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A model for approximating the EMF variability from cellular telephony base stations

Abstract. *Long-term EMF measurements in the vicinity of several base stations indicate that regardless of the base station type (GSM or UMTS), a similar repeatable pattern in the radiation characteristics has been observed associated with different user activity schemes over a 24-hour long period. However, such precise logging requires large amount of data needs to be collected. In order to compress the numerous readings a simple piece-wise linear model has been proposed to describe the measured characteristics with as few as 14 parameters.*

Streszczenie*. Długo-zmienne pomiary w pobliżu wielu stacji bazowych wskazują na to, że bez względu na rodzaj stacji (GSM lub UMTS) daje się zaobserwować podobny, powtarzalny wzorzec charakterystyki promieniowania związany z różną aktywnością użytkowników w trakcie cyklu 24-godzinnego. Jednakże, tak precyzyjna rejestracja wymaga zebrania dużej ilości danych. W celu kompresji licznych odczytów zaproponowano kawałkami liniowy model do opisu zmierzonych charakterystyk za pomocą jedynie 14 parametrów. (****Model aproksymacji zmienności pola elektromagnetycznego od stacji bazowych telefonii komórkowej****).*

Keywords: electromagnetic field, variability, compression, radiation.
Słowa kluczowe: pole elektromagnetyczne, zmienność, kompresja, promieniowanie.

Introduction

The electromagnetic field (EMF) especially emitted by radiocommunication systems, is nowadays considered as one of the factors impacting the environment. Electromagnetic emissions are liable to regulations as regards both the correct spectrum management as well as environmental and human exposure. The permitted EMF levels in the environment, the measurement methodology and the rules of evaluating compliance with requirements, are contained in a set of norms, legal enactments, directives and recommendations [1,2,3]. The analysis of the permitted EMF levels cited in these sources, demonstrates however a significant differences in the EMF impact evaluation on the environment. Biomedical research on the EMF impact have been carried out for a few decades, but relatively few well-documented investigations can be actually found. This is chiefly due to the lack of a properly documented evaluation of the actual EMF exposure in the appropriate time perspective. At the time when the broadcast transmitters – usually large-power ones, localized in selected areas – were the basic EMF sources, it sufficed to evaluate the environmental exposure thru single measurements at representative points. It was also relatively easy to determine the exposed and the control group. The recent two decades have brought remarkable changes to the EMF morphology in the environment. It is a results of changes in the nature of the newly appeared EMF sources. There has been observed a significant scattering of the sources associated with the development of the mobile radiocommunications, such that presently the base stations of these systems are dominant EM emitters to the environment. The base stations operate with relatively low levels but they are numerous and deployed at very different sites beginning with antenna towers thru building roofs and indoors. Another feature of sources belonging to this EMF class is a variable transmitter power dependent of the telecom traffic intensity and propagation conditions between the base station and the user terminal. In order to evaluate the real environmental exposure to the EMF form these systems it is indispensable to carry out long-tem monitoring measurements.

Monitoring EMF measurements from cellular telephony base stations

Monitoring measurements are carried out according to various schemes; a general rule remaining such that it is possible to recreate, sufficiently accurately, the real sequence of changes in the EMF at the measure point. It means, among others, that there should exist a possibility to detect and eliminate any artifacts such as, for instance, instantaneous fades or unjustified peaks in the measured EMF. This feature requires that appropriate amount of data be initially gathered which, after their processing, will lead to the achievement of the final effect. Such data collected in a long period will become a basic tool for long-term evaluation of the environment exposure to EMF.

In order to determine the EMF level variability in time a number of monitoring measurements have been carried out with the use of both wideband and selective meters. Measurements with the wideband meter were performed in the direct vicinity of the base station transmit antennas in such a manner as to minimize the influence of other EMF sources. Measurements with selective meters were carried out at greater distances, monitoring radio channels of a particular base station. In order to minimize the amount of the collected data, long-term variability of the electric strength in the vicinity of BS was investigated in the first place. Example outcomes are presented in fig.1.

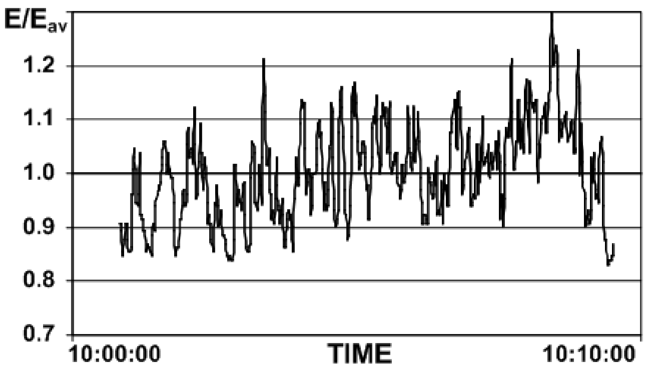

Fig.1. An example of EMF measured with 1 second sampling period in the vicinity of a base station

In general, during a normal traffic, changes in the field strength do not exceed 10% between successive samples spaced a second from each other. A broader analysis allowed to assume the sampling period equal to 30 seconds. Longer intervals between samples could have lead to a risk of losing significant information, especially in the low telecom traffic period [4].

More than a hundred monitoring sessions, each lasting from 3 up to 10 days have been carried out, with the sampling period between 10 and 60 seconds. However for the purpose of evaluating the EMF time variability in the base station vicinity, the following algorithm has been accepted: a minimum repeatable EMF level is found from the entire monitoring session and this value is treated as reference to which all other values are normalized. In this way the EMF variability coefficient is obtained in a direct fashion.

Measurements were performed in the neighborhood of base stations of different localizations which also implied different telecom traffic characteristic. The analysis of the achieved results allows one to assume that the electromagnetic field level is variable in time with the a variability repeatable with a daily cycle. On weekends, the maximum EMF levels were observed to be lower by c.a. 20-30%, though this figure cannot be considered a rule. This statement refers to typical base stations which the authors considered to be stations servicing condominium districts, suburbs, rural and urban areas. In each of these cases a similar scheme of the EMF variability in time has been observed. Beside the mentioned base stations, there are stations servicing specific areas, e.g. large fairs sites and football pitches, railway stations and airports, leisure areas etc. The EMF time variability in the base stations vicinity is directly bound to the subscribers' activity in that area. Consequently, the EMF level variability in their vicinity can be quite different than it would be with base stations considered as typical. For instance, base stations servicing fairs reach the maximum activity during the fairs, after which the traffic practically drops down to zero. In the activity period the base stations often operates at a full load, and in the case of the UMTS – also with the full transmitters power. In the GSM system, even with a full station capacity, the transmitters powers are not maximum which results from usually good transmission conditions. Such a base station is characterized by the EMF variability level in time not much different than that from typical base stations.

A proposed simplification of the measured characteristic

As was stated in Section 2, measurements performed with a significant (and sufficient) resolution, exhibit a considerable changeability of the power emitted by a base station with time. The measurements carried out in the full day cycle for four different cellular network transmitters are presented in fig.2 and fig.3 showing the normalized electric field strength.

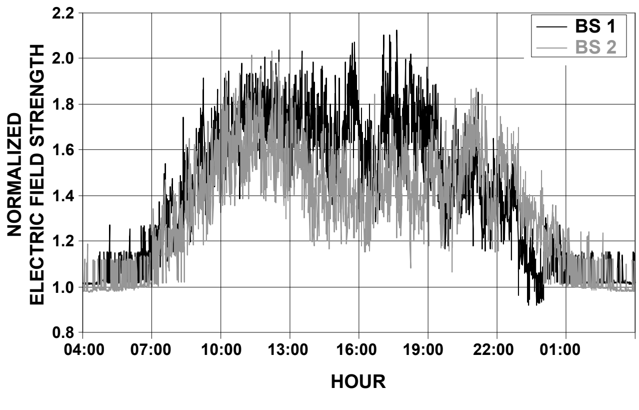

Fig.2. Emitted radiation measured from base stations no. 1 and 2

As once can see, despite this fast-varying nature of the obtained outcomes seen in the presented diagrams, there is a clearly distinguishable tendency in a large scale, common to all of the examined base stations. Namely, after a decreased activity transmission period falling into the night and early morning hours (i.e. between c.a. 1 a.m. and 7 a.m.), base stations start transmitting with a progressively rising slope until a stable region is reached (i.e. between c.a. 7 a.m. and 11 a.m.) corresponding to peak telecom traffic hours. From this point on the readings persist at a more or less constant level until the end of the workday (at c.a. 7 p.m.) where-from following a downward swoop until it reaches the lowest user activity period at late night hours and remains in this state until 1 a.m.

To summarize, all of the 2880 samples can therefore be as well represented by a trapezoidal characteristic, as shown, for example, in fig.4. In this form it is fully defined by four manually selected markers (M_1–M_4) determining the limiting boundaries dividing the characteristic into the flat (R_1 and R_3), rising (R_2) and falling (R_4) regions.

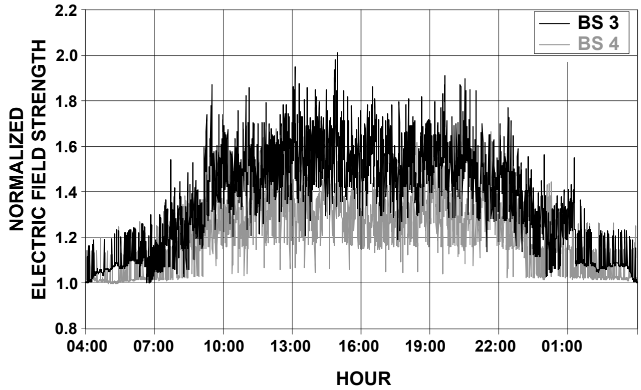

Fig.3 Emitted radiation measured from base stations no. 3 and 4

A practical justification to such a treatment of the measured data can be derived from the fact that such measurements, to be reliable, are usually performed periodically in a great number. The data thus obtained poses some obvious inconvenience regarding their storage and comfort of fast display and analysis. Therefore, the authors recommend a simple method of com-pressing the numerous samples (as a reminder: 2880 samples taken during a day from a single base station for the sake of accuracy) into a set of ten parameters, as will now be explained.

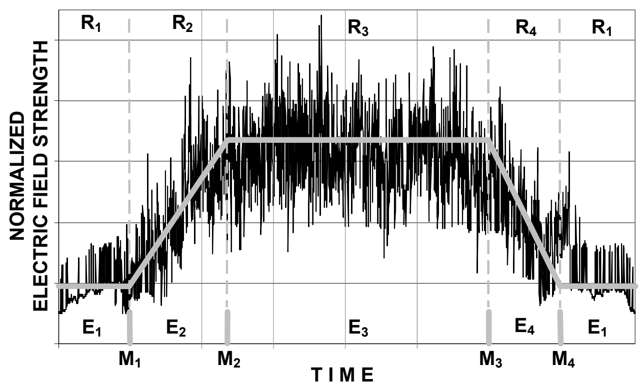

Fig.4 A proposal for a simplified model of the base station emissions

The extraction of large-scale parameters with which to mathematically express these regions may be done by either simple arithmetical averaging (for the flat region) or by performing the linear regression for skew regions (R_2, R_4), as given by equation (1). It is further assumed that all emissions in R_1 region are solely due the technical traffic, carrying no or negligible user traffic.

$$E_{\mathrm{eq}} = \begin{cases} b & \text{in regions } \mathrm{R}_1, \mathrm{R}_3 \\ m \cdot E_{av} + b & \text{in regions } \mathrm{R}_2, \mathrm{R}_4 \end{cases} \tag{1}$$

The equivalent value of the measured electric field E_{eq} has therefore, in general, two coefficients – the directional m coefficient (equal to zero in the flat regions thus omitted in the formula) and four absolute terms b. Both can be calculated from the set of sampled field values E_i according to equation (2), where E_{av} stands for the average electric field over the entire range of interest, t_i represents the discrete instances where the i-th field sample E_i was measured and t_{av} denotes the mid time of the region.

$$\begin{cases} m = \dfrac{\sum (E_i\text{-}E_{av})(t_i\text{-}t_{av})}{\sum (E_i\text{-}E_{av})^2} \\ b = E_{av}\text{-}m \cdot t_{av} \end{cases} \tag{2}$$

It is obvious that this way of simplifying the full characteristic inevitably and irretrievably leads to some loss of information on the small-scale behavior. In order to at least partially preserve some vestigial data on this effect for future use, it is proposed to find the standard deviation σ of the electric field individually for each region prior to its simplification, which adds extra four parameters (σ_1–σ_4) to the previous set of 10 describing the long-term behavior, yielding eventually 14 parameters in total. The value of σ will therefore be a representative measure of the dispersion in the original electric field value from the straight-line trend obtained by means of the linear regression.

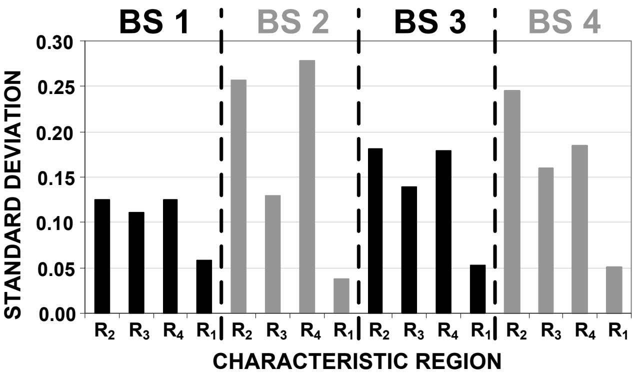

Fig.5 Standard deviations obtained in different regions for base stations BS1-BS4

The observation of σ obtained for different regions (see fig.5) for all base stations leads to an interesting corollary that regardless of which BS is analyzed, the traffic is most uneven in terms of its standard deviation in the rising (R_1) and falling (R_4) regions. In the peak telecom intensity region (R_3), though the absolute e-field values are the greatest, as for the traffic diversity it is less severe than in the neighboring regions. Quite expectedly, in the lowest-activity hours (R_1) both the absolute e-field value and the traffic diversity is also the lowest of all regions.

Concluding, the set of fourteen parameters to which the initial characteristic has been reduced includes:

- four markers M_1–M_4,
- straight-line coefficients: {b_2 ; m_2} and {b_4 ; m_4} for regions R_2 and R_4, respectively;
- average (peak) emission value in regions R_1 and R_3;
- four standard deviations (σ_1–σ_4).

For the purpose of long-term trends analysis such as monthly or annual, it may turn out to be useful to calculate the day-averaged $EMF_{av|24h}$.

Conclusions

The analyses presented herein, based on a representative number of monitoring EMF measurements in the surrounding of the cellular system base stations, allow to draw the following conclusions:

- the EMF from a base station is cyclically variable with a 24-hour repetition period;
- the daily variability exhibits two periods of nearly constant EMF level and two transition periods;
- the EMF variability can be described with a simplified model presented in the work, which allows to remarkably reduce the amount of data obtained during the monitoring measurements, still preserving vital information on the EMF variability;
- the assumption of the algorithm proposed in the paper (i.e. referencing the variability to the minimum value) allows to utilize the attained data for a long-term estimation of the EMF intensity, based on a single measurement [5]. In this case the modeled data are to be treated as correction factors to the measurement result.

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