MEASUREMENT AND PROCESSING TECHNIQUES FOR THE EXPOSURE ASSESSMENT OF ELECTROMAGNETIC FIELDS OF BASE STATIONS USING SPREAD-SPECTRUM MODULATION

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ABSTRACT

When executing frequency-selective measurements around GSM/UMTS base stations to check the compliance with exposure guidelines, the use of spread-spectrum techniques should be taken into account when interpreting the measurement results and when estimating the exposure in the worst-case situation. In this paper techniques for measuring GSM signals using frequency hopping and processing the obtained measurement results are discussed. The measurement of a WCDMA signal used in UMTS with a spectrum analyser is also studied by means of a simple simulation model.

INTRODUCTION

In the last years, people are more and more concerned about the possible health-adverse effects of electromagnetic radiation. Due to the large number of installed base stations, many people are confronted with base station antennas in their neighbourhood and are worried about their exposure to the electromagnetic radiation originated by these base stations. To provide protection against excessive exposure to electromagnetic fields, authorities have issued maximum exposure limits for the electromagnetic fields, based on recommendations by international organisations like WHO and ICNIRP [1]. To check whether base stations comply with the exposure limits, measurements of the electromagnetic field have to be executed. Both broadband and frequency-selective measurements can be used, however broadband electromagnetic field probes are mostly not sufficiently sensitive to measure the typical field values around base stations. Moreover broadband devices cannot be used to determine the relative contributions of all electromagnetic sources to the total exposure. Therefore frequency-selective measurement set-ups are preferred to check compliance with exposure guidelines [2].
The frequency-selective set-up consists of an antenna sensitive to the electric or magnetic field, and a spectrum analyser. Because the electromagnetic field is known for each frequency and each frequency band is assigned to an operator, the responsible for the largest contribution to the exposure to electromagnetic fields can easily be traced.
Another advantage of the frequency-selective measurement is that the measured data can be processed to obtain an estimate of the exposure in the worst-case situation. Since the emitted power of a base station will vary in time, it is important that the exposure is always below the limits. Thus it is necessary to estimate the worst-case exposure from the measured data.
In the next sections, some aspects of measuring signals that use spread-spectrum techniques with a frequency-selective set-up are studied. In the second section this is done for the use of slow frequency hopping in GSM (Global System for Mobile communications), while in the third section the measurement of the WCDMA (Wideband Code Division Multiple Access) signal (used in UMTS or the Universal Mobile Telecommunications Services) with a spectrum analyser is considered.

MEASURING GSM SIGNALS USING FREQUENCY HOPPING

The power emitted by a GSM base station will vary in time: the transceivers that are not carrying the broadcast channel (BCCH) are only transmitting when there is traffic present. Moreover, when downlink power control is enabled, the transmitted power in a time slot for a certain user will depend on the reception quality of that mobile user. On the other hand, the transceiver that transmits the broadcast channel will always transmit a constant and maximum power. So,

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when measuring the electromagnetic field in a frequency channel without a BCCH, it is likely that the instantaneous measured electromagnetic field differs from the maximum electromagnetic field that might ever occur (i.e. the situation where all transmitters are active and are operating at full power). To estimate the electromagnetic field in the worst-case situation, the spectrum analyser is used in maximum hold mode. In this way the maximum electromagnetic field values that have been measured during a certain period are retained. This is a good estimate for the worst-case exposure when all transceivers have been active during the measuring period. However, there occurs a problem when frequency hopping is used.

Frequency hopping in GSM is used to make the signal more resistant to fading and interference: the carrier frequency of the narrowband channels (200 kHz wide) is changed each time slot. Two implementations of frequency hopping exist [3]: in base band hopping the traffic is switched each time slot to another transceiver, which is operating at a fixed frequency; in synthesised hopping the traffic is sent over the same transceiver, but the transceiver changes each time slot its carrier frequency. So in base band hopping the number of frequency channels over which the transceiver hops is equal to the number of transceivers present in the base station. In synthesised hopping the number of frequency channels can be significantly larger than the number of transceivers. The use of base band and synthesised frequency hopping is illustrated in Fig. 1.

In Fig. 1 the results of a 24-hour measurement of the GSM frequency band is shown. In Fig. 1 the histogram of the measured powers is plotted for each frequency. The width of the histogram bins was chosen 1 dB. When the colour of a bin is dark, there is a large probability that the measured values are located in the considered bin. In Fig. 1 we can see that in the frequency band 942 – 953 MHz, the power levels are confined to a certain value. In this frequency band the frequency channels carrying the BCCH are located. In the frequency band from 935 – 942 MHz, we see that certain frequency channels are confined around various power levels: these are the frequency channels that are used in base band hopping: there are only a limited number of frequency channels that are used and they are not always active (depending on the amount of traffic). In the frequency band of 953 – 960 MHz synthesised frequency hopping is illustrated. All frequency channels are used, but the probability that they are used is much lower than in the case of base band hopping.

When measuring the electromagnetic field with a spectrum analyser in maximum-hold mode, every frequency channel that has been used during the measuring period, will be present in the retained trace. There are several ways to process the obtained maximum hold trace to estimate the exposure in the worst-case situation. A first approach is to cumulate the electromagnetic field values over all channels. In this way, all used channels will be interpreted as if they are continuously present at the maximum electromagnetic field level that has occurred during the measuring period. In the case of base band frequency hopping, this interpretation is a good estimate for the worst-case situation where all transmitters are continuously active: because each transceiver has a fixed carrier frequency, the number of used channels agrees with the number of present transceivers. However, when synthesised hopping is used, and the number of hopping channels (e.g. 30) is significantly higher than the number of transceivers (e.g. 4), the worst-case situation would be largely overestimated.

To prevent this overestimation of the worst-case exposure, it is possible to cumulate only over the maximum number of simultaneously active frequency channels. This means that the number of transceivers should be known for each

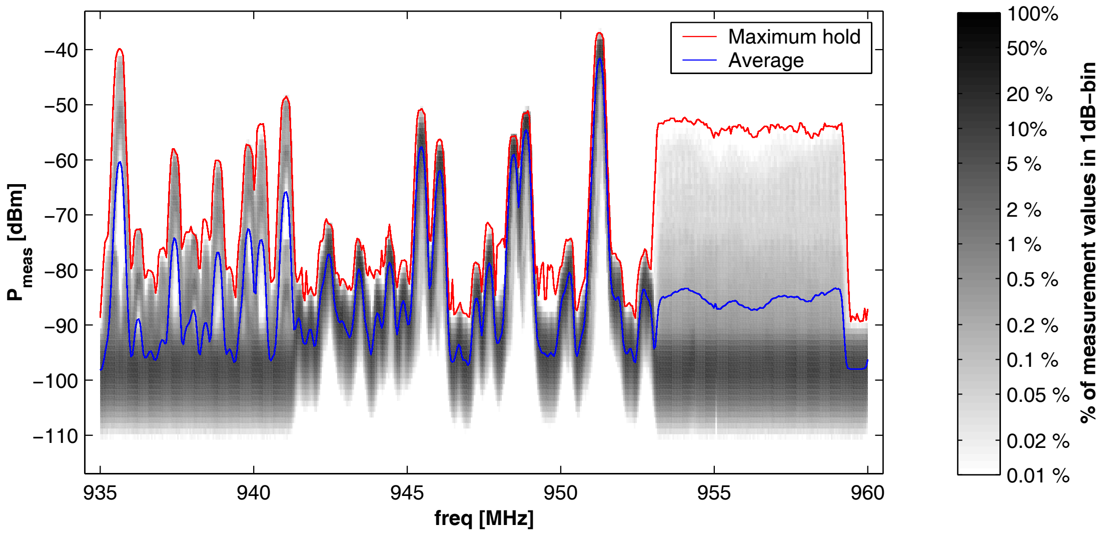

Fig. 1. Histogram (with 1 dB bins) of the frequency spectrum in the GSM band from a 24-hour measurement. The maximum occurred values are shown in red, the average measured power values in blue.

antenna (e.g. provided by the operator).
An alternative method to estimate the worst-case exposure is to determine the strongest frequency channel for each antenna and estimate the electromagnetic field in the worst-case situation by multiplying the electromagnetic field at the strongest channel with the square root of the maximum number of transmitters that can be simultaneously active (i.e. the number of present transceivers). Analogously the electromagnetic field at the frequency channel containing the BCCH can be extrapolated to estimate the worst-case exposure. This is advantageous because this frequency channel is for each cell sector always present and is operated at a strong constant power level.
In Fig. 1, the maximum-hold curve is approximately 20 dB above the average curve for the frequency band with base band hopping, 5 dB for the frequency band with BCCH channels and 40 dB for the band where synthesised frequency hopping is applied. It is obvious that when the trace obtained from maximum-hold mode would be used to calculate the total exposure, this exposure would be largely overestimated.

MEASURING WCDMA SIGNALS USED IN UMTS

Just like in GSM the UMTS-signal is spread over the spectrum to provide robustness against fading. UMTS uses Wideband CDMA with a chip rate of 3.84 Mcps and a roll-off factor α of 0.22 [4]. Because most spectrum analysers have a maximum resolution bandwidth that is smaller than 5 MHz, the power present in one frequency channel cannot be measured by reading the measured power at the carrier frequency. If the power spectrum does not change much over the frequency range, the total power can be estimated from the power present at the carrier frequency by correcting with a factor equal to the signal bandwidth divided by the noise bandwidth of the resolution filter. Because the WCDMA signal has noise-like properties, the use of an RMS-detector to obtain the powers would be ideal. However many spectrum analysers do not possess an RMS-detector, so a sample or positive-peak detector should be used. Although a sample detector gives a better idea about the real power of the noise-like signal, the positive-peak detector can be used when the crest factor of the signal is known. The crest factor CF is defined as follows

$$CF = 10 \log (P_S / P) \tag{1}$$

with P_S the maximum instantaneous power that has occurred during the measurement period and P the average power of the measured signal. The crest factor can only be used when the measuring time is sufficiently long: for short measurement periods the measured peak power will depend strongly on the sample of bits that determine the instantaneous power. Generally, the crest factor for a certain signal is defined for the whole bandwidth of the signal. However when the resolution bandwidth is smaller than the signal bandwidth, the crest factor will also depend on the resolution filter. For a wide resolution filter, only a small number of chips will contribute to the power at a certain frequency and the variations of the peak power will be smaller than for the measurement with a narrow resolution filter.
An important aspect of WCDMA is the use of fast power control, both in downlink as in uplink: the transmitter changes its power at a rate of 1500 times per second. This means that the spectrum analyser should be used in maximum-hold mode to obtain the maximum field value that has occurred during the measurement period.
To study the behaviour of the WCDMA signal measured with a spectrum analyser, a simulation model for the spectrum analyser (see Fig. 2) was used (in base band representation). In the model, the input signal $s_{in}(t)$ is multiplied with the local oscillator signal $\exp(j\,\pi\,\Delta f_{sp} / \Delta T_{sw}\, t^2)$ which has an instantaneous frequency equal to $\Delta f_{sp} / \Delta T_{sw}\, t$. Then the mixed signal is sent through the resolution filter (an ideal Gaussian filter) and a detector. The detector can be a sample detector, a positive-peak detector or an RMS-detector. Both the positive-peak detector and the RMS detector give as result the maximum value respectively RMS-value of the measurement samples in a frequency bin (defined as the interval between two consecutive frequency points).
To illustrate the influence of the used detector and the used resolution bandwidth on the measurement of an UMTS signal with a spectrum analyser, simulations have been executed on a spectrum analyser with respectively 5 MHz, 1 MHz and 100 kHz resolution bandwidth. The results are shown in Fig. 3. From these simulations a crest factor of 4.5 dB appears for the resolution filter of 5 MHz, 5.5 dB for 1 MHz and 6 dB for 100 kHz. It is also clear that although the same sweep time has been used, the variation of the measurement values depends on the used resolution filter: this variation is much larger for small resolution bandwidths (because more chips contribute to the measured values). It is

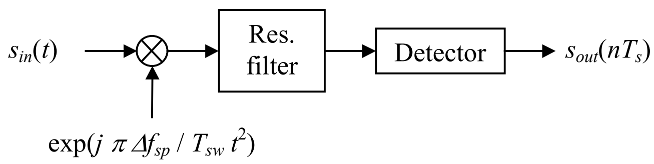

Fig. 2. Scheme of the simulation model for the spectrum analyser.

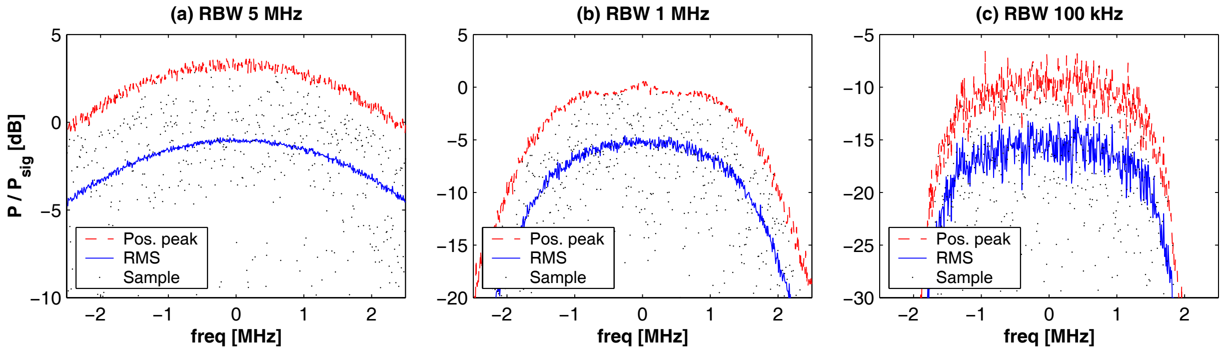

Fig. 3. Influence of the used resolution bandwidth (RBW) and the used detector on the measurement results for a WCDMA signal (sweep time ΔT_{sw} = 50 ms).

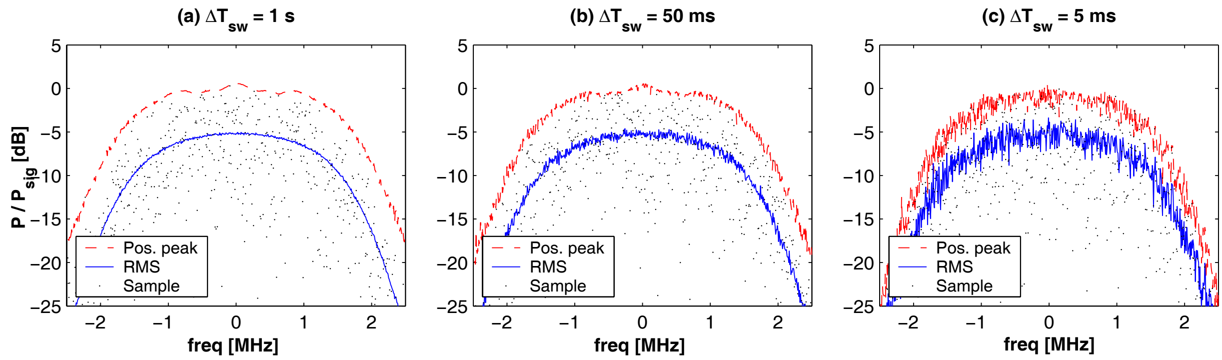

Fig. 4. Influence of the used sweep time ΔT_{sw} on the variation of the measurement samples (RBW = 1 MHz).

also shown that the measured power level depends on the used resolution bandwidth. The level of the measurement with the 100 kHz filter is 10 dB below the level measured with the 1 MHz filter.

In Fig. 4, the influence of the sweep time is shown. The simulations were made for a resolution filter of 1 MHz and for a sweep time of (a) 1 s, (b) 50 ms and (c) 5 ms. It is shown that a longer sweep time results in a smoother signal for both the positive peak detector and the RMS-detector. A longer sweep time has no influence on the results obtained with the sample detector.

CONCLUSION

In this paper it is shown that when frequency selective measurements are executed to check compliance with exposure guidelines, the use of spread-spectrum techniques should be taken into account when interpreting the measurement results. For measurements around GSM base stations, it is possible that the worst-case exposure is overestimated when synthesised frequency hopping is used and the spectrum analyser is operated in maximum hold mode. When the number of transceivers at the base station are known, the worst-case exposure can be estimated more accurately. When measuring the WCDMA signal for UMTS base stations, the obtained measurement results should be corrected when measuring with a spectrum analyser with a resolution filter that is too narrow. Moreover the use of the positive peak detector will result in an overestimation of the exposure because of the noise-like properties of the WCDMA signal.

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