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THE USE OF TRADITIONAL SPECTRUM ANALYZERS TO MEASURE THE ELECTROMAGNETIC POLLUTION GENERATED BY WIMAX DEVICES

Giovanni Betta, *Domenico Capriglione*, *Gianfranco Miele*, *Luca Rossi*

DAEIMI, University of Cassino, Cassino (FR), Italy, {betta,capriglione,g.miele,l.rossi}@unicas.it

Abstract − Worldwide Interoperability for Microwave Access (WiMAX), based on the IEEE 802.16 standards, is a technology that offers mobile broadband access to multimedia and internet applications at low cost for operators and end-users. Similarly to cellular phone or other Radio Frequency devices, WiMAX has to be considered as a possible source of electromagnetic pollution and so, monitoring its emission, could be necessary to verify the compliance with the applicable limits. Generally, the monitoring of the electromagnetic pollution is performed by means of a suitable measurement chain constituted by an antenna connected to a traditional spectrum analyzer. The use of this kind of device to measure the power of digital modulated noise-like signals, such as WiMAX, requires to carefully set many instrument parameters to obtain reliable measurement results, otherwise a significant underestimate or overestimate of the human exposure can be obtained.

In this framework, this paper presents a suitable measurement method and spectrum analyzer proper settings able to warrant reliable measurements of electromagnetic emissions due to WiMAX devices.

Keywords: Electromagnetic Field Measurements, Spectrum Analyzer, Power Measurements, WiMAX, EMC.

1. INTRODUCTION

The last few years have been characterized by the continuous increasing demand for mobile broadband access to multimedia and internet applications, creating a great interest among the existing operators to explore new technologies and network architectures able to offer such services at low cost for operators and end-users. The main candidate that complies to these requirements is WiMAX, for which it is expected a wide diffusion in a short time.

This technology will revolutionize the way to communicate allowing many people to stay connected with voice, data, video services and, in the same time, a total mobility. In particular, the WiMAX technology is based on the IEEE 802.16 standards [1] that fix the following objectives:

- Flexible Architecture: WiMAX supports several system architectures including Point-to-Point, Point-to-Multipoint and ubiquitous coverage;
- Quality of Service (QoS): WiMAX can be dynamically optimized for the mix of traffic that is being carried;
- High mobility: WiMAX using the OFDM and OFDMA like physical layers can support full mobility at speeds up to 160 km/h;
- Wide coverage: WiMAX supports multiple modulation levels and when the system is equipped with a high-power amplifier and can operate with a low-level modulation, it is able to cover a wide geographic area;
- High capacity: the WiMAX can provide wide bandwidth to end-users.

On the other hand, as cellular phone and other Radio Frequency (RF) systems, WiMAX devices will operate at relatively low distances from other electronic systems and people, then it becomes important to consider this device as a possible source of electromagnetic pollution with reference to both the aspects of electromagnetic compatibility (EMC) and of human exposure.

These aspects become significant particularly for medical equipment [2], in transportation environment [3], during the use of high sensitivity instruments [4], [5], as well as when different wireless networks share the same area [6]. In addition, the possible effects of the WiMAX emissions on the human health should not be neglected. Indeed, there have been a large number of occupational studies over several decades, particularly on cancer, cardiovascular disease, adverse reproductive outcome, and cataract, in relation to RF exposure. More recently, there have been studies of residential exposure, mainly from radio, television transmitters, and mobile phones. Results of these studies to date give no consistent or convincing evidence of a causal relation between RF exposure and any adverse health effect [7]. In absence of reliable results the international community adopts a "prudent avoidance" approach by following the suggestions given by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which defines the maximum electromagnetic field strength in area where the people exposure hold out several hours (such as airports, schools, hospitals and job places) [8].

For RF fields in the frequency range 100 kHz-10 GHz, the power density (the power per unit area normal to the direction of propagation) time-averaged over any six minutes period should be estimated and compared with the maximum tolerable value, in force in each country.

Consequently, as it happens for other RF sources, also for WiMAX system, the monitoring of the electromagnetic pollution is necessary.

To this aim, as suggested by international recommendations, a suitable measurement chain have to be employed. It should be constituted by an antenna connected to a spectrum analyzer which is employed to estimate the power detected in a specific bandwidth [9]. As for the spectrum analyzer, general guidelines about the best instrument settings (span, resolution bandwidth, video bandwidth, sweep time, detector) are given only for “traditional” sources such as FM and AM radio, TV, Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS) [9], [10]. On the contrary, no guidelines are provided for modern signals, such as digital terrestrial communications (DVB), WiFi, and WiMAX to cite a few.

Generally, as for noise-like signals characterized by wide bandwidths and often pulsed transmission modes, the use of specific modern high-cost instruments is suggested, such as Vector Signal Analyzers, and Real Time Spectrum Analyzers [11]. But, the monitoring of the electromagnetic fields requires other instrument properties, such as small size, light weight and low-cost that are instead met in a traditional medium performance portable spectrum analyzers [9]. They rarely have adequate resolution bandwidths (needed to assure reliable measurements also in the case of wideband signals, as for example WiMAX signals) or they are provided of proper facilities which can help the user through suitable automatic measurement procedures. Also in presence of automatic procedures, the measurements on digital modulated signal can be improved by carefully selecting some parameters including the detector, the sweep time, the measurement method, the Intermediate Frequency and Video filters bandwidths [10].

With reference to WiMAX, in [12] a theoretical study has investigated the capability of use a traditional spectrum analyzer to evaluate the electromagnetic pollution provided by WiMAX devices, but no experimental validation was provided by carrying out the measurements with actual instruments on real signals. In addition, the great variety of WiMAX physical layer setting (mainly in terms of modulation, bandwidth and operating mode) was not considered.

In this framework, starting from previous experience in the field [13]-[15], the authors investigate on the feasibility of reliably measuring the electromagnetic fields strength due to WiMAX devices by means of traditional spectrum analyzers. To this aim an experimental measurement campaign on a large set of actual and emulated WiMAX signals has been performed.

2. OVERVIEW OF WIMAX TECHNOLOGY

The WiMAX Forum is a consortium that has promoted the IEEE 802.16 standards for broadband wireless access systems.

The original IEEE 802.16 [16] standard offered a point-to-point communication link using traditional Quadrature Amplitude Modulation (QAM) and it works between 10 GHz and 66 GHz [17], [18]. Successively in 2004 the WiMAX Forum emanated a new standard known as 802.16d [17] that gives radical changes to 802.16

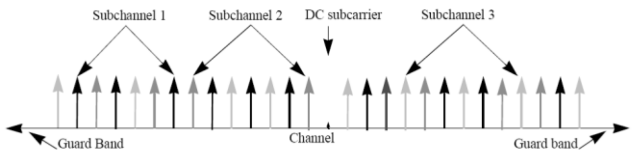

Fig. 1. Example of channel subdivision for standard 802.16d using the OFDMA mode

physical layer containing specifications for the operations between 2 GHz and 11 GHz. In particular, operational frequencies in 10-66 GHz respects the [16], while for frequencies below 11 GHz, where propagation without Line On Site (LOS) must be accommodated, other two alternatives are provided: (i) Orthogonal Frequency Division Multiplexing (OFDM) and (ii) Orthogonal Frequency Division Multiple Access (OFDMA). The former uses OFDM symbols constituted by 256 subcarriers with a variable carrier spacing and consequently it can transmit on different channel bandwidths from 1.25 MHz to 28 MHz. The OFDMA mode can serve various subscribers simultaneously, assigning each subscriber a specific group of subcarriers called sub-channel (see Fig. 1). Each symbol is constituted by 2048 carriers [20].

The enhancement necessity of nomadic, portable and mobile wireless access, has brought the WiMAX Forum to promote a new standard the IEEE 802.16e [19] that provides improved support for intercell handoff, directed adjacent-cell measurement, and sleep modes to support low-power mobile station operation. Moreover as transmission method the standard IEEE 802.16e uses the Scalable OFDMA (SOFDMA) that is similar to OFDMA. This transmission mode scales the Fast Fourier transform (FFT), used to make the symbols, to the channel bandwidth in order to keep the carrier spacing constant across different channel bandwidths. Constant carrier spacing results in a higher spectrum efficiency in wide channels, and a cost reduction in narrow channels. In IEEE 802.16e standard FFT subcarrier numbers are 128, 256, 512, 1024 or 2048 in 1.25, 2.5, 5, 10, 20 MHz bandwidths respectively [20].

The IEEE 802.16d/e standards define a set of adaptive modulation that can be used to trade-off data rates for system robustness under various wireless propagation and interference conditions. The allowed modulation types are Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (16-QAM) and 64-QAM.

Moreover WiMAX systems can be deployed as Time Division Duplexing (TDD), Frequency Division Duplexing (FDD), or Half-Duplex FDD. In the TDD configuration, the base station (BS) and subscriber equipment transmit (SE) on the same RF frequency but at a different time. In the FDD configuration, they transmit on separate RF frequencies and overlap each other at a specific time. The Half-Duplex FDD configuration combines the characteristics of FDD and TDD. However, the BS and SE transmit on different frequencies like FDD, and at different time like TDD.

3. THE PROPOSED APPROACH

The assessment of RF electromagnetic field strength requires the estimation of the time-averaged power over any six minutes period by means of a measurement chain composed by three fundamental components: a probe (typically a broadband antenna) able to detect the electromagnetic field, a frequency selective instrument able to identify the spectral components of the input signal and a shielded cable for connecting the probe and the measurement instrument. The electromagnetic field strength at a given point can be derived by the measurement of the equivalent plane wave power density (the power per unit area normal to the direction of propagation), S_{EQ} [dBW/m^2]:

$$S_{EQ} = P_{SA} + C_A + AF \tag{1}$$

where P_{SA} [dBW] is the time-averaged power over a six minutes period measured with the spectrum analyzer, C_A is the cable attenuation [dB], AF [dB/m] is the antenna factor.

Of course, all the components of the measurement chain contribute to the overall accuracy. Typically, the overall uncertainty component due to the cable attenuation, antenna factor, and mismatching with the measurement instrument is less than ± 1.5 dB [21]. Consequently, to obtain an overall measurement uncertainty no greater than ± 2.0 dB (as required in [9]) is fundamental that all systematic and random contributions due to the P_{SA} measurement are smaller than about ± 1.3 dB. In addition, this value has to be further reduced when the measured level approaches the applicable exposure limit. These hard constraints, first of all, require to precisely quantify and correct all the systematic effects involved during the measurements, which could be even more significant in the case of pulsed digital modulated signals with high modulation frequencies such as WiMAX. Indeed, besides the well known level uncertainty typical of a spectrum analyzer, other level errors on the average power can be introduced when pulsed and digital modulated signals are measured [22].

As described in the previous section, WiMAX can operate in many ways by adopting different modulation schemes, by allocating different channel bandwidth and data rate and by using different channel access techniques. All these peculiarities can make critical both the spectrum analyzer settings and the measurement method which should carefully set to obtain reliable power measurement results. Otherwise, a significant underestimate or overestimate of the human exposure can be obtained.

Therefore, in order to guide the user to the most proper choices, a suitable measurement setup has been realized to accurately characterize the WiMAX radiated emissions (see fig. 2). A signal generator Agilent Technologies™ E4438C provided of WiMAX personality is used to emulate the WiMAX signals. It is connected to a 2-way power divider by means of a suitable calibrated coaxial cable (C1). The first output of the power divider is directly connected to a reference instrument (via its own probe), instead the second output to a traditional spectrum analyzer by means of a suitable calibrated coaxial cable (C2). Since its good accuracy (< 0.2 dB) and repeatability, a RF power meter Agilent Technologies™ N1911A, equipped with a broadband probe, N1921A (50 MHz-18 GHz input frequency range) and with IEEE 802.16 measurement personality has been used as reference instrument.

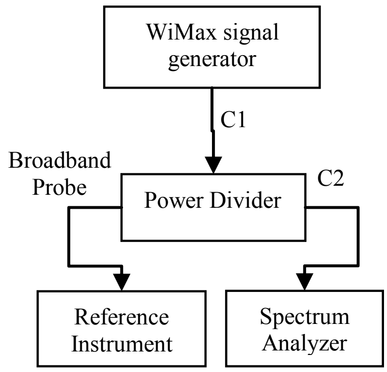

Fig. 2. Measurement setup for the characterization of the WiMAX radiated emissions

As for the measurement method, since the WiMAX signal features, the "channel power" and "zero-span" measurement techniques are the most proper [10], [13]. Then, several parameters including span analysis, sweep time, resolution bandwidths, integration bandwidth and detector have been varied with the aims of identifying the more appropriate instrument settings which allow the deviation from the reference instrument to be minimized. From the analysis of these deviations the eventual systematic and random contributions due to the spectrum analyzer will be quantified, thus allowing a suitable measurement methodology and instrument settings to be defined.

4. EXPERIMENTAL RESULTS

The results achieved by using a general purpose spectrum analyzer ESA 4402B (9 kHz-3 GHz input frequency range) by Agilent Technologies™ are reported in this section.

The analyses have been carried out by fixing the output power of the generator at 10 dBm-amplitude, the center frequency of the signal at 2.4 GHz, a frame duration of 5 ms and a FFT size of 1024.

A. Detector and sweep time effects

The analyses were carried out by considering two generator settings (here in after *A* and *B*) IEEE 802.16 compliant. They differ from one another only for the channel bandwidth imposed (10 MHz and 28 MHz, respectively).

As for the spectrum analyzer, since it maximum IF filter bandwidth was 5 MHz (less than the selected WiMAX channel bandwidths), the "channel power" measurement method was employed, having fixed the analysis span at 40 MHz, the Resolution Bandwidth (RBW) at 300 kHz, and the Video Bandwidth (VBW) at 3 MHz, automatically selected by the instrument. Instead, the integration bandwidths (IBW) equal to 10 MHz and 28 MHz were considered for *A* and *B* generator settings, respectively. Three values of sweep time (here in after *ST*) were considered: 1 s, 60 s and 360 s. They require 360, 6 and 1 acquired traces, respectively, for providing an average value calculated over a six-minute time period (as required for the RF electromagnetic pollution assessment).

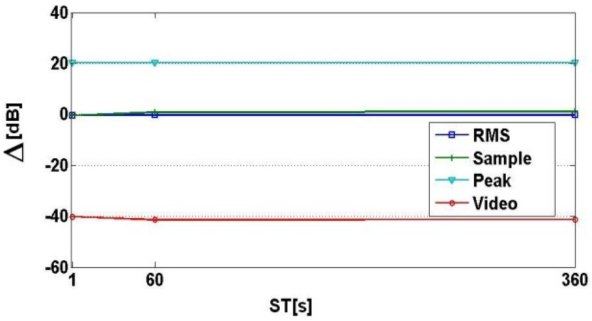

Fig. 3. Δ versus the sweep time (ST) for different detectors (generator setting *A* is involved).

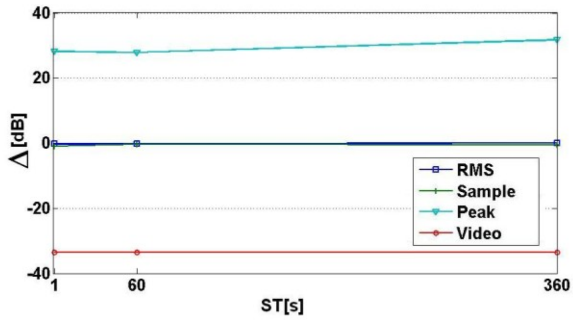

Fig. 5. Δ versus the sweep time (ST) for different detectors (generator setting *B* is involved).

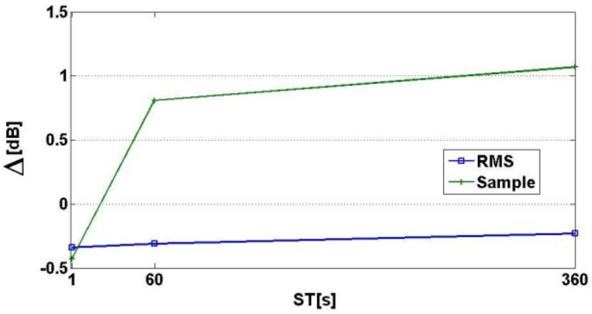

Fig. 4. Δ versus the sweep time (ST) for detector Power RMS and Sample (generator setting *A* is involved).

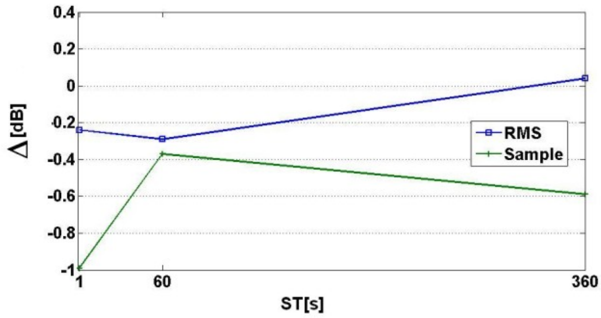

Fig. 6. Δ versus the sweep time (ST) for detector Power RMS and Sample (generator setting *B* is involved).

As for the detector, in order to investigate its effect on the measurement results the experiments were performed by considering the following ones: Positive Peak, Sample, Power Average RMS, Video Average. Even if the best performance are expected for the Power Average RMS detector (since the WiMAX signal features) [10], [11], [13], [22], the main reasons for investigating on the detector effects are: 1) low-cost portable spectrum analyzers are often not equipped with the RMS detector (often they have Sample and Peak); 2) if the effect of the detector is systematic it can be quantified to provide a suitable correction factor; 3) generally the instrument default settings automatically select the detector apart from the characteristics of the input signal to be analyzed.

Figure 3 reports the obtained results, showing the mean deviation (estimated on ten consecutive experiments), Δ, of the spectrum analyzer measurements from the reference instrument for different sweep times and detectors. For each configuration, the mean value Δ and the corresponding experimental standard deviation (σ) are also reported in table 1.

The obtained results prove that the Power Average RMS detector offers the best performance in terms of both bias and repeatability, with values allowing reliable results to be achieved ($(|\Delta|+\sigma_{SA}) < 1.3$ dB) apart from the selected sweep time. As for the Video Average and Peak detectors, they

Table 1. Δ: Comparison between the spectrum analyzer and the reference instrument for different detectors and sweep times. σ_{SA}: spectrum analyzer mean standard deviation, σ_{PM}: power meter mean standard deviation. (generator setting *A* is involved)

Detector	Sweep Time [s]	Δ [dB]	σ_{SA} [dB]	σ_{PM} [dB]
Power RMS	1	-0.34	0.03	0.01
	60	-0.31	0.06	0.01
	360	-0.23	0.16	0.02
Sample	1	-0.43	0.30	0.01
	60	0.81	1.59	0.00
	360	1.07	2.86	0.01
Video Average	1	-40.15	0.17	0.01
	60	-41.35	0.09	0.01
	360	-41.29	0.18	0.01
Peak	1	20.27	0.08	0.01
	60	20.33	0.08	0.00
	360	20.25	0.04	0.01

Table 2. Δ: Comparison between the spectrum analyzer and the reference instrument for different detectors and sweep times. σ_{SA}: spectrum analyzer mean standard deviation, σ_{PM}: power meter mean standard deviation. (generator setting *B* is involved)

Detector	Sweep Time [s]	Δ [dB]	σ_{SA} [dB]	σ_{PM} [dB]
Power RMS	1	-0.24	0.04	0.01
	60	-0.29	0.23	0.01
	360	0.04	0.12	0.01
Sample	1	-0.99	1.44	0.01
	60	-0.37	0.08	0.01
	360	-0.59	3.18	0.01
Video Average	1	-33.46	0.08	0.01
	60	-33.48	0.07	0.01
	360	-33.47	0.04	0.01
Peak	1	28.13	0.04	0.00
	60	27.81	0.01	0.00
	360	28.72	0.02	0.00

Table 3. Δ: Comparison between the spectrum analyzer and the reference instrument for different spans and sweep times. σ_{SA}: spectrum analyzer mean standard deviation, σ_{PM}: power meter mean standard deviation. (generator setting *A* and RMS detector are involved)

Detector	Span	Sweep Time [s]	Δ [dB]	σ_{SA} [dB]	σ_{PM} [dB]
Power RMS	40 MHz	1	-0.34	0.02	0.01
		60	-0.31	0.05	0.00
		360	-0.13	0.16	0.01
	20 MHz	1	-0.22	0.06	0.01
		60	-0.15	0.07	0.00
		360	-0.14	0.08	0.01
	15 MHz	1	-0.28	0.08	0.00
		60	-0.26	0.09	0.01
		360	-0.42	0.09	0.00

show the worst performance in terms of bias with a power overestimate for the Peak detector and a power underestimate for the Average one.

Both these detectors offer good repeatability and their performance do not depend from the sweep time. Vice-versa, the Sample detector offers relatively small biases that are compensated by the largest measurement dispersion (see fig.4). Among the considered sweep times, only ST = 1 s allows the condition ($|\Delta|+\sigma_{SA}$) < 1.3 dB to be satisfied, thus warranting the measurement uncertainty required in [9].

As for the generator setting *B*, similar considerations with respect to setting *A* can be made about the behavior of the detectors (see figures 5-6 and table 2). More in detail, the Power RMS shows the best performance in terms of both bias and repeatability whereas Average and Peak provide a power underestimate and overestimate, respectively. Their biases are incremented of about 7-8 dB with respect to ones achieved with the generator setting *A*, and good repeatability are achieved. As for the Sample detector, also in this case the bias is relatively small even if this kind of detector offers the worst repeatability. In particular, among the considered sweep times, only ST = 60 s allows the condition ($|\Delta|+\sigma_{SA}$) < 1.3 dB to be satisfied.

B. Span effects

The influence of the span was experimentally evaluated by fixing the following spectrum analyzer settings: IBW = 10 MHz, RBW = 300 kHz and VBW = 3 MHz.

Three values of *ST* were selected (1 s, 60 s and 360 s) and the Power RMS and Sample detectors have been considered.

The span values considered were: 40 MHz, 20 MHz and 15 MHz. For each configuration, ten consecutive experiments were carried out.

Table 3 and 4 synthesize the obtained results showing the deviation, Δ, between the measurements achieved by the spectrum analyzer and the reference instrument for different spans, sweep times and detectors.

Focusing the attention on the Power RMS detector (Table. 3), some considerations can be drawn:

Table 4. Δ: Comparison between the spectrum analyzer and the reference instrument for different spans and sweep times. σ_{SA}: spectrum analyzer mean standard deviation, σ_{PM}: power meter mean standard deviation. (generator setting *A* and Sample detector are involved)

Detector	Span	Sweep Time [s]	Δ [dB]	σ_{SA} [dB]	σ_{PM} [dB]
Sample	40 MHz	1	-0.43	0.30	0.01
		60	0.81	0.47	0.01
		360	1.07	0.20	0.00
	20 MHz	1	-0.03	0.57	0.01
		60	-1.29	0.36	0.00
		360	-1.24	1.11	0.01
	15 MHz	1	-0.69	0.31	0.01
		60	-0.23	1.47	0.00
		360	-0.23	1.56	0.00

i) fixed the span, the sweep time do not influence significantly the measurement results in terms of both bias and repeatability;

ii) fixed the sweep time, the span weakly influence the measurement results with a better performance achieved for 20 MHz and 40 MHz spans, and sweep time equal to 360 s;

iii) whatever be the combination of sweep time and span considered, we have ($|\Delta|+\sigma_{SA}$)< 1.3 dB.

As for the Sample detector, given the general larger dispersion of the measurement results, it cannot evidenced a worst or a best configuration. Nevertheless, for each considered span, once again, only the sweep time equal to 1 s allows the condition ($|\Delta|+\sigma_{SA}$)< 1.3 dB to be satisfied.

5. CONCLUSIONS

A traditional medium-performance spectrum analyzer was used for measuring the electromagnetic pollution generated by a WiMAX device.

Due to the pulsed and noise-like behavior of the WiMAX signal, the “channel power” method was adopted for evaluating the signal power.

Many experiments were carried out with the aim of identifying the best instrument settings to be employed for achieving accurate measurements.

In particular, the effects of some parameters that could be arbitrary chosen by a user, such as the Sweep Time, the Span and the type of Detector, were analyzed in detail.

The obtained results prove that generally the “channel power” method allows accurate (< ± 1.3 dB) and repeatable power measurements to be achieved if the RMS detector is adopted/available.

If a Sample detector is used, a proper choice of the ST can significantly improve the quality of the measurements, thus allowing to satisfy the minimum requirements defined in technical standard documents concerning the admissible uncertainty in measurements of human exposure to electromagnetic field.

Finally, for given signal characteristics, the use of Peak and Average detectors seems to be possible because their main consequences are significant biases on the measurement results but characterized by high repeatability (i.e. systematic effects). However, the bias value strongly depends on the signal features (as an example the bandwidth), consequently, they could be adopted only if the input signal characteristics are a priori known.

Further studies will be addressed to give a wider generality to the obtained results. The measurement campaign will be repeated by considering other spectrum analyzers of different manufacturers and on actual WiMAX signals.

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