10th IMEKO TC7 International Symposium
June 30–July 2, 2004, Saint-Petersburg, Russia

PC-BASED MEASUREMENT INSTRUMENTS: UNCERTAINTY ASSESSMENT UNDER ELECTROMAGNETIC DISTURBANCES

Salvatore Nuccio[1], *Ciro Spataro*[1] *and Giovanni Tinè*[2]

[1]Department of Electrical Engineering, University of Palermo, Italy
[2]I.S.S.I.A. – CNR – Palermo, Italy

Abstract – In the paper we examine if and how, in a generic measure performed by using a generic PC-based measurement instrument, the measurement uncertainty is influenced by the electromagnetic disturbances. With this aim, by means of experimental tests, we check how the electromagnetic threats affect the single uncertainty sources. In order to apply standard requirements and criteria, we consider the IEC-61326 standard and follow the test procedures prescribed by the IEC-61000-4 series standards. The results show that, in many cases, both radiated and conducted emissions boost the uncertainty sources and, consequently, increase the uncertainty values, worsening the measurement quality.

Keywords: uncertainty estimation, electromagnetic immunity, data acquisition systems.

1. INTRODUCTION

Nowadays is quite common to perform a wide variety of measurements by using a data acquisition card inserted into a PC and processing the acquired samples by means of the PC processor itself.

These systems, henceforth called PC-based measurement instruments (PCBMI), are quite less expensive if compared with the traditional stand-alone instrumentation and moreover can be easily reconfigured to carry out different kinds of measurements. However, since the PCBMIs are usually assembled and programmed by the users themselves, often using components by different manufacturers, the characterization of these instruments involves a series of problems which are exactly caused by their modularity and reconfigurability; this has implied a limited diffusion of the PCBMIs in the industrial environment and in the test and calibration laboratories, where it is compulsory to characterize all the employed mesasurement instruments and to assess the uncertainties associated to all performed measurements.

The problems tied to the PCBMIs characterization become more complicated, if we consider that the features of this kind of measurement instrumentation can be altered by the electromagnetic (EM) disturbances. Other Authors have dealt with the topic and in [1], the analysis of the behaviour of the PCBMIs, in the presence of EM disturbances, is carried out by means of a series of experimental tests in a shielded and semi-anechoic chamber, subjecting a data acquisition system to various EM perturbations. As results of this analysis, only the SINAD (Signal to Noise and Distortion Ratio) and the SFDR (Spurious Free Dynamic Range) are reported. But these parameters do not take into account some of the main uncertainty sources, such as offset and gain, so they can be useful to characterize the overall dynamic performances of an instrument, whereas they lose their validity when it is necessary to evaluate the actual measurement uncertainty.

For this purpose, according to the well know ISO – “Guide to the Expression of Uncertainty in Measurement” (GUM) [2], the starting point should be the assessment of the standard uncertainties associated to each uncertainty source. Therefore, there is the need to separately examine the influence of the EM disturbances on each source. However, only considering the A/D conversion process, we should consider as uncertainty sources at least offset, gain, quantization, non-linearity, cross-talk, settling time and timing jitter [3]. Taking into account the influence of the EM disturbances on all these uncertainty sources would be a very hard task. But, considering that beside offset and gain, each source gives a contribution to the SINAD value, we examine, using an experimental approach as in [1], the disturbances’ effects only on the offset, gain and SINAD values.

In order to apply standard requirements and criteria for the immunity experiments, we take into account the IEC-61236 standard [4], where various EM phenomena are considered. As for the experiments setup and management, we adhere to the procedures described in the IEC-61000-4 series [5].

In the following we describe the immunity requirements and criteria of the aforesaid standards (chapter 2), the tested instrument characteristics and specifications, the environment and the instruments used for the immunity tests and the experiment setup (chapter 3). In chapter 4 we experimentally analyze how each considered uncertainty source is influenced by the EM disturbances and, in chapter 5, how these threats affect the uncertainty values. The conclusions are presented in chapter 6.

2. IMMUNITY STANDARDS

The IEC-61236 specifies minimum requirements for immunity and emissions regarding electromagnetic compatibility (EMC) for electrical equipment for measurement, control and laboratory use. Since any PCBMI can be considered equipment for measurement, control and laboratory use, it should satisfy the IEC-61326 requirements. But in spite there are no particular rules for the PCBMIs, these instruments show some peculiarities: unlike the stand-alone instruments, which can be characterized by the same manufacturer as for the EMC specification, they are usually constituted of various components from different manufacturers. Even having access to the EMC specifications of each component, extending these specifications to the whole measurement chain is not completely straightforward. All the components of a PCBMI have to be considered as a single equipment under test (EUT), and for each particular configuration, the immunity tests must be carried out. Only in this way, the complete characterization of the PCBMI from the EMC viewpoint, and consequently, the correct uncertainty evaluation can be carried out.

As for the immunity requirements, in the considered standard, the interfaces of the EUT with the external EM environment are classified in five ports: enclosure port; AC power port; DC power port; earth port; input/out port. The considered EM phenomena are: radiated radio-frequency (RF) disturbances; bursts; surges; conducted RF disturbances; voltage interruptions; electrostatic discharges. For each phenomenon and for the suitable port, the immunity requirements and limits are given for normal environments, industrial locations and for controlled EM environments.

In the following the considered disturbances, the related standards and the prescribed immunity test levels are described.

2.1. Radiated RF disturbances

The test procedures are described in the IEC-61000-4-3 standard, which relates to the immunity requirements and test methods for equipment subjected to radiated fields in the frequency range 80 ÷ 1000 MHz. The disturbance frequency shall be incrementally swept with a 1% step size and the disturbance fields shall be 80% amplitude modulated with a 1 kHz sine wave.

As prescribed in the IEC-61326 standard RF fields with 1, 3, 10 V/m strength are irradiated towards the tested instruments.

2.2. Bursts

The test procedures are described in the IEC-61000-4-4 standard, which relates to the immunity requirements and test methods to repetitive electrical fast transients (burst) caused by switching transient. A burst consists of a sequence of a limited number of distinct pulses; the single pulse characteristics shall be: rise time 5 ns ± 30%; duration 50 ns ± 30%; repetition rate 2.5 kHz ± 30% or 5.0 kHz ± 30% (depending on the test voltage level); burst duration 15 ms ± 20% and burst period 300 ms ± 20%.

According to [4], the instruments are subjected to 1kV and 2 kV bursts injected into the power supply of the tested instruments.

2.3. Surges

The test procedures are described in the IEC-61000-4-5 standard, which relates to the immunity requirements and test methods to unidirectional surges caused by overvoltages from switching and lightning transients. The surge is a transient wave propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease. The surge is simulated by a voltage pulse wave whose characteristics shall be: front time 1.2 μs ± 30%; time to half-value 50 μs ± 20%.

As prescribed in [4], the instruments are subjected to 0.5, 1 and 2 kV surges, coupled with the power supply of the tested instruments.

2.4. Conducted RF disturbances

The test procedures are described in the IEC-61000-4-6 standard, which relates to the immunity requirements to the conducted disturbances induced by intended RF transmitters in the frequency range 0.15 ÷ 80 MHz. The frequency shall be incrementally swept with a 1% step size and the disturbance signals shall be 80% amplitude modulated with a 1 kHz sine wave.

According to IEC-61326 standard, disturbances with 1 V and 3 V amplitude are injected in the power supply of the tested instruments.

2.5. Voltage interruptions

The test procedures are described in the IEC-61000-4-11 standard, which relates to the immunity requirements and test methods for equipments sensitive to disturbances caused by fault on power line.

As prescribed in [4], the tested instruments are subjected to 1-cycle long interruptions.

2.6. Electrostatic discharges (ESD)

The test procedures are described in the IEC-61000-4-2 standard, which relates to the immunity requirements and test methods for equipment subjected to static electricity discharges, from operators directly, and to adjacent objects. The single ESD characteristics shall be: rise time in the range 0.7 ÷ 1.0 ns; first peak current 15 A ± 10% or 30 A ± 10% (depending on the test voltage level).

According to [4], air (4 kV) and contact (4kV, 8 kV) discharges with both positive and negative polarities are applied in various points of the enclosure ports. The test voltage shall be increased from the minimum to the selected test level, in order to detect any threshold of possible failure.

3. IMMUNITY TESTS

3.1. The tested instruments

The core of a PCBMI is the data acquisition board (DAQ) inserted into a PC. In this framework we have considered four different National Instrument™ DAQs, whose technical characteristics are reported in Table I.

TABLE I. Characteristics of the tested DAQs

DAQ Type	AT-MIO 16E-10	PCI-MIO 16XE-10	DAQCard-AI 16XE10-50	PCI 6110
BUS Type	ISA	PCI	PCMCI	PCI
Number of channels	16	16	16	4
ADC Type	Successive approximation	Successive approximation	Successive approximation	Delta sigma
Resolution (bit)	12	16	16	12
Maximum sampling rate (kS/s)	100	100	200	5000
Maximum input signal ranges (V)	± 10	± 10	± 10	± 42
Bandwidth (kHz)	150	255	39	7200

The PCMCI DAQ is inserted in the notebook AUSUS™ 7300 ad the other three DAQs are inserted in the appropriate slot of various common motherboards mounted on various common PC cases.

The DAQs are linked to a shielded connector box NI SCB68 through a shielded cable NI SCH6868 (1m). We tested also a not-shielded configuration linking the DAQs to a CB-68LP connector block trough a R6868 ribbon cable (1m). To link the measurement point to the various connector boxes, we used a RG-58 type coaxial cable (0.5 m) or a LMR0-600-DB double-shielded coaxial cable for the full-shielded configurations.

3.2. The disturbances generation

The radiated immunity tests were carried out both in an EM anechoic chamber and in a GTEM cell. The chamber operates in the frequency range 0.08÷18 GHz and its sizes are 9.4 x 6.4 x 5.55 m; for the chamber tests, the disturbances are generated by a Hewlett & Packard™ HP 8648B, amplified by a Schaffner™ CBA9434, and radiated by a Schaffner™ CBL6143 bilogarithmic antenna. The GTEM cell is a Schaffner™ 750 operating in the frequency range 10 kHz ÷ 18 GHz; for the cell tests, the disturbances are generated by a Rohde & Schwarz™ SMR20 and amplified by a Schaffner™ CBA9477B.

The bursts and surges instrumentation are a Schaffner™ NSG2050 mainframe, a Schaffner™ PNW2225 plug-in to generate the bursts and a Schaffner™ PNW2055 plug-in to generate the surges. The bursts and surges are coupled into the mains feed via the plug-in internal coupling-decoupling network.

The conducted RF disturbances are generated by the signal generator Hewlett & Packard™ HP8648B; the coupling with the mains feed is obtained by an artificial network type M4 by Fischer™.

The voltage interruptions are generated by a Schaffner™ PNW2003 with a drop out variable from 2 ms to 99 s.

The electrostatic discharges are generated by an EMTEST™ ESD30.

3.3. The input signals generation

In order to correctly characterize a PCBMI and to accurately calculate the offset, gain and SINAD values, we should use input signals with very great accuracy and very high spectral purity, generated by very high priced generators. However, in this contest we are only interested in the variations of offset, gain and SINAD values of the EUT subjected to the EM disturbances, with respect to the not perturbed conditions. The only imperative characteristics required to the generator are its repeatability and its stability. Therefore, as inputs for the tested PCBMIs, DC and sinusoidal signals are generated by the Agilent™ 33120A function and arbitrary waveform generator.

All the measurements are performed in differential mode, sampling at the maximum rate and setting the gain to 1. The evaluation of the characteristics of the EUT is carried out following the procedures prescribed in [3]. Static offset and gain values are calculated by drawing up the transfer characteristic, which, in turn is obtained from a five-point least minimum squares method. The SINAD values are calculated using a not-coherent sampling and consequently a Hanning windowing is used.

After the warm up of the generator and of the EUT, we verified that the measured offset, gain and SINAD values are compatible with the manufacturer specifications; and after the evaluation of the offset and SINAD measurement stability and repeatability, we have submitted the EUTs at the EM disturbances.

4. TESTS RESULTS

4.1. Radiated RF disturbances

In order to test the PCBMIs under radiated emissions, we performed various tests inside the chamber and the GTEM cell, varying PCs, DAQs, cables and connector boxes of the tested PCBMIs, the position of these components and the frequency and strength of the disturbance fields. In all cases, we observed that spurious frequencies arise during the signals acquisition. These spurious components are a DC component, the disturbance modulating signal and its harmonics; in the prescribed frequency range, the disturbance carrier signal and its harmonics are completely filtered by the limited bandwidth of the tested instruments. By analysing the acquired signals, we verified that the amplitude of the spurious frequency components (and consequently the coupling intensity and the immunity level) is:

- weakly depending on the DAQ, motherboard and case models and strongly depending on the shielding dress of cables and connector boxes;
- slightly depending on the PC and connector box position and strictly depending on the signal cables position;
- strictly depending on the disturbance strength, but not-depending on the disturbance frequency, except when the system resonates, allowing a much tighter coupling and strongly increasing the spurious frequencies amplitude.

In any case the presence of these spurious frequencies reduces the SINAD value and alters the offset value. For instance, in fig. 1-2, we report the offset, gain and SINAD values, as a function of the disturbance frequency, illuminating, inside the GTEM cell, the PCMCI DAQ in shielded configuration with a 10V/m disturbance field. Each reported value is the mean of 100 measured values. The dotted lines stand for the values measured without disturbance.

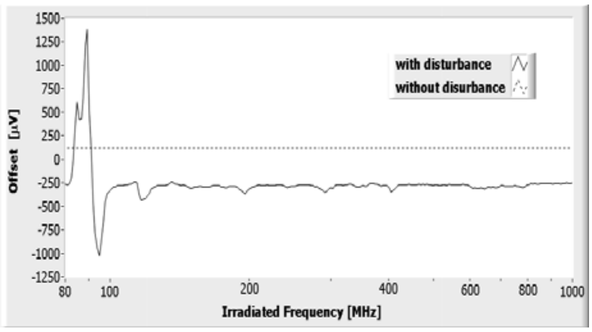

Fig. 1. Offset values under radiated disturbance

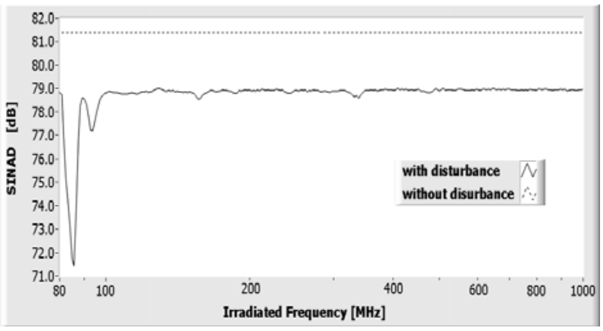

Fig. 2. SINAD values under radiated disturbance

4.2. Bursts

We started the experiments using a not-shielded configuration, connecting the NI PCI-MIO-16XE-10 to the CB-68LP connector block through the R6868 ribbon cable, and the connector box to the signal generator through the RG-58 coaxial cable. A 2 kHz, 5 V_{peak} sine wave was generated as input for the EUT.

During the burst injection into the supply cable, visible spikes, superimposed to the sinusoidal signal, appear causing a variation of the offset and SINAD values. In order to check if the bursts can perturb as well the signal generated by the Agilent^{TM} 33120A, we generated a 0 V DC signal and compared the acquired signal with the one acquired closing the RG-58 coaxial cable into a 50 Ω impedance. The obtained results (fig.3) are identical; consequently the signal generator can be considered immune to the bursts.

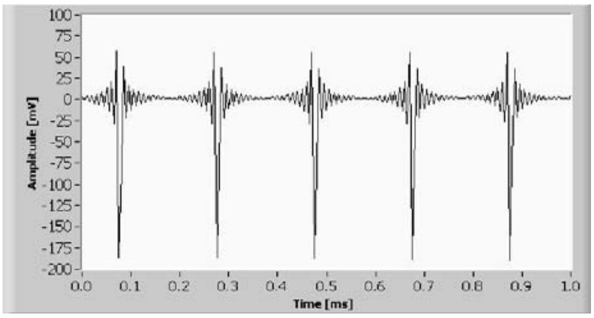

Fig. 3. burst effect on an acquired 0 V DC signal

However we noticed that the acquired disturbance level depends on the reciprocal position of the EUT signal cables and the supply cable, where the bursts are injected. This means that the disturbance injected in the supply cable is radiated by the cable itself and produces an EM interference with the EUT. With the aim to quantify the radiated coupling mechanism, we tested a full-shielded configuration, connecting the DAQ to the NI SCB68 shielded connector box through the shielded cable SHC68-C68, and the connector box to the signal generator through the LMR0-600-DB cable. With this configuration, no visible effects can be observed when the EUT is subjected to the bursts; therefore, from this experiment, we can deduce that the coupling mechanism between disturbance and EUT is only radiated and only caused by the emissions of the supply cable. To find another evidence of this thesis, we tested again the not-shielded configuration of the EUT, but shielding the supply cable. Also in this way, the EUT is immune to the bursts.

We tested the other DAQs, other PC cases and motherboards and in each case we observed the same behaviour, namely that there are no conductive coupling paths, but only radiated coupling paths between the EM disturbance and all the tested EUTs. As a consequence the coupling intensity and the disturbances effects are strictly depending on the experiment layout, in particular on the length, the dress and the reciprocal position of the signal cables and of the supply cable. This entails that the reproducibility of the experiments results cannot be ensured if at least length, shielding and mutual position of the cables are not defined and characterized. But actually in the IEC 61000-4-4 standard there are no particular rules regarding these aspects, since the standard implicitly considers just conductive coupling paths. For this reason we carry out only a qualitative analysis, without reporting the quantitative results obtained performing the tests.

4.3. Surges

Injecting into the supply cable surges and repeating the same methodology employed for the bursts, we obtained similar results, specifically that the full-shielded configurations are practically immune to the surges, while with a not-shielded configuration the surges effects are manifestly visible on the acquired signals. As instance in fig. 4 the 1 kV surge effect on a 0 V DC signal is shown.

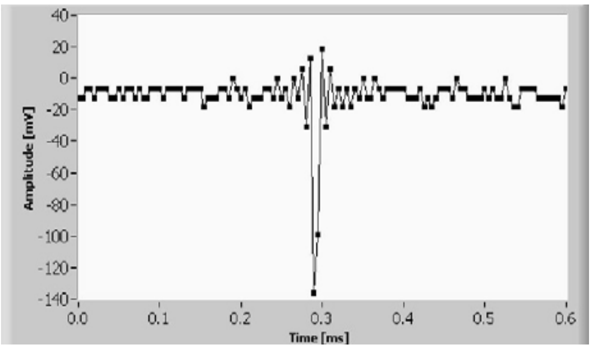

Fig. 4. Surge effect on an acquired 0 V DC signal

Also in this case the coupling mechanism is only radiated and, consequently the surges impact is strictly depending on the length, the dress and the reciprocal position of the signal cables and of the supply cable.

4.4. Conducted RF disturbances

Subjecting the EUTs to the conducted RF fields, it can be noticed that once more the coupling mechanism between disturbance and EUT is only radiated. Therefore, for the full-shielded configuration of the EUTs, no visible effects appear while a RF threat crosses the supply cable, and no variations of offset, gain and SINAD values were observed. Repeating the experiments onto the not-shielded configuration, the emission radiated by the supply cable couple with the EUT and spurious frequencies arise during the signals acquisition. These spurious components are a DC component, the disturbance carrier signal and its harmonics and the disturbance modulating signal and its harmonics. Of course some of these components can appear in their alias version or can be completely filtered, depending on the sampling frequency and on the instrument bandwidth. In any case the presence of these spurious frequencies reduces the SINAD value and alters the offset value. As instance in fig. 5 we report the frequency analysis of a 0 V DC signal, when the EUT is subjected to a 3 V, 8 MHz sine wave, 80 % amplitude modulated with a 1 kHz sine wave. Once again the effects of the conducted RF fields depend on the length, shielding and placement of the cables.

4.5. Voltage interruptions

When the tested EUTs are subjected to 1-cycle supply interruptions, no visible effect appears during the signals acquisition, either with full-shielded configuration or with not-shielded configuration.

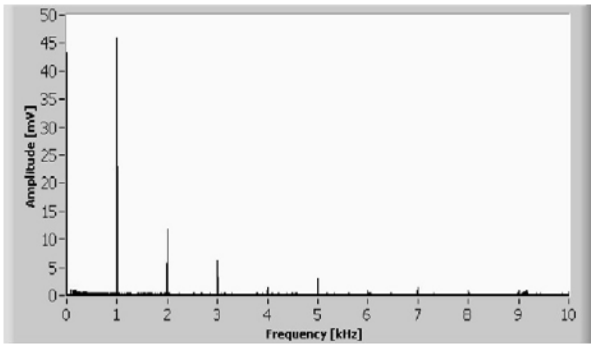

Fig. 5. Frequency analysis of an acquired 0 V DC signal under RF conducted emission

4.6. Electrostatic discharges (ESD)

Contact and air discharges in both polarities were applied in various points of the EUT, starting from 1 kV and increasing the test level value with a step size of 0.5 kV. No visible effects were observed and therefore, with respect to the not-perturbed conditions, no changes were detected in the offset, gain and SINAD values.

4.7. Software immunity

After the EM immunity characterization of the hardware block of the measurement instruments, we realized some PCBMIs performing various measurements (RMS value, frequency, spectral analysis, THD), with the aim to test the behavior of the software block of the EUT. The NI LabView™ 6.1 (operating in Windows™ 98 environment) is the programming language used to drive the acquisition boards, to process the acquired samples and to realize the user interface.

During all the immunity tests, no faults of the software were detected, no system resets occurred and the measurement instruments kept on working without any loss of functions.

5. UNCERTAINTY EVALUATION

In a previous work [6], we proposed two methods to assess the uncertainties in the measurement performed by a generic PCBMI: a theoretical method based on an original application of the uncertainties propagation law of the GUM; and a numerical method which, by means of an ad hoc developed software tool, estimates the uncertainties using the Monte Carlo approach. With both approaches, the evaluation is done starting from the DAQ specifications and the combined uncertainty values are calculated using only the standard uncertainties associated to offset, gain and SINAD.

Given that, under EM disturbances and mainly under radiated RF fields, the offset values can appreciably change and the SINAD values can lower, the standard uncertainties, associated to these uncertainty sources, increase and therefore also the combined standard uncertainty increases. For example in table II, we report the maximum shifts of the offset and SINAD values from the respective values calculated without emissions, when the system with the PCMCI DAQ is subjected to radiated disturbances in the GTEM cell.

TABLE II – Maximum deviation of the characteristics of the EUT from the values calculated without disturbances

Characteristic	Maximum deviation		
	3 V/m shielded	**10 V/m shielded**	**3 V/m not-shielded**
Offset	140 μV	1255 μV	-1042 μV
SINAD	0.6 dB	10.0 dB	4.2 dB

Another interesting result is that, when the board channels are inverted, the polarity of the induced disturbance changes sign, and therefore also the maximum deviations reported in table II change sign. This means that, when the PCBMI is subjected to EM fields, the manufacturer specifications have to be increased of these maximum deviation values, obtaining the values of table III.

TABLE III – EUT specifications under radiated fields

Characteristic	Specification			
	0 V/m	**3 V/m shielded**	**10 V/m shielded**	**3 V/m not-shielded**
Offset	±815 μV	±955 μV	±2070 μV	±1857 μV
SINAD	81.4 dB	80.8 dB	71.4 dB	77.2 dB

Starting from these values and from the gain specification and applying one of the methods suggested in [6], it is possible to calculate the combined standard uncertainty. For instance, in table IV we report the uncertainty values calculated by using the Monte Carlo approach, for the mean value measurement of a 2.5 kHz, 9 V_{peak} sinusoidal signal, coherently acquiring 200 samples at the sampling rate of 100 kS/s. (the gain specification of the considered DAQ is ± 95 ppm).

TABLE IV – Combined standard uncertainty values

0 V/m	3 V/m shielded	10 V/m shielded	3 V/m not-shielded
± 1.2 mV	± 1.3 mV	±2.3 mV	±2.0 mV

5. CONCLUSION

In this paper we carried out a series of experiments to investigate the electromagnetic immunity of the PC-based measurement instruments under electromagnetic threats, according to the rules prescribed in the IEC-61326 and IEC 61000-4 series standards. The systems were characterized measuring some of their metrological performances and in particular, the offset, gain and SINAD values were calculated.

The results show that the PC-based measurement instruments are quite susceptible to radiated RF fields and completely immune to the electrostatic discharges and voltage interruptions. As for the other conducted disturbances (bursts, surges and conducted RF threats), the experiments demonstrate that the coupling mechanism is only radiated and is caused by the EM emissions of the supply cable when it is crossed by the conducted disturbance; therefore a good shielding makes the EUTs sufficiently immune to these disturbances. In these cases, particular attention has to be paid for the not-shielded configurations, given that the emissions radiated by the supply cables themselves can alter the instrument performances. However it is difficult to quantify the disturbances effects, since their intensity is strictly tied to the length, dress and reciprocal position of the supply cables and of the signal cables.

In general, under EM disturbances, the performances of the instruments can get worse, since the offset specification limits could expand and the SINAD value could decrease; consequently, the standard uncertainty associate with offset and SINAD increase. For these reasons, when any PC-based measurement is performed under EM emissions, the combined standard uncertainty associated with the measurement result can increase, causing deterioration of the measurement quality.

Our next target is to find a common basis to establish, by means of simple and fast tests, if and how the real electromagnetic environment, where the measurement is performed, can upset the measurements carried out by a generic PC-based measurement instruments, when it is functioning in its real operative condition.

REFERENCES

[1] G. Betta, D. Capriglione, C. De Capua, C. Landi, “A comparative analysis in term of conducted susceptibility of PC-based data acquisition systems” *in Proc. of XVII IMEKO World Congress*, Dubrovnik, Croatia, June 2003.

[2] ISO, “Guide to the expression of uncertainty in measurement”, International Organization for Standardization, Geneva, Switzerland, 1995.

[3] IEEE Std 1241, 2000, “IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters”.

[4] IEC 61326 “Electrical equipment for measurement, control and laboratory use – EMC requirements”, 2002.

[5] IEC 61000-4-Series “Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques".

[6] S. Nuccio, C. Spataro, “Approaches to evaluate the virtual instrumentation measurement uncertainties” *IEEE Transactions on Instrumentation and Measurement*, **51**(6), 1347-1352, 2002.

Authors: Prof. Salvatore Nuccio and Dr. Ciro Spataro
Dipartimento di Ingegneria Elettrica
Università degli Studi di Palermo
Viale delle Scienze, 90128 - Palermo, ITALY
Phone (+39) 0916615270 - Fax (+39) 091488452
e-mail: nuccio@unipa.it; spataro@diepa.unipa.it.
Dr. Giovanni Tinè
I.S.S.I.A (Istituto di Studi sui Sistemi Intelligenti per l'Automazione) – CNR (Centro Nazionale Ricerche)
Viale delle Scienze, 90128 - Palermo, ITALY
Phone (+39) 0916615206, e-mail: tine@cerisep.pa.cnr.it.