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HOW TO USE TRADITIONAL SPECTRUM ANALYZERS FOR CORRECT EVALUATION OF THE HUMAN EXPOSURE TO ELECTROMAGNETIC FIELDS GENERATED BY WIMAX DEVICES

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Abstract

Worldwide Interoperability for Microwave Access (WiMAX), based on the IEEE 802.16 standards, is a technology that offers low cost mobile broadband access to multimedia and internet applications 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 compliance with the applicable emission 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 use proper measurement methods and 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 investigates the feasibility of using the traditional spectrum analyzer to perform the electromagnetic pollution measurements due to WiMAX devices. A large experimental campaign is carried out to identify the most proper measurement method and spectrum analyzer settings able to warrant reliable measurements.

Keywords: electromagnetic field measurements, spectrum analyzer, power measurements, WiMAX, EMC.

1. Introduction

The last few years have been characterized by the continuously 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 with these requirements is WiMAX, for which a wide diffusion in a short time is expected.

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

- 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

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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 equipments and people, it becomes important to consider them as possible sources of electromagnetic pollution with reference to both the aspects of electromagnetic compatibility (EMC) and of human exposure.

These aspects become particularly significant for medical equipment [2], in transportation environment [3], during the use of high sensitivity measurement instruments [4, 5], as well as when different wireless networks share the same area [6]. With reference to the human exposure, a large number of occupational studies over several decades, have analyzed the correlation among cancer, cardiovascular disease, adverse reproductive outcome, cataract and the RF exposure. More recently, studies of residential exposure, mainly from radio, television transmitters, and mobile phones have been issued. 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 areas 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 the WiMAX system, monitoring of the electromagnetic pollution is necessary.

To this aim, as suggested by international recommendations, a suitable measurement chain has 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 television (DTT), 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 match with a traditional medium-performance portable spectrum analyzers characteristics [9]. Unfortunately 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 devoid 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 Resolution and Video bandwidths [10].

With reference to WiMAX, in [12] a theoretical study has investigated the capability of using a traditional spectrum analyzer to evaluate the electromagnetic pollution provided by WiMAX devices, but no experimental validation was provided. In addition, the great variety of WiMAX physical layer settings (mainly in terms of modulation, bandwidth and operating mode) was not considered in detail.

In this framework, starting from previous experiences in the field [13–16], the authors investigate on the feasibility of reliably measuring the electromagnetic field strength due to WiMAX devices. A number of experiments will be addressed to the identification of eventual correction factors and/or instrument settings able to overcome the difficulties arising for the characterization of the WiMAX pollution emissions when performed with traditional spectrum analyzers. To this aim a large experimental measurement campaign on a large set of emulated WiMAX signals has been performed.

2. Brief overview of WiMAX physical layer

In 1998 the IEEE 802.16 group was formed with the aim of developing a LOS-based point-to-multipoint wireless broadband system for operation in the 10–66 GHz band. The resulting standard was based on a single-carrier physical (PHY).

The IEEE 802.16 group subsequently produced an amendment to the standard, called 802.16a, to include NLOS applications in the 2–11 GHz band, using an orthogonal frequency division multiplexing (OFDM)-based physical layer. The support for orthogonal frequency division multiple access (OFDMA), was also included. Further revisions resulted in a new standard in 2004, called IEEE 802.16-2004, which replaced all prior versions and formed the basis for the first WiMAX solution. These early WiMAX solutions based on IEEE 802.16-2004 targeted fixed applications, and generally it is referred to as fixed WiMAX [17].

In 2005, the IEEE group completed and approved IEEE 802.16e-2005, an amendment to the IEEE 802.16-2004 standard that added mobility support. The IEEE 802.16e-2005 forms the basis for the WiMAX solution for nomadic and mobile applications and is often referred to as mobile WiMAX [18].

These standards were developed to suit a variety of applications and deployment scenarios and are able to offer a variety of fundamentally different design options. For example, there are multiple physical-layer choices: a single-carrier-based physical layer called Wireless-MAN-SCa, an OFDM-based physical layer called WirelessMAN-OFDM, and an OFDMA-based physical layer called WirelessMAN-OFDMA. They provide different channel bandwidth solutions such as 1.25, 1.75, 3.5, 7, 14, 1.25, 5, 10, 15, 8.75, 20, 25, 28 MHz. They define a set of adaptive modulations that can be used to trade-off data rates for system robustness under various wireless propagation and interference conditions. The allowed modulation types are Quadrature Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (16-QAM) and 64-QAM. Several different transmission schemes are defined single carrier, OFDM and Scalable-OFDMA (SOFDMA) with 128, 256, 512, 1024 and 2048 subcarriers.

For practical reasons of interoperability, the scope of the standard needs to be reduced, and a smaller set of design choices for implementation need to be defined. The WiMAX Forum, a consortium that has promoted the IEEE 802.16 standards for broadband wireless access systems, does this by defining a limited number of system profiles and certification profiles. A system profile defines the subset of mandatory and optional physical- and MAC-layer features selected from the IEEE 802.16-2004 or IEEE 802.16e-2005 standard. It should be noted that the mandatory and optional status of a particular feature within a WiMAX system profile may be different from what it is in the original IEEE standard. Currently, the WiMAX Forum has two different system profiles: one based on IEEE 802.16-2004, OFDM-PHY, called the fixed system profile; the other one based on IEEE 802.16e-2005 scalable OFDMA-PHY, called the mobility system profile. A certification profile is defined as a particular instantiation of a system profile where the operating frequency, channel bandwidth, and duplexing mode are also specified. WiMAX equipment is certified for interoperability against a particular certification profile [19].

The WiMAX Forum has thus far defined five fixed certification profiles and fourteen mobility certification profiles. The widespread used certification profiles for the OFDM-PHY provide a fixed FFT size equal to 256. Since the FFT size is fixed, the subcarrier spacing varies with channel bandwidth. When larger bandwidths are used, the subcarrier spacing increases, and the symbol time decreases. Two bandwidths are admitted: 3.5 and 7 MHz. The most used certification profiles for OFDMA-PHY provide a FFT size scalable from 128 to 2048. When the available bandwidth increases, the FFT size is also increased such that the subcarrier spacing is always 10.94 kHz, allowing a good balance between satisfying the delay spread and Doppler spread requirements for operating in mixed fixed and mobile environments. A subcarrier spacing of 10.94 kHz implies that 128, 512, 1024, and 2048 FFT are used when the channel bandwidth is 1.25, 5, 10, and 20 MHz, respectively. It should, however, be noted that mobile WiMAX may also include additional bandwidth profiles. For example, a profile compatible with WiBro will use an 8.75 MHz channel bandwidth and 1024 FFT. This obviously will require a different subcarrier spacing and hence will not have the same scalability properties. 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].

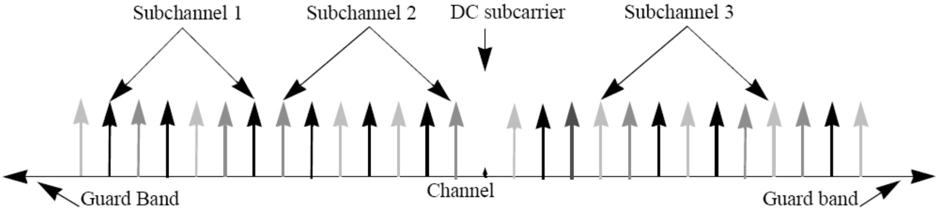

Fig. 1. Example of channel subdivision for standard 802.16d using the OFDMA mode.

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 coaxial 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} [W/m^2], as described in [9]:

$$S_{EQ} = \frac{|E|^2}{Z_0}, \tag{1}$$

where E [V/m] is the rms incident electric field strength and Z_0 [Ω] is the impedance of a plane wave in a free space. The square of the rms incident electromagnetic field strength can be easily evaluated by:

$$|E|^2 = V_R^2 \cdot AF^2 \cdot C_A^2, \tag{2}$$

where V_R [V] is the rms voltage measured by the receiver, AF [1/m] the antenna factor and C_A the cable loss.

Supposing that the time-averaged power over a six minutes period measured with the spectrum analyzer is denoted as:

$$P_{SA} = \frac{V_R^2}{Z}, \tag{3}$$

where Z [Ω] is the input impedance of the measurement instrument, V_R can be obtained from (3).

As a consequence substituting the relations (2) and (3) in (1) and expressing this new relation in decibels it is possible to obtain:

$$S_{EQ} = 10 \cdot \log_{10} P_{SA} + 10 \cdot \log_{10} AF^2 + 10 \cdot \log_{10} C_A^2 + 10 \cdot \log_{10} \left(\frac{Z}{Z_0} \right), \tag{4}$$

where S_{EQ} is expressed in dBW/m^2.

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 measuring 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]), it 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 features can make critical both the spectrum analyzer settings and the measurement method which should be 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 with a 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). For its good accuracy (< 0.2 dB with a 95% of confidence level) 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 the reference instrument.

As for the measurement method, since the WiMAX signal features, the “channel power” measurement technique should be the most proper [10, 13]. Then, in the following, this measurement method has been adopted and 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 and the repeatability to be improved. From these analyses 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.

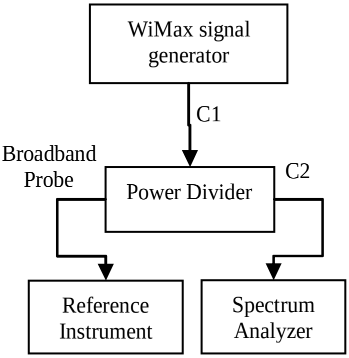

Fig. 2. Measurement setup for the characterization of the WiMAX radiated emissions.

4. Experimental results

In this section the results achieved over a number of experiments are reported. They have been performed by investigating the following main aspects:

- different WiMAX signal settings (in terms of FFT size, bandwidth and power) have been considered: these analyses are useful to set-up the measurement method for the different signal configurations that could be experienced in actual scenarios;
- different spectrum analyzer settings (in terms of detector, sweep time, and span) have been considered: these analyses are useful to quantify the effects of instrument settings on the measurement accuracy (in terms of bias and repeatability) and to identify the proper analyzer settings;
- two spectrum analyzers provided by different manufacturers have been considered: this analysis is indispensable to verify the generality of the results. At first, a general purpose spectrum analyzer, Agilent Technologies™ E4402B (9 kHz – 3 GHz input frequency range) has been used to tune the measurement method, then, the obtained results have been assessed by considering the spectrum analyzer FSH8 (9 kHz – 8 GHz input frequency range) by Rohde & Schwarz.

The following parameters has been fixed during all the measurement campaign. As for the WiMAX signal, a center frequency equal to 2.4 GHz and a frame duration of 5 ms have been selected, these settings will not affect the result's generality. As for the spectrum analyzer, a resolution bandwidth (RBW) equal to 300 kHz and a video bandwidth (VBW) equal to 3 MHz have been respectively fixed, as suggested by common good practice for the analyses of digital modulated signals [11, 22] and as experienced by the authors in similar application [13].

4.1. Detector and sweep time effects

The analyses were carried out by considering a test signal characterized by a Mobile WiMAX OFDMA-PHY profile and having a nominal bandwidth equal to 10 MHz, a 1024-FFT size, and a nominal total power equal to 10 dBm.

As for the spectrum analyzer, as previous said, the "channel power" measurement method has been employed, an integration bandwidth (IBW) equal to the nominal bandwidth of the signal was imposed. Three values of sweep time (hereinafter *ST*) were taken into account: 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). The frequency span was fixed at 40 MHz to include the signal bandwidth.

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 (hereinafter Peak), Sample, Power Average RMS (hereinafter Power RMS), Video Average. Even if the best performance is expected for the Power RMS detector (given 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 Power RMS detector (often they have only Sample and Peak detectors);
2. if the effect of the detector is really systematic it could 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 (in many cases either the sample or peak detector is selected as default).

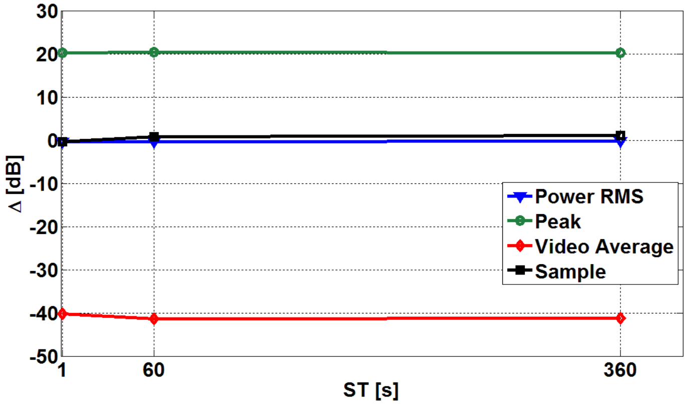

Fig. 3. Δ versus the sweep time (ST) for different detectors (generator setting *A* is involved).

Fig. 3 reports the obtained results, showing the mean deviation Δ (estimated on ten consecutive experiments), 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 deviations of the spectrum analyzer and of the power meter, σ_{SA} and σ_{PM}, respectively, are also reported in Table 1.

The obtained results prove that the Power RMS detector offers the best performance in terms of both bias and repeatability, allowing reliable results to be achieved $((|\Delta|+\sigma_\Delta)< 1.3$ dB) for each considered sweep time, where σ_Δ is the repeatability of the bias and is equal to:

$$\sigma_\Delta = \sqrt{\sigma_{SA}^2 + \sigma_{PM}^2}\,. \tag{5}$$

As for the Video Average and Peak detectors, they show the worst performance in terms of bias with significant power overestimate for the Peak detector and power underestimate for the Video Average one. Both these detectors offer good repeatability and their performance do not depend from the sweep time.

Table 1. Comparison between the spectrum analyzer and the reference instrument for different detectors and sweep times. Δ: deviation of the spectrum analyzer from the power meter, σ_{SA}: spectrum analyzer standard deviation, σ_{PM}: power meter standard deviation.

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	0.06	0.02
Sample	1	-0.43	0.08	0.01
	60	0.81	0.09	0.01
	360	1.07	0.09	0.01
Video Average	1	-40.15	0.03	0.01
	60	-41.35	0.04	0.01
	360	-41.29	0.05	0.01
Peak	1	20.27	0.08	0.01
	60	20.33	0.08	0.01
	360	20.25	0.04	0.01

Vice-versa, the Sample detector offers relatively small biases (compared with ones provided by the Peak and Video Average detectors) that are counterbalanced by the largest measurement dispersion. In addition, differently from the other detectors the bias sign depends on the selected sweep time. Among the considered sweep times, only ST = 1 s allows the condition $(|\Delta|+\sigma_\Delta) < 1.3$ dB to be satisfied with the Sample detector, thus warranting the measurement uncertainty required by [9].

To analyze the effects of the bandwidth of the signal under test, further experiments were designed and carried out, considering three Mobile WiMAX OFDMA-PHY profile test signals characterized by the following nominal bandwidths:

A. a signal bandwidth equal to 5 MHz and a 512-FFT size;
B. a signal bandwidth equal to 10 MHz and a 1024-FFT size;
C. a signal bandwidth equal to 20 MHz and a 2048-FFT size.

As for the spectrum analyzer, the same previously-described instrument settings were taken into account, except for the IBW that was chosen equal to the nominal bandwidth of the test signal and the ST that was imposed equal to 1 s in compliance with previous experimented.

Table 2. Comparison between the spectrum analyzer and the reference instrument for different detectors and signal bandwidths. Δ: deviation of the spectrum analyzer from the power meter, σ_{SA}: spectrum analyzer standard deviation, σ_{PM}: power meter standard deviation.

Detector	Signal bandwidth [MHz]	Δ [dB]	σ_{SA} [dB]	σ_{PM} [dB]
Power RMS	5	-0.39	0.02	0.01
	10	-0.34	0.03	0.01
	20	-0.39	0.02	0.01
Sample	5	-0.49	0.09	0.01
	10	-0.43	0.08	0.01
	20	-0.59	0.09	0.01
Video Average	5	-33.03	0.05	0.01
	10	-40.15	0.03	0.01
	20	-45.98	0.05	0.01
Peak	5	18.09	0.04	0.01
	10	20.27	0.08	0.01
	20	20.77	0.04	0.01

Analyzing the results reported in Table 2 it is possible to highlight that:

1. values obtained with Power RMS and Sample detectors do not seem to be affected by the signal bandwidth;
2. the Power RMS detector shows the best repeatability and it is not influenced by the signal bandwidth;
3. the Sample detector shows the worst repeatability and it is not influenced by the signal bandwidth, but in all analyzed circumstances the condition $(|\Delta|+\sigma_\Delta) < 1.3$ dB is satisfied;
4. Δ values obtained with Video Average and Peak detectors seem to be significantly influenced by the signal bandwidth.

On the contrary the Video Average and Peak detectors show a good repeatability that is not affected by the signal bandwidth.

Consequently even though the Video Average and Peak detectors are characterized by good repeatability, their use is advised against, except when the bandwidth of the test signal is well known. For these reasons in the next stages of this work they will be not considered.

4.2. Signal settings effects

To analyze if the above experienced metrological performance can be extended also to further signal settings, several experiments were carried out. In particular, four generator settings were considered:

A. a signal bandwidth equal to 3.5 MHz and a 256-FFT size (hereinafter setup A);
B. a signal bandwidth equal to 5 MHz and a 512-FFT size (hereinafter setup B);
C. a signal bandwidth equal to 10 MHz and a 1024-FFT size (hereinafter setup C);
D. a signal bandwidth equal to 20 MHz and a 2048-FFT size (hereinafter setup D).

The signals B, C and D comply with the Mobile WiMAX OFDMA-PHY profile, instead the test signal A complies with the Fixed WiMAX OFDM-PHY profile. For each signal setting, two signal power configurations, 10 and 20 dBm-amplitude respectively, were also imposed. As for the spectrum analyzer the optimal instrument settings experienced in the previous stage were imposed (span = 40 MHz, detector Power RMS, RBW = 300 kHz, VBW = 3 MHz, ST = 1 s).

Table 3. Comparison between for different WiMAX signal settings. (Power RMS detector is involved).

Setup	**Nominal power [dBm]**	**Δ [dB]**	**σ_{SA} [dB]**	**σ_{PM} [dB]**
A	10	-0.41	0.03	0.01
	20	-0.46	0.02	0.01
B	10	-0.46	0.02	0.01
	20	-0.46	0.02	0.01
C	10	-0.27	0.02	0.01
	20	-0.34	0.01	0.01
D	10	-0.27	0.01	0.01
	20	-0.26	0.01	0.01

Table 3 reports the obtained results. Some considerations can be drawn:

1. whatever the combination of setup and nominal power, the condition $(|\Delta|+\sigma_\Delta) < 1.3$ dB is always satisfied;
2. having fixed the setup, the nominal power of the signal does not influence the value of Δ and σ_{SA};
3. the spectrum analyzer always underestimates the signal power for every setup;

setup A and setup B show the worst performance. This is due to the small ratio between the signal bandwidths and the span which in turn decreases the number of points employed to measure the signal spectrum.

4.3. Method generalization

To generalize the above mentioned considerations a new measurement campaign has been performed by using a general-purpose spectrum analyzer, manufactured by a different company, Rhode & Schwarz™ FSH-8 (9 kHz – 8 GHz input frequency range).

The method assessment has been performed by considering WiMAX signals characterized by different bandwidths and levels. In particular, a comparative analysis of the measurement results obtained with the Rhode & Schwarz™ FSH-8 and Agilent Technologies™ E4402B was performed. The considered test signals were characterized by a center frequency of the signal equal to 2.4 GHz, a frame duration of 5 ms. Then, a nominal power equal to 10 dBm and 20 dBm, and a bandwidth equal to 10 MHz (1024-FFT size) and 20 MHz (2048-FFT size) have been considered.

As for the spectrum analyzers, the optimal instrument settings experienced in the previous stage were imposed (*i.e.* ST = 1 s, span = 40 MHz, RBW = 300 kHz, VBW = 3 MHz, Power RMS detector, and IBW equal to the signal bandwidth). For each configuration, ten consecutive experiments were carried out.

Tables 4 and 5 synthesize the obtained results, some conclusions can be drawn:

1. the bias with respect to the reference instrument is practically not influenced by the spectrum analyzer used;
2. the performance of both spectrum analyzers is not influenced by the signal bandwidth;
3. the performance of both spectrum analyzers is weakly influenced by the signal power in terms of bias but it does not worsen the experimental standard deviation;
4. whatever the measurement instrument, it results $(|\Delta|+\sigma_{SA}) < 1.3$ dB, confirming the generality of the proposal.

Table 4. Comparison of FSH-8 and E4402B spectrum analyzers with reference instrument for different WiMAX signal bandwidths.

Bandwidth [MHz]	**$\Delta_{FSH\text{-}8}$ [dB]**	**$\sigma_{FSH\text{-}8}$ [dB]**	**Δ_{E4402B} [dB]**	**σ_{E4402B} [dB]**	**σ_{PM} [dB]**
10	-0.31	0.01	-0.27	0.02	0.01
20	-0.31	0.01	-0.27	0.01	0.01

Table 5. Comparison of FSH-8 and E4402B spectrum analyzers with reference instrument for different WiMAX signal levels.

Nominal power [dBm]	**$\Delta_{FSH\text{-}8}$ [dB]**	**$\sigma_{FSH\text{-}8}$ [dB]**	**Δ_{E4402B} [dB]**	**σ_{E4402B} [dB]**	**σ_{PM} [dB]**
10	-0.31	0.01	-0.27	0.02	0.01
20	-0.43	0.01	-0.34	0.01	0.01

5. Conclusions

A suitable experimental analysis for investigating problems in measuring the electromagnetic pollution generated by WiMAX devices by using a traditional medium-performance spectrum analyzer was presented. 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 arbitrarily chosen by the user, such as ST, span and type of detector, were analyzed in detail.

To generalize the measurement results and become less dependent by the measurement instrument used, two general purpose medium performance spectrum analyzers of different manufacturers were used.

The obtained results have proved that generally the "channel power" method allows accurate (< ± 1.3 dB) and repeatable power measurements to be achieved if the Power RMS detector is adopted/available. Generally, with the Power RMS detector a power underestimate is always observable and its entity mainly depends on the input signal bandwidth with respect to the span employed during the measurements and on the input signal power. Significant dependence on the other instrument settings has not been observed.

Vice-versa, if a Sample detector is used, proper choice of the ST is crucial to achieve accurate measurements, thus allowing the minimum requirements defined in technical standard documents, concerning the admissible uncertainty in measurements of human exposure to electromagnetic field to be satisfied.

Peak and Video Average detectors are not advised, because even if their main consequences are significant biases on the measurement results and high repeatability (*i.e.* systematic effects could be suitably compensated), nevertheless, the bias value is strongly correlated with the signal features (as an example the bandwidth). Consequently, they could be adopted only if the input signal characteristics are a priori known or they can be estimated with a good accuracy.

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