topic of [33], where it is found that the distribution of the power density S can be described by the sum of three Gaussian distributions representing different time intervals during the day (night hours, rush hours and work hours) and that the ratio between the three average values is constant in all sampled locations. Also, the ratio between the total power density S and the power density of the BCCH S_{BCCH} (i.e., the equivalent number of TRXs channels N_{TRX}) is investigated, and found to be typically less than 4 for the GSM900 network. Results show that exposure from a GSM900 and GSM1800 cell can vary by ± 4.5 dB throughout the day because of traffic variations. Focus on the measurement method that accounts for time variability of exposure is given in [34], which proposes a dual frequency & time analysis of the downlink GSM band. A *weighting factor* is introduced to obtain the average exposure for each GSM channel from the maximum exposure. By this approach, each channel can be appropriately weighted when used to assess that average exposure in the whole GSM downlink band. Comparison with the methodology reported in [7,6] shows that assessment by the standards can overestimate exposure by an amount between 25% and 60%. Although pretty accurate, the method proposed is time consuming because it requires each channel of interest to be measured separately in the time domain to obtain the weighting factor.

Configuration of the measurement instrument is the main focus of [35]: influence of the resolution bandwidth (RBW) and sweep rate (SWR) of the spectrum analyzer (SA), of the channel traffic, and of the constant bit sequences on EMF strength measurements and rejection of adjacent channels is studied through a Simulink® model of the GSM transmitter and SA. The optimal configuration for narrow-band measurements is then proposed as follows: $RBW = 30\,\text{kHz}, \text{SWR} \leqslant 20\,\text{MHz}$. Model predictions are in good agreement with experimental results.

This paper presents a methodology to assess exposure to EMR in the GSM band taking time variability into account. The main originality stands in the contemporary acquisition of both peak and average exposure with narrow-band instrumentation, so that their time variation can be accurately correlated, differentiating between BCCHs and TCHs. This approach allows for comparisons between a conservative value of the exposure and the average exposure referenced by the measurement standards. Measurements are acquired over one week to highlight differences that may arise between days that are nominally identical, like working days. The goal is to provide a critical discussion of the measurement methods provided by the standards [6–8]. The statistical analysis was performed with the *R-project* [36] software.

2. Methodology, experimental setup and results

Measurements were taken with the measurement system shown in Fig. 1, composed of a SA and a vertically polarized biconical antenna at 170 cm above the floor, working in the frequency range from 800 MHz to 2 Ghz. A 7 m coaxial cable was used to connect the antenna and the measurement instrument. Voltage readings $V_{\text{dB}}\mu\text{V}(f)$ from the SA were converted to E-field strength ($E_{\text{dB}\mu\text{V/m}}(f)$) through antenna factor $AF_{\text{dB/m}}(f)$ and cable attenuation $\alpha_{\text{dB}}(f)$ values, according to the equation:

$$E_{\text{dB}\mu\text{V/m}}(f) = V_{\text{dB}\mu\text{V}}(f) + AF_{\text{dB/m}}(f) + \alpha_{\text{dB}}(f), \qquad (1)$$