16th IMEKO TC4 Symposium
Exploring New Frontiers of Instrumentation and Methods for Electrical and Electronic Measurements
Sept. 22-24, 2008, Florence, Italy

Effects of the Electromagnetic Disturbances in the DAQ-Based Measurement Instruments and their Compensation

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

[1] *DIEET - University of Palermo, ITALY, nuccio@unipa.it; ciro.spataro@unipa.it*
[2] *ISSIA - CNR Palermo, ITALY, tine@pa.issia.cnr.it*

Abstract- In previous works, we analysed the behaviour of data acquisition board based measurement instruments when they are subjected to the electromagnetic disturbances prescribed by the IEC-61326 Standard. The study has shown that the effects of both radiated and conducted emissions alter the performances of this instrumentation when not-shielded configurations are used; in fact, in these cases, the parameters which characterise a data acquisition board can reveal an appreciable degradation. On the contrary, even the heaviest disturbances cause a negligible impact if the good practices of shielding are observed. Since the full-shielded configurations are quite expensive, it would be useful to find a way to safely employ also a not-shielded configuration in the hostile electromagnetic environments. With this aim, in the paper, we propose two methods for the compensation of the electromagnetic disturbances impact. The first one is a software approach, applicable in cases of steady disturbances. The second approach is based on a two channels acquisition technique applicable with boards which can simultaneously acquire two signals. The practical application of both methods has produced satisfactory results.

I. Introduction

One of the main reasons which has limited the diffusion of the measurement instruments based on a data acquisition board (DAQ) is the fact that their behaviour under electromagnetic (EM) disturbances is practically unknown. In fact, for the manufacturer of a stand alone instrument, which can directly characterise his product, it is rather easy supplying information about the levels of conducted or radiated disturbances that can alter the instrument performances; on the contrary, with regard to more complex measurement systems which can be constituted of various components provided by different manufacturers, the analysis of their EM immunity degree is really not simple. Even having access to the EM compatibility (EMC) data of each component, the extension of these specifications to the whole measurement chain is not completely straightforward. The whole measurement system has to be considered as unique equipment under test (EUT). Only in this way, a complete characterisation of the measurement system from the EMC viewpoint can be carried out.

In the family of the complex measurement systems, we can unquestionably include the DAQ-based measurement instruments that are instruments approached as a data acquisition board connected to a standard personal computer which processes the acquired data to obtain the measurement results.

Other Authors have dealt with the EM immunity of the DAQs. In [1,2] there is the study of the feature decrease due to the PC internal EM environment. However the analysis is carried out starting from a characterisation of the EM field internal to the computer cases, therefore cannot be straightforwardly extended to the effects caused by external EM interference.

In [3,4], the analysis of the behaviour of a DAQ, in the presence of conducted radio-frequency disturbances, is carried out by means of a series of experimental tests in a controlled EM environment, taking into account, as indicators of the EM immunity, the variations of the SINAD (SIgnal to Noise and Distortion Ratio) and the SFDR (Spurious Free Dynamic Range) values.

We decided to extend this analysis to all the EM disturbances prescribed by the IEC 61326 Standard [5], which specifies minimum requirements for immunity and emissions regarding electromagnetic compatibility for electrical equipment for measurement, control and laboratory use. As indicators of the EM immunity degree, we used the variations of three figures of merit which characterise a DAQ, namely offset, gain and SINAD. The experiments performed under both radiated [6] and conducted [7] emissions have shown that only the not-shielded configurations of DAQ-based measurement instruments are susceptible to the EM disturbances, while the full-shielded configurations are practically immune.

However a full-shielded configuration of the whole measurement chain is quite expensive; therefore, in

order to safely employ also the not-shielded configurations in a hostile EM environment, we defined two procedures which, in some case, assure the compensation of the disturbance effects. The first approach is based on a simple and fast test which permits the localisation and the successive elimination, via software, of the effects of the EM disturbances. The other approach consists of a hardware compensation obtained by simultaneously acquiring the measurement signal by two channels.
In the following, a recapitulation of the results obtained subjecting the DAQs to the standardised disturbances is made (chapter II); successively the software (chapter III) and the hardware (chapter IV) compensation techniques are presented, discussed and validated; the conclusions are outlined in chapter V.

II. Results of the test prescribed by the IEC 61326 Standard

The IEC 61326 Standard prescribes to subject the EUT to the following EM phenomena: radiated radio-frequency (RF) disturbances; bursts; surges; conducted RF disturbances; voltage interruptions; electrostatic discharges; rated power frequency magnetic field. For each phenomenon the immunity requirements and limits are given for normal environments, industrial locations and for controlled EM environments. As for the instrumentation, setup and management of the experimental tests, the IEC 61326 refers to the IEC-61000-4 series Standards [8].
We have tested various DAQs with various resolutions and various maximum sampling rates, subjecting to the EM disturbances the total measurement chain, constituted of cables, antialias filter, connector box, DAQ and computer. Both full-shielded configurations and not-shielded configurations have been tested. The environment and the instrumentation used to generate the EM disturbances are full-compliant with [8]. As inputs for the tested EUTs, DC and sinusoidal signals have been generated by the Agilent™ 33120A function and arbitrary waveform generator. All the measurements have been performed in differential mode, sampling at the maximum sampling rate.
In order to test the DAQs under radiated emissions, we performed various tests inside both a semi-anechoic chamber and a GTEM cell. RF fields with 1, 3, 10 V/m strength are irradiated towards the tested instruments, as prescribed in [5]. The disturbance frequency is incrementally swept in the frequency range 80 ÷ 1000 MHz with a 1% step size and the disturbance fields are 80% amplitude modulated with a 1 kHz sine wave [8]. All the tests were performed varying PCs, DAQs, cables and connector boxes, the reciprocal positions and orientations 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 [6]. 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. In any case, mainly for the not-shielded configurations, the presence of these spurious frequencies reduces the SINAD value and alters the offset value. By analyzing 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.
As for the conducted disturbances, we started the experiments with the burst, which consists of a sequence of a limited number of distinct pulses whose characteristics are prescribed in [8].
Using the not-shielded configurations, during the burst injection into the supply cable, visible spikes, superimposed to the sinusoidal signal, appear causing a temporary variation of the offset and SINAD values [7]. However we noticed that the acquired disturbance level depends on the reciprocal position of the 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. With this arrangement, no effects are observed when the EUT is subjected to the bursts; therefore, from this experiment, we can deduce that the coupling modality between disturbance and EUT is only radiated and only caused by the emissions of the supply cable [7]. 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 DAQ is immune to the bursts.
Injecting into the supply cable a surge, which is a voltage pulse wave whose characteristics are prescribed in [8] and repeating the same methodology employed for the bursts, we obtained similar

results, namely 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 [7].
With the same methodology, we tested the effects of the conducted RF fields, injecting in the supply cable of the tested instruments 1 V and 3 V amplitude disturbances. The disturbance frequency is incrementally swept in the frequency range 80 ÷ 1000 MHz with a 1% step size and the disturbance signals are 80% amplitude modulated with a 1 kHz sine wave [8]. Once more the coupling mechanism between disturbance and EUT is only radiated. Therefore, for the full-shielded configuration of the EUTs, no observable 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 configurations, 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 [7]. 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.
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.
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 until reaching, as prescribed in [5], the 8 kV level. No effects were observed and therefore, with respect to the not-perturbed conditions, no changes were detected in the offset, gain and SINAD values.
Eventually, the EUTs were subjected to 50 – 60 Hz magnetic field reaching the 30 A/m strength level prescribed for industrial locations. Also in this case, no effects were observed.
Besides subjecting the instruments to the standardised EM emissions prescribed in [5], we performed a series of tests in locations where unknown disturbances were present [9]. Also in these cases, for the not-shielded configurations, the offset values can appreciably change and the SINAD values can lower, while the EM disturbances have no effect on the full-shielded configurations.
Summarising the results of the tests performed both under standardised disturbances and under unknown disturbances, it is possible to state that the radiated and conducted emissions can alter the performances of the not-shielded configurations, while on the contrary they produce a negligible impact on the full-shielded configurations. However a full-shielded configuration of the whole measurement chain is quite expensive, since it is necessary to employ rather costly cables and connector boxes and the measurement shell be performed by skilled personnel. Therefore, it would be useful to find a way to safely employ also a not-shielded configuration in locations where EM disturbances are probable. For this purpose, starting from the analysis of the huge amount of tests performed, we have perfected two methods for the compensation of the electromagnetic disturbances impact: a software approach and a hardware technique.

III. Software compensation of the EM disturbance effects

To outline the software approach for the compensation, we started analysing two interesting phenomena: we experimentally noticed that the disturbance effect is linearly added to the measurement signal (obviously excluding the cases which cause the A/D converter saturation and excluding the alias phenomena which however are avoided by the insertion of the low-pass filter). Moreover, we observed that, simultaneously applying various EM threats, the effects of these disturbances combine in an approximately linear way. Therefore, for whatever input signal, if it is known, it is possible to quantify the consequences produced by the actual EM conditions. It is clear that, in order to localise the effects of the EM disturbances, the most accurate and least expensive signal to use is a 0 V DC signal.
It is enough, therefore, to close the measurement chain in short circuit and, by means of a time and/or frequency analysis, it is possible to localise and evaluate the effects of the EM disturbances, even if the these are unknown. If possible, better results can be obtained closing the measurement chain in an impedance equal to the one of measurement point.
In the cases of steady disturbances and if their effects are not within the bandwidth of interest of the measurement, it is possible to implement, into the software part of the instruments, algorithms to compensate for the disturbance effects.
In order to validate the proposed approach, we performed various measurements in locations where heavy EM disturbances were present.
Let us consider the National Instruments™ AI 16XE10-50 DAQ in not-shielded configuration operating in the nearness of a voltage source inverter working in steady conditions.

By means of this DAQ we measure the DC, RMS and THD values of a distorted 50 Hz voltage signal whose characteristics are reported in column I of tab. I. The signal is generated by the Agilent™ 33120A. The measurement is performed in differential mode, setting the gain to 1, sampling at 100 KS/s and choosing a 100 ms time window.
Before performing the measurements, we short circuited the measurement chain and performed a frequency analysis, which is reported in fig.1.
The analysis show that the inverter is producing a visible interference with the DAQ, generating a 15.5 mV DC component; a 831 Hz component and its III and V order harmonics.
For the measurement at issue, these components will not alter the measured THD value, but will alter the measured RMS and DC value. Performing the measurement, in fact, we get the values reported in column II of tab. I (all the reported values are the means of 50 measurements).
Filtering the disturbance components and subtracting the DC value measured during the test, it is possible to correct the results, obtaining the data reported in column III of tab. I.

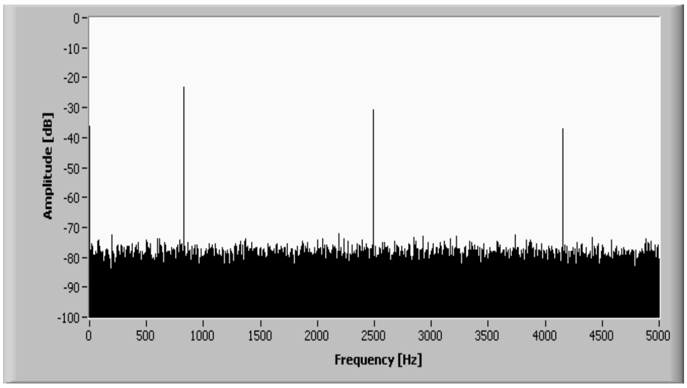

Fig.1. Frequency analysis with short circuited measurement chain in the nearness of the voltage source inverter

Table I - Mean values of the measures performed in the nearness of the voltage inverter

	I	II	III	IV
DC value (V)	0.1000	0.1157	0.1001	0.1002
RMS value (V)	6.3902	6.3912	6.3902	6.3901
THD %	8.96	8.96	8.96	8.96

For this measurement, therefore, the impact of the voltage source inverter can be practically removed by implementing the appropriate compensation algorithm and the DAQ can be safely used even with a not-shielded configuration.
Repeating the measurement with a full shielded configuration and without the compensation algorithm, the inverter impact is almost completely negligible; in fact we obtained the value reported in column IV of tab. I. The results obtained with the last experiment ensure that the EM disturbance has no effect on the signal generator.
We repeated the same measurement in the proximity of a 15 kVA welding machine. Before performing the measurements, we short circuited the measurement chain and we carried out a frequency analysis which is reported in fig.2.
In this case, the EM disturbance produces a heavy, broadband and not steady interference with the DAQ and therefore the repeatability of the measurement get worse. Moreover, the disturbance effect occupies the bandwidth of interest and therefore, in these EM environment conditions, it is not possible to correct the disturbance impact

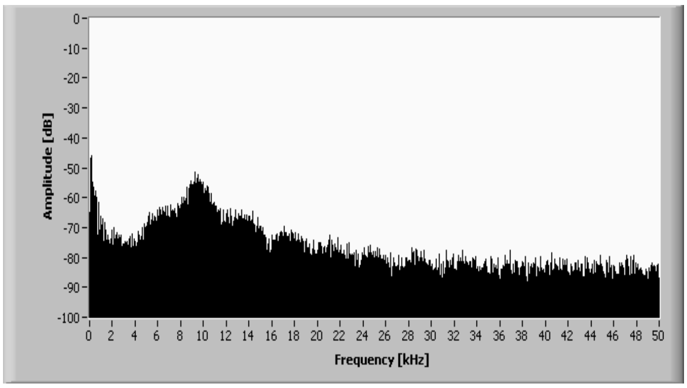

Fig.2. Frequency analysis with short circuited measurement chain in the nearness of the welding machine

IV. Hardware compensation of the EM disturbance effects

The basis for the definition of the hardware approach was given from the consideration that the coupling between EUT and EM environment is always radiated. Even in case of conducted disturbances, it has been proved [7] that there are not conducted paths and that the coupling modality is only radiated and only caused by the emissions of the supply cable which is crossed by the conducted disturbance. Starting from this assumption, we conceived a procedure for the compensation of the EM disturbance effects, based on a two channel acquisition technique.

The measurement signal is sent to the first channel and, simultaneously, to the second channel, but with inverse polarity; the cable paths are arranged in a manner that the EM emissions induce the same effects on the two channels. Adding and dividing by two, via software, the data acquired by the two channels, we should obtain the measurement signal without the effect of the EM disturbances.

We performed various tests in order to verify the efficacy of this approach and a good compensation has been obtained with the DAQs provided of an analog-to-digital converter for each acquisition channel. In these cases, in fact, the simultaneity of the acquisition performed by the two channels is guaranteed.

For instance, in the following are reported the results obtained using a National Instrument™ PCI 6110 DAQ. The measurement signal is a 1.5 V DC signal provided by a battery; the signal is acquired in differential mode by two channels, using a 50 KS/s sampling rate and a 10 ms time windows. The interference is caused by a 10 V/m 82 MHz radiated field, 80% amplitude modulated with a 640 Hz sine wave. In absence of the EM disturbance, the measured DC value is 1.513 V (obtained as mean value of the 5000 acquired samples). Repeating the measurement in presence of the emission, the disturbance produces, on the first channel, a 18 mV reduction of the DC component and the appearance of a 28 mV 640 Hz spurious tone. On the second channel, the disturbance reveals itself as a 18 mV increase of the DC component and the appearance of a 26 mV 640 Hz spurious tone which has the same phase of the spurious of the first channel. Adding and dividing by two, the data acquired by the two channels, a new signal is obtained. The DC component of this signal is identical at the not-perturbed case and the amplitude of the spurious tone is reduces at 1.5 mV level.

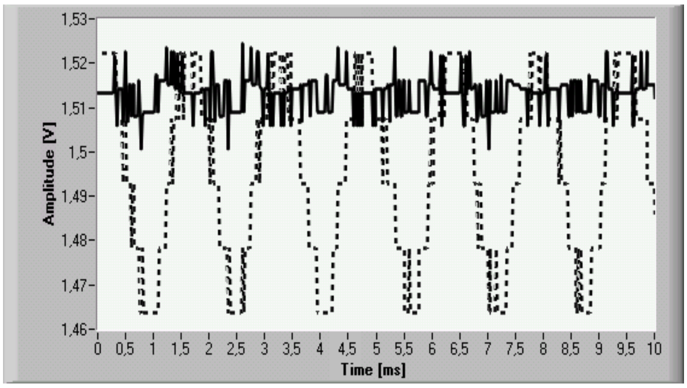

Fig. 3. Acquired data with and without compensation in presence of RF emission

In fig.3, the acquired data are plotted. The dotted line stands for the not-compensated signal acquired by the first channel and the continuous line stands for the compensated signal.

We performed the same measurement injecting into the EUT supply cable a 4 kV burst. Also in this case, the impact of the EM disturbance is quite heavy (fig. 4); in fact the standard deviation of the two signals is 0.20 V. However, on both channels, the EM disturbance effect is practically identical. Therefore, also in this case, a good compensation is obtained (fig.4), reducing the standard deviation at a 0.01 V value.

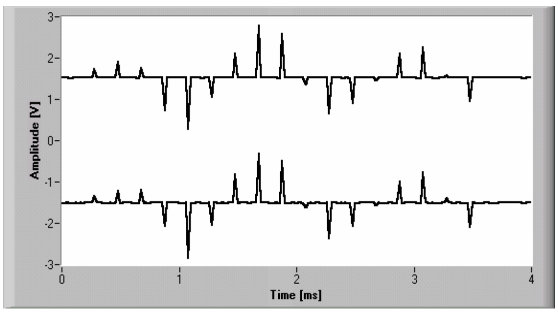

Fig. 4. Acquired data in presence of burst

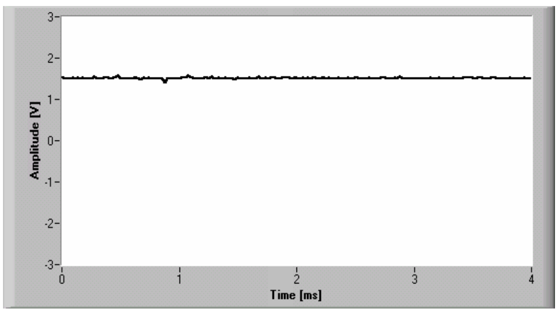

Fig. 5. Compensated signal

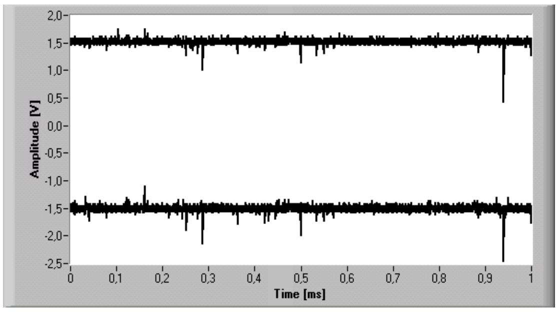

Fig. 6. Acquired data in the nearness of the welding machine

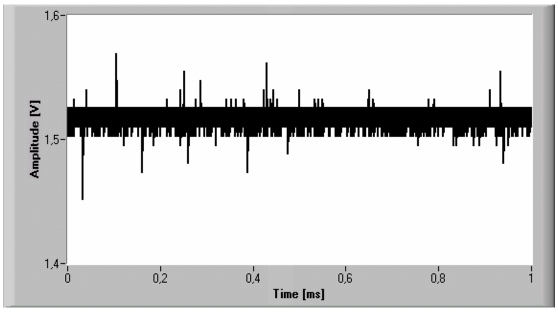

Fig. 7. Compensated signal

The same measurement has been repeated in the nearness of a 15 kVA welding machine. In this case, the EM interference produces on the two channels a variation range of 1.35 V (fig.6), which the proposed approach reduces at a 0.12 V level (fig.7)

The two channels compensation technique can not be applied to the DAQs with multiplexer and an unique analog-to-digital converter. In these cases, in fact, there is a delay between the two channels and, therefore, the compensation is incomplete for high frequency disturbances and null for the impulsive disturbances which interest only an acquired sample.

Obviously, this technique implies some drawbacks: it is necessary to use two channels to acquire only one signal, it is necessary to employ two anti-alias filters and, unavoidably, crosstalk errors are introduced.

V. Conclusions

Starting from the experimental results obtained subjecting various configurations of DAQ-based measurement instruments to the EM disturbances prescribed in the IEC-61236 Standard, in the paper we defined and proposed two approaches for the real-time compensation of the effects of unknown EM disturbances. The first approach, applicable in case of steady disturbances, is based on a simple and fast test which permits the localisation and the successive elimination, via software, of the effects of the EM disturbances. The other approach consists of a hardware compensation obtained by simultaneously acquiring the measurement signal by two channels, where the same disturbance is induced with opposite polarity.

Both methods lead to satisfactory results and allow a safe employment of the not-shielded configurations even in locations where heavy EM disturbances are present.

References

[1] V.Haaz, A.Pistnek: “Influence of a Disturbing EM Field on the Real Number of Effective Bits of PC Plug-in Boards” *in Proc. of XIV IMEKO World Congress*, Tampere, Finland, September 1997.

[2] M.Pokorny, J.Roztocil: “Influence of Magnetic Field on Measurement Using A/D Plug-in Boards” in *Proc. of IMTC 1997*, Ottawa, Canada, May 1997.

[3] G.Betta, D.Capriglione, C.De Capua, C.Landi: “EMC characterization of PC-based data acquisition systems” *in Proc. of ISIE*, L’Aquila, Italy, June 2002.

[4] 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.

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

[6] S. Nuccio, C. Spataro, G. Tinè: “Immunity of a Virtual Instrument to Radiated Electromagnetic Disturbances”, *Proc. of IMTC 2003, Vail, CO, USA, May 2003.*

[7] S. Nuccio, C. Spataro, G. Tinè: “Immunity of a Virtual Instrument to Conducted Electromagnetic Disturbances”, in P*roc. of IMTC 2004, Como, Italy, May 2004*.

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

[9] S. Nuccio, C. Spataro, G. Tinè: “Impact of Industrial Environments on the PC-Based Measurements”, *in Proc. of IMTC2007, Warsaw, Poland, May 1-3, 2007.*