ACCURATE ELECTROMAGNETIC EXPOSURE ASSESSMENT AROUND UMTS BASE STATIONS WITH A SPECTRUM ANALYSER

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ABSTRACT

The purpose of the investigation was to derive the optimal configuration of the spectrum analyser when used for the exposure assessment around base stations, together with the associated uncertainty and the underlying rationale for the chosen settings. A base-band simulation model for both the spectrum analyser and the Universal Mobile Telecommunications System (UMTS) communication signals has been developed to investigate the behaviour of the spectrum analyser when used for exposure assessment. Simulations and theoretical derivations enable to determine the theoretical bounds on the achievable accuracy for the measurement of a mobile communications signal and to examine the impact on the measurement result of one individual setting of the spectrum analyser. The simulation and theoretical models have been validated with measurements on a realistic UMTS test-signal.

INTRODUCTION

During the last years, considerable efforts have been invested to harmonise the different measurement procedures for exposure assessment around base stations [1]. Since the reference levels for the electric or magnetic fields in the different exposure guidelines that have been proposed [2] are frequency-dependent, and because the contribution of a certain operator to the total exposure can be distinguished on basis of the used frequency band, frequency-selective measurements provide an accurate and reliable way to assess the exposure around different sources. It should be noted that in the case of UMTS, because the same frequency band is shared between different base stations, a channel decoder will provide more information to assess the worst-case exposure. However, frequency-selective measurements remain an attractive alternative because of their general applicability. To minimise the uncertainty, the settings of the spectrum analyser should be chosen with care. In [3] an analogous study has been made, where the optimal settings have been derived for the GSM system.

SIMULATION MODEL

Spectrum Analyser Model

The model that has been used for the spectrum analyser is shown in Fig. 1. The signal to be measured r(t) is first mixed with the signal from the local oscillator $LO(t)$. Then, the mixed signal is filtered by the resolution filter with frequency response $H_{RB}(f)$, which is typically a Gaussian filter. The signal is consecutively sent to an envelope detector. Depending on the detector mode, the value displayed by the spectrum analyser each period T_S, will be the sampled value of the measured signal $|s(t)|$, the maximum or minimum value over the previous period of length T_S, or the RMS (Root Mean Square) value, measured over this previous period. If this is expressed mathematically, the signal before the detector will be given by [3]

$$|s(t)| = |\frac{\sqrt{\pi}RBW}{\sqrt{2\ln 2}} \int_{-\infty}^{+\infty} r(t+v)e^{-\jmath 2\pi \frac{\Delta f_{SP}}{2T_{SW}}(t+v)^2} e^{-\frac{v^2\pi^2 RBW^2}{2\ln 2}} \mathrm{d}v|, \tag{1}$$

where RBW is the resolution bandwidth, Δf_{SP} the frequency span and T_{SW} the sweep time of the spectrum analyser.

Model for the UMTS signal

In Fig. 2, the low-pass model for the UMTS signal is given. In UMTS, the information bits to be transmitted are first spread and scrambled with code chips, that have a higher chip rate than the bit rate of the information signals. The real and imaginary part of these chips are assumed to be equally probable between 1 and -1. Each channel to be transmitted is then multiplied individually by a certain gain factor. The in-phase and quadrature signals are scaled, multiplied with a Root Raised Cosine (RRC) filter $h_{PS}(t)$ and are summed, after which they are transmitted on the carrier. This results in the signal $r(t)$. An alternative representation for this low-pass signal is

$$r(t) = \sum_j g_j \sum_n e^{j\phi_{c,j,n}} h_{\text{PS}}(t - nT_c), \qquad (2)$$

where $\varphi_{c,j,n}$ can take the values $\pi/4$, $3\pi/4$, $5\pi/4$ or $7\pi/4$ with equal probability, and T_C is the period of the chips (i.e. the inverse of the chip rate of 3.84 Mcps). In UMTS the transmit power of a certain channel is changed at a rate of 1500 times per second. Even if the power is set to be constant, it will continuously be increased and decreased with a certain power step, that can take a value between 0.5 dB and 3 dB. In the following, power control in the UMTS signal will be modelled by a continuously changing gain between 1 and α at a rate of 1500 Hz. The models will be validated on a Generic UMTS Signal (GUS) that has been developed for studying the biological effects of exposure to UMTS-like signals, assuming worst-case circumstances. The GUS-signal has extensively been described in [4].

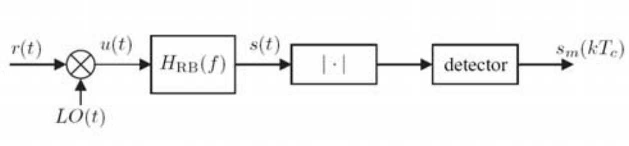

Fig. 1: Model for the spectrum analyser.

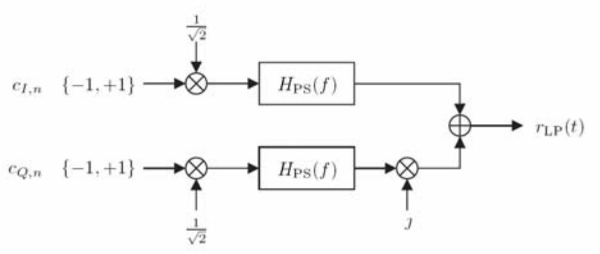

Fig. 2: Low-pass model for the WCDMA signal.

BEHAVIOUR OF THE SIGNAL

Sample Detector

In the case that there is no power control present, and that the resolution bandwidth is smaller than 500 kHz, the distribution of the signal measured with the sample detector will be approximately Rayleigh, with parameter

$$s_{\text{smp}} \approx \frac{1}{2}\sqrt{\sum_j g_j^2 T_c RBW \sqrt{\frac{\pi}{\ln 2}}}, \qquad (3)$$

so that the mean μ_{smp} and the standard variation σ_{smp} of the sampled signal without power control can be expressed as

$$\mu_{\text{smp}} = \sqrt{\frac{\pi}{2}} s_{\text{smp}}, \qquad \text{and} \qquad \sigma_{\text{smp}}^2 = \frac{4-\pi}{2} s_{\text{smp}}^2. \qquad (4)$$

If the resolution bandwidth is larger than 500 kHz and only one channel is dominant, the measured signal will show a discrete behaviour, although the main course of the probability density function (PDF) will still be given by the Rayleigh distribution. Taking power control into account, the mean and standard deviation of the signal become

$$\mu_{\text{PC,smp}} \approx \frac{1+\alpha}{2}\mu_{\text{smp}}, \qquad \text{and} \qquad \sigma_{\text{PC,smp}}^2 \approx \frac{1+\alpha^2}{2}\sigma_{\text{smp}}^2 + \frac{(1-\alpha)^2}{4}\mu_{\text{smp}}^2, \qquad (5)$$

assuming that the sample time is not an even period of the power control period, so that the sample time is equally distributed between periods where the transmitted power is at a high level and periods where the power is low.

RMS Detector

The distribution of the measured RMS value can be calculated from the distribution of the mean square (MS) value. If power control is not taken into account, the mean and standard variation of the MS value will be given by

$$\mu_{\text{MS}} \approx \sum_j g_j^2 \sqrt{\frac{\pi}{4\ln 2}} T_C RBW, \qquad \text{and} \qquad \sigma_{\text{MS}} \approx \frac{T_C}{2}\sum_j g_j^2 \sqrt{\frac{RBW}{T_S}} \left(\frac{2\pi}{\ln 2}\right)^{\frac{1}{4}}, \qquad (6)$$

so that the standard variation on the mean square value will decrease for longer measurement periods T_S (which can be understood due to the law of large numbers). Considering also power control, the standard deviation will be for a large part determined by the ratio of the measuring period to the power control period. The mean value and the squared standard deviation of the mean squared signal will be given by [5]

$$\mu_{\mathrm{MS,PC}} = \frac{1+\alpha^2}{2}\mu_{\mathrm{MS}}, \qquad \text{and} \qquad \sigma^2_{\mathrm{MS,PC}} = \frac{1+\alpha^4}{2}\sigma^2_{\mathrm{MS}} + \mu^2_{\mathrm{MS}}\frac{\left(1-\alpha^2\right)^2}{12}\left(\frac{2R_S}{T_{\mathrm{PC}}}-1\right)\left(\frac{2T_{\mathrm{PC}}}{T_S}-1\right)^2, \tag{7}$$

where $R_S = |T_S - [T_S / 2\ T_{\mathrm{PC}}]\ 2\ T_{\mathrm{PC}}|$ is the remainder part of the measuring period T_S when divided by the double power-control period $2\ T_{\mathrm{PC}}$.

In Fig. 3, the comparison is made between the standard deviation on the measured GUS-signal and the results predicted by (7). As it could be expected, the standard deviation is the smallest if the measuring period contains an even number of power control periods, while it is the largest if it contains an odd number of power control periods. Except for the large resolution bandwidth of 5 MHz, the agreement between simulations and measurements is excellent. For measuring periods $T_S < 2\ T_{\mathrm{PC}}$ the standard deviation on the RMS value is mainly caused by the power variation of the measured signal, while for the small resolution bandwidth of 10 kHz, the standard deviation can mainly be attributed to the use of a small resolution filter. From Fig. 3 it also appears that the standard deviation of the RMS measurement decreases with the increasing measuring period, and if the effect of power control can be neglected, the standard deviation decreases following the law $T_S^{-1/2}$.

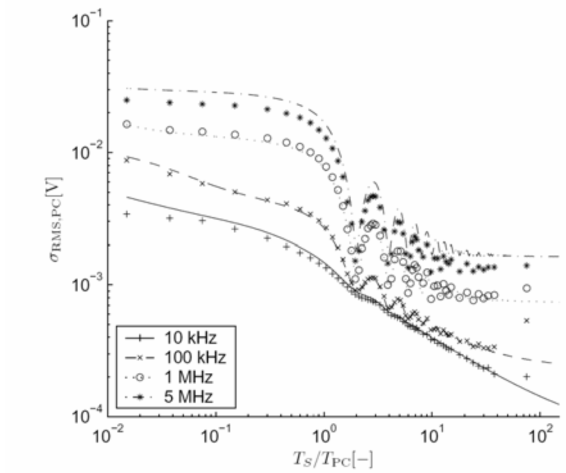

Fig. 3: Comparison between the standard deviation on the measured RMS signal of the GUS signal and the standard deviation calculated (lines) from (7).

Positive-Peak Detector

The distribution of the positive-peak signal will be highly dependent on the tail behaviour of the distribution. The Rayleigh distribution will not longer be adequate, and a higher-order approximation of the PDFs should be made, as it has been shown in the theoretical model derived in [6]. From this model the mean and the standard deviation can be derived. If the measurement period increases, the mean of the measured maximum will increase, while the standard deviation will decrease. In Fig. 4, the comparison is made between the results from the theoretical model, taking into account power control, and measured results on the GUS-signal. The mean of the value measured by the positive-peak detector increases with increasing measuring periods T_S. There is a good agreement between measurements and model, except for the 5 MHz resolution filter (because then the pulse shaping filter cannot be considered as flat over the width of the resolution filter). There is also a deviation for the 10 kHz resolution bandwidth for short measuring times T_S, due to the long time response of the small resolution filter.

From Fig. 4, it can also be observed that the curve shows a breaking point around the power control period T_{PC}, because the distribution of the mean will be dominated for long measurement periods by the period where the signal was in the high state, while for measuring periods smaller than the power control period, both the high as the low state will determine the total distribution. As it can be seen in Fig. 5, the standard deviation on the positive-peak signal is for measurement periods T_S smaller than T_{PC}, dominated by the variation due to power control, and remains almost constant. For longer measurement periods, the positive-peak level is dominated by the high state of the signal. The agreement between measurements is rather good for the 10 kHz and 100 kHz resolution filter, and somewhat worse for the 1 MHz resolution filter, while for the 5 MHz resolution filter there is no agreement because of the invalidity of the theoretical model.

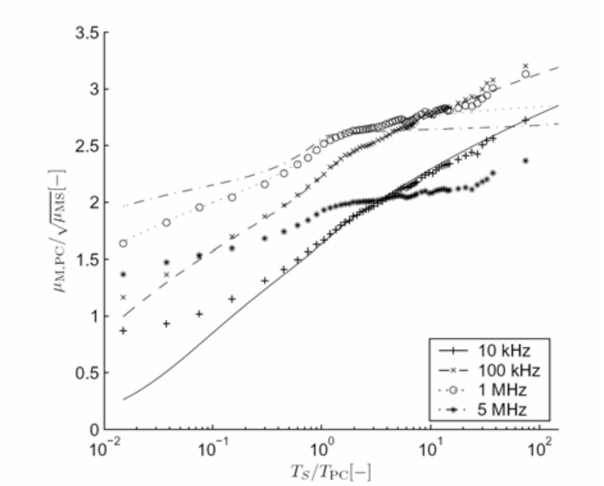

Fig. 4: Comparison between the mean of the normalised measured positive-peak signal of the GUS signal and the mean calculated from the theoretical model.

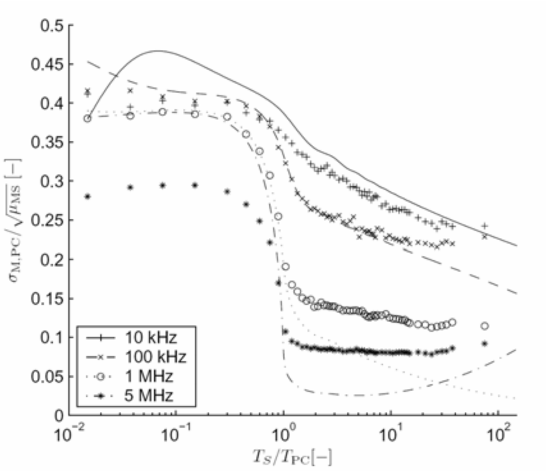

Fig. 5. Comparison between the standard deviation on the normalised measured positive-peak signal of the GUS signal and the theoretical standard deviation.

OPTIMAL SETTINGS

From the observations made above, the optimal settings for the spectrum analyser can be derived. The measuring period over one frequency bin should ideally be two times the power control period. In that case the standard variation on the measured value will be at a local minimum. If a longer measuring period would be taken, and the power of the UMTS signal is continuously changing, it is impossible to state whether the measured maximum corresponds to one or more periods that the transmitted power was at maximum. For the choice of the resolution filter, a compromise should be made between a large standard variation, and low leakage of power in adjacent channels. As it is shown in Fig. 3 and Fig. 5, the standard deviation will be higher for smaller resolution filters. It is proposed to choose the resolution filter as 500 kHz, since for this resolution bandwidth the signal will still show a discrete behaviour if one channel is dominant. Since the RMS power does not depend on the measurement time, the RMS detector is preferred to measure the exposure. The power can also be estimated from a positive-peak measurement, but in that case the measured power should be corrected because the UMTS signal shows a noise-like behaviour [5].

CONCLUSION

In this paper, the optimal settings of the spectrum analyser have been derived when used for exposure assessment around UMTS base stations. These optimal settings have been based on simulations and theoretical derivations on a base-band model for the spectrum analyser and the UMTS signal. The simulation and theoretical models have been validated with measurements on a realistic UMTS signal.

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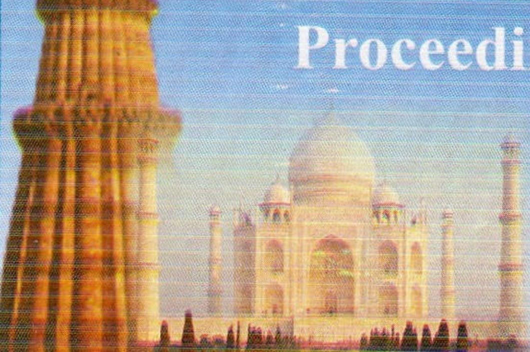

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