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A COMPARATIVE ANALYSIS IN TERMS OF CONDUCTED SUSCEPTIBILITY OF PC-BASED DATA ACQUISITION SYSTEMS

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Abstract − In this paper, a performance comparison between PC-based data acquisition systems is carried out with reference to their immunity to electromagnetic conducted disturbances. The aim is to identify suitable measurement procedures at present not available both in the literature and in EMC standards. The data acquisition system (personal computer and data acquisition board) is approached as a whole system and subjected to the more relevant conducted interference considered by EN standards, electrical fast transient and noise by conducted radio frequency field. Experimental tests, carried out in a shielded environment, highlight the relevance of a specific EMI characterisation of this apparatus.

Keywords : EMC, DAQ boards, immunity tests.

1. INTRODUCTION

In all the applications involving digital signal processing, the utilisation of Data Acquisition Systems (DAS) is widespread. In particular, the most diffused configuration is based on a personal computer with an embedded Data Acquisition (DAQ) board. These solutions are characterised by high flexibility, easiness of use, good metrological performances, high reliability achievable with low-cost compared with other solutions. These requirements have to be assured also in presence of external disturbances, often present since DAS are almost always located in a hostile electromagnetic environment [1]. Both conducted (through both signal and power lines) and radiated interference (intentional and non-intentional radiators) can reach the DAS through several coupling paths. It is then significant to investigate DAQ board performance, taking also into account the influence of the set-up: internal (inside the PC) and external electromagnetic environments.

An analysis of the performance decrease due to the internal electromagnetic environment is carried out in [2]-[5]. This interesting approach proves that nominal quality indexes of DAQ board (*e.g.* signal-to-noise and distortion ratio, SINAD, spurious free dynamic range, SFDR, and effective number of bit, ENOB) depend on the PC internal electromagnetic environment and consequently, its EMC characterisation should be carried out in order to assure the EMC reliability of DAQ performance.

Moreover, the authors evidenced, by means of a frequency domain analysis, a qualitative performance decrease of a PC-based DAS when subjected to external disturbances [6].

Starting from this experience, in this paper the authors verify the obtained results on other DAQ boards with the aim of defining test procedures for the electromagnetic susceptibility characterisation of DAS. In particular an accurate analysis of the performance decreases is carried out finding out time and frequency domain parameters influenced by conducted external noise coupled on power lines.

2. MEASUREMENT PROCEDURES FOR EVALUATING CONDUCTED SUSCEPTIBILITY OF DAS

In this section, procedures to evaluate performance decreases of DAQ boards are proposed. Different approaches are followed depending on the external disturbance considered in the specific immunity test.

Basic EN 61000-4-1 publication (which lists the most common conducted and radiated immunity tests) has to be followed also taking into account both typical installation environment and noise susceptibility of PC-based DAS. Among all the possible conducted disturbances, only Electric Fast Transients (EFT) and Noise by Conducted Radio Frequency Field (CCW) are considered hereafter since they are the only that cause significant DAS performance decreases [6].

In particular, in order to evaluate the influence of the above-mentioned disturbances on the A/D performances, a procedure for the dynamic characterisation of the DAS is considered. An external to PC expansion board is used to cable a suitable sinusoidal test signal that is provided by a low-cost signal generator (Function Generator 33120A by Agilent Technologies).

Both the considered immunity tests are executed in agreement with EN 61000-4-4/6 specifications and namely with the test set-up shown in Fig. 1.

Suitable procedures will be set-up to highlight susceptibility of DAS to these types of disturbances. They have to be approached differently on the basis of their different characteristics and dynamics. In particular, the Electric Fast Transient noise is an intrinsically transitory phenomenon, whereas the Noise by Conducted Radio Frequency Field is a continuous phenomenon.

In the following, the proposed test procedures for the evaluation of DAS susceptibility will be described in detail.

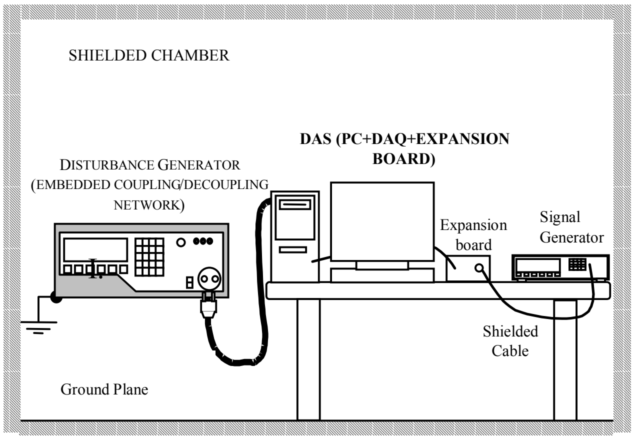

Fig. 1. The test set-up for Conducted Immunity Tests

2.1 Electrical Fast Transient test method

The Electrical Fast Transient (EFT) test is executed in order to investigate the immunity of a system when subjected to transient disturbances such as those originating from switching transients (interruption of inductive loads, relay contact bounce, and so on). The disturbance signal used in the test is a burst that consists of a fixed number (75) of fast transients (rise time of 5 ns) lasting 15 ms, coupled into the power supply of the equipment under test by means of a suitable coupling/decoupling network. The EFT burst generated and the test set-up are EN 61000-4-4 compliant. In particular, the repetition rate of the transients was chosen equal to 5 kHz, as suggested by the standard, whereas the burst period was fixed equal to 300 ms (see Fig. 2). The amplitude of the pulses depends on the specific test level; a + 500 V burst was considered in the following. The EFT noise signal was applied on a single conductor of the PC power supply.

Examples of Fig. 3 show sinusoidal signals sampled in presence of EFT noise, for two different frequencies of the input signal. It is possible to note that, as consequence of EFT, the acquired signals are distorted by spikes, with a consequent variation of the peak value of the sampled signal. Therefore, the peak value will be considered as the main parameter for characterising the EFT susceptibility in the time domain.

In order to determine the most suitable procedure to verify the DAS susceptibility, a large number of tests were carried out keeping constant the burst amplitude (+500V coupled on the power line) and varying amplitude and/or frequency of test signal, sampling frequency of the A/D. Peak values of sampled signals were recorded. At first, a test set was executed, obtained by varying amplitude and/or frequency of test signal and keeping constant the sampling

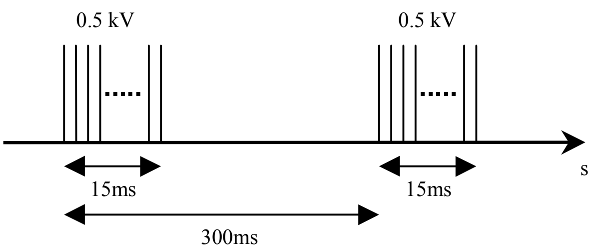

Fig. 2. Example of a EFT noise

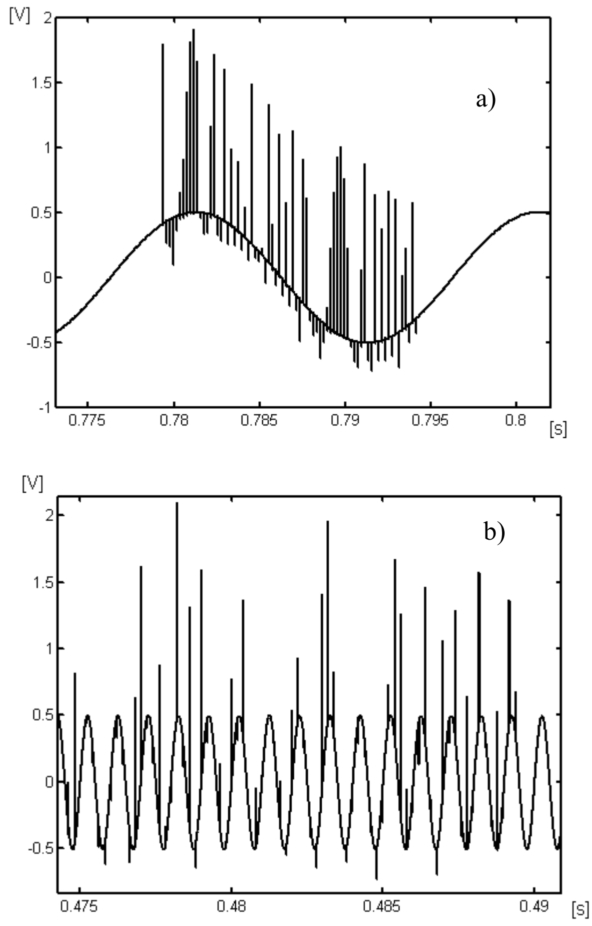

Fig. 3 – Effects of a 500V Burst on sinusoidal test signals
a) f = 50 Hz, b) f = 1 kHz

frequency (equal to 500 kS/s, maximum value allowed by the considered DAQ board). The evolution of the V_{pEFT}/V_{pn} ratio is reported in Fig. 4, being V_{pn} the nominal peak value of test signal and V_{pEFT} the peak value in presence of the EFT noise.

The obtained results prove the influence of EFT noise on the DAS performance and allow some consideration to be made:

(i) The lower the amplitude of the input signal, the higher the peak value of the corrupted signal and, consequently, the greater the V_{pEFT}/V_{pn} value. In

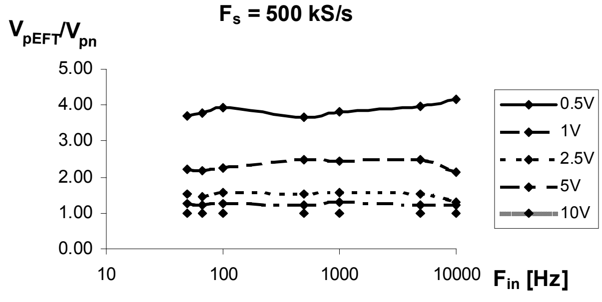

Fig. 4. Evolution of V_{pEFT}/V_{pn} as a function of the test signal frequency for different test signal amplitudes V_{pn}

particular, the most critical operating conditions were obtained with a test signal of 0.5 V amplitude. This value was then considered in the following tests with the aim of considering the operating condition with a higher sensitivity to the disturbance.

(ii) The V_{pEFT}/V_{pn} value weakly depends on the frequency of test signal, as evidenced by Fig. 4. Therefore, any input frequency could be used to test the DAS susceptibility. Nevertheless, since the burst duration fixed by EMC standard EN 61000-4-4 is equal to 15 ms, a more easily evaluation of the EFT influence can be achieved choosing the period of the input signal equal to the 15 ms (frequency equal to 66.66 Hz). In fact, in this case the effect of the burst is spanned on a single period of the input signal and therefore an easier and faster analysis is achievable.

(iii) Using a 10 V amplitude test signal, the V_{pEFT}/V_{pn} value is equal to one for each frequency for the saturation of A/D input channel. Consequently, it cannot be used to evaluate the susceptibility of the DAS in this test condition. However, the EFT noise affects the sampled signal as can be evidenced by a frequency domain analysis. In particular, the power spectrum of the corrupted sampled signal can be evaluated by an FFT algorithm operating on a single period (15 ms) of the input signal. Fig. 5 allows a comparison between the power spectrum in absence and presence of EFT noise to be carried out, highlighting a floor level increase of about 20dB in presence of the EFT noise. Consequently, for low-level test signals, a time domain analysis is satisfactory to evaluate the EFT DAS susceptibility, whereas at level test signals close to the full scale, a frequency domain analysis is more suitable.

Another test set was carried out with the aim of finding out the optimum sampling frequency to be used. In this case the amplitude and frequency of the input signal were fixed to 0.5 V and 66.66 Hz, respectively. A large number of experiments were executed by varying the sampling frequency from 10 kS/s up to 500 kS/s. The mean value of the V_{pEFT}/V_{pn} ratio together with its standard deviation are shown in Fig. 6. It highlights that the V_{pEFT}/V_{pn} values

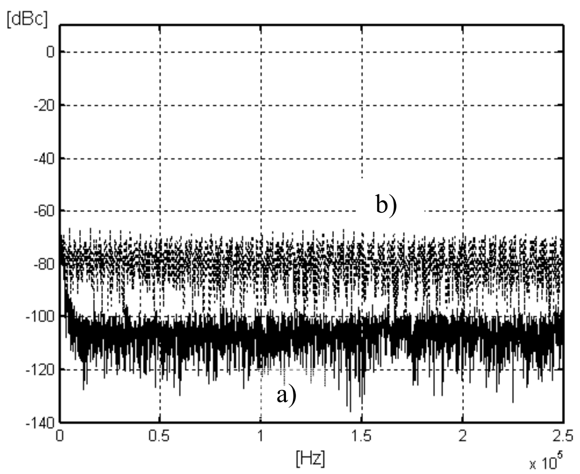

Fig. 5. Comparison between power spectra in absence (a) and presence (b) of EFT noise (input signal amplitude 10 V)

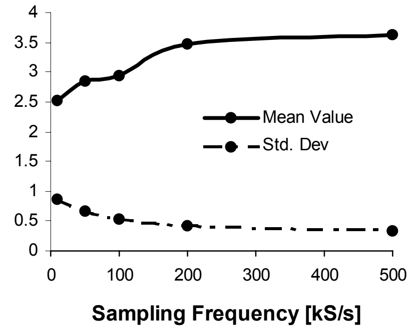

Fig. 6. V_{pEFT}/V_{pn} mean and standard deviation values versus sampling frequency

(continuous line) and its standard deviation (dotted line) depend on the sampling frequency. This is due to the high dynamic of any EFT spike with respect to the sampling frequency. Consequently, the maximum sampling frequency (500 kS/s for the considered DAQ board) assures more reliable results.

Concluding, the performed analysis gives some practical indications useful to configure the set-up in DAS EFT immunity tests aimed to assure the reliability of the results. In particular a suitable procedure could be suggested. Denoting the frequency of the test signal with F_i, the sampling frequency with F_s and the amplitude of test signal with V_{pn}, the following recommendations can be given:

(i) V_{pn} = small with respect to the A/D full scale for a time domain analysis, or close to A/D full scale for a frequency domain analysis;

(ii) F_i = 66.66 Hz;

(iii) F_S = maximum achievable by the board under test.

2.2 Noise by Conducted Radio Frequency Field Test Method

The conducted radio frequency field test, here in after CCW (Conducted Continuous Wave) is executed in order to investigate the immunity of the system when subjected to a source of disturbance including electric and magnetic fields, simulating those coming from intentional RF transmitters. The disturbance signal (AM modulated sinusoidal carrier) is coupled into the power supply of the equipment under test by means of a suitable coupling/decoupling network. The noise signal and the test set-up are EN 61000-4-6 compliant.

Generally, the disturbance signal is a continuous sinusoidal wave spacing in the range 150 kHz - 80 MHz whose amplitude depends on the specific test level. Taking into account the electromagnetic typical installation environment of DAS, the amplitude of disturbing signal was chosen equal to 3 V. The disturbing signal was applied simultaneously on both the power supply conductors of the PC and without AM modulation, in order to simplify the frequency domain analysis.

Fig. 7 shows a sinusoidal signal (a) and its spectrum (b) in presence of a CCW noise. It highlights that, generally, a time domain analysis does not allow the disturbance influence to be detected, whereas a frequency domain analysis clearly shows a spurious harmonic located at the injected noise frequency. As consequence, the dynamic performance of DAS worsens in terms of both SINAD and, above all, SFDR [6].

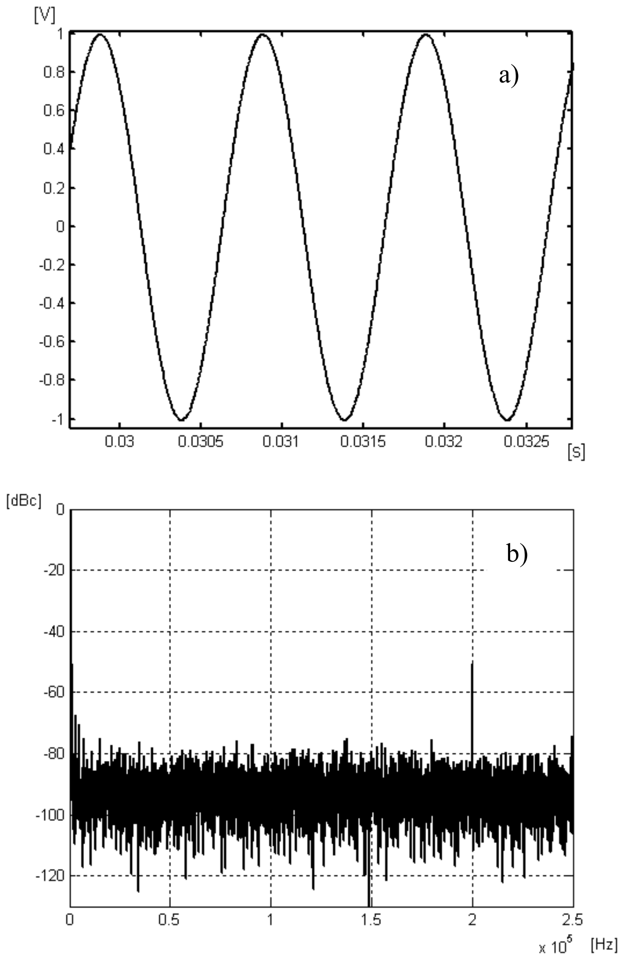

Fig. 7 A sinusoidal signal (a) and its spectrum (b) in presence of a CCW noise (1 kHz test signal frequency, 200 kHz disturbing signal frequency and 500 kS/s sampling frequency).

Therefore in the following, a frequency domain analysis will be considered to evaluate the influence of CCW noise on the DAS. Consequently, the DAS susceptibility procedure will be based on a suitable FFT test with aim of monitoring the SINAD and SFDR. Sampling and signal frequencies as well as the number of acquired points were carefully chosen in order to assure a coherent sampling according to IEEE Std 1241-2000 [7].

In this case also, in order to determine the more suitable procedure that allows the susceptibility of DAS to be highlighted, a large number of tests were carried out. In particular, the amplitude of the disturbance (3 V coupled on power line conductors) was kept constant and some parameters such as the disturbing signal frequency, test signal amplitude and frequency, A/D sampling frequency were varied.

At first, a test set was executed, obtained by varying amplitude and/or frequency of test signal and keeping constant both the sampling frequency (equal to 500 kS/s, maximum value allowed by the considered DAQ board) and the disturbing frequency (220 kHz).

In these test conditions, the most influenced parameter was the SFDR, whose evolution is reported in Fig. 8, being V_{pn} the nominal peak value and F_{in} the frequency of test signal respectively.

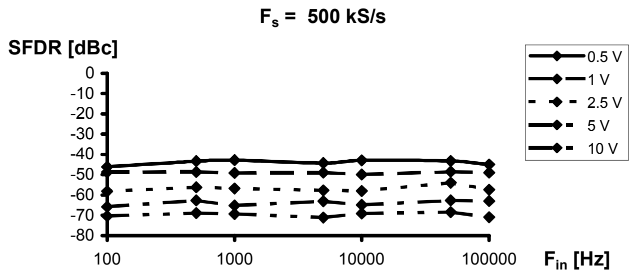

Fig. 8 SFDR versus the input signal frequency F_{in} for different values of the input signal amplitudes

The achieved results prove the influence of CCW noise on the DAS performance and allow some considerations to be made:

(i) The lower the amplitude of the input signal, the higher the SFDR value. In particular, the most critical operating conditions were obtained with a test signal of 0.5 V amplitude. This value was then considered in the following tests.

(ii) The SFDR value weakly depends on the frequency of test signal, as evidenced by Fig. 8. Therefore, any input frequency could be used to test the DAS susceptibility. A low frequency should be preferable since the non-ideality of the test generator could introduce spurious harmonics close to the disturbance one. A 100 Hz input test signal was then considered in the following tests.

Another test set was executed with the aim of evaluating the link between the DAS performance and the disturbing frequency, spanning in the EN 61000-4-6 range (150 kHz - 80 MHz).

These investigations proved that for disturbing frequency smaller than the Nyquist frequency (250 kHz) the spurious harmonics due to the injected noise are clearly visible because their amplitude are greater than the floor level [6]. For disturbance frequency (denoted with F_d) in the range 150 kHz - 250 kHz, the SFDR evaluation is easy and allows the CCW DAS susceptibility to be highlighted. The SFDR value weakly increases when the disturbing frequency increases, as shown in Fig. 9.

A CCW disturbing frequency close to the Nyquist frequency gives rise to the most critical operating conditions and consequently the worst performance of DAS.

Vice-versa, for disturbing frequency higher than Nyquist

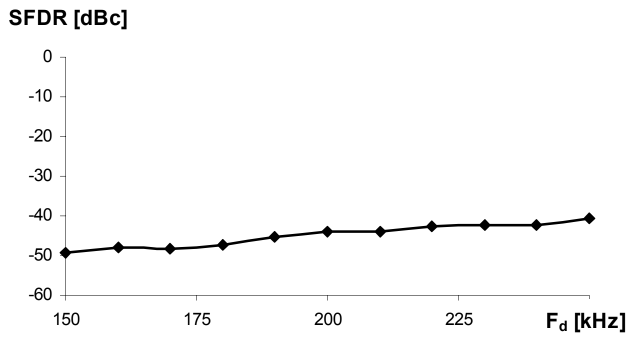

Fig. 9. SFDR versus disturbing frequency

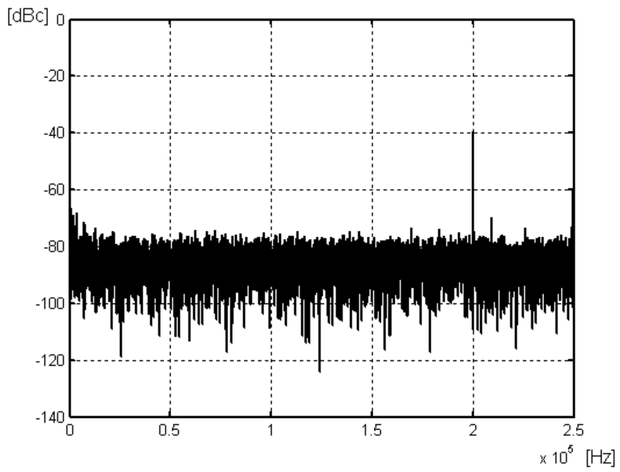

Fig. 10. Spectrum of a signal distorted by a 300 kHz CCW noise

frequency (F_d > 250 kHz), the DAS performance depends on the presence/absence of an anti-aliasing filter on the A/D input channel. In particular, a suitable low pass filter assures no performance decrease for frequencies greater than Nyquist frequency, whereas the disturbances are shifted within the Nyquist bandwidth when the anti-aliasing filter is absent. The shifted harmonics should introduce spurious harmonics that cause the increase of noise and consequently worse dynamic performance. In the specific case, DAQ boards without anti-aliasing filter was considered.

By means of the frequency domain analysis executed for disturbing frequency F_d greater than 250 kHz, two conditions were found:

(i) Disturbing frequency close to the Nyquist frequency: it is possible estimate the SFDR to evaluate the CCW DAS susceptibility since the shifted spurious harmonic is clearly visible (Fig. 10);

(ii) Disturbing frequency far from Nyquist frequency: in this case, it is difficult to locate the spurious harmonic due to the injected noise and consequently to estimate the SFDR decrease. Nevertheless, the sampled signal is influenced by high frequency CCW as showed in Fig. 11, the noise floor increases and, consequently, the SINAD decreases. This phenomenon is due to the sampling spectral replicas that are shifted (for aliasing effect) in the Nyquist bandwidth. These replicas are attenuated with respect to the first one and then, they weakly influence the normal operative working of the DAS, especially with the increase of the disturbing frequency.

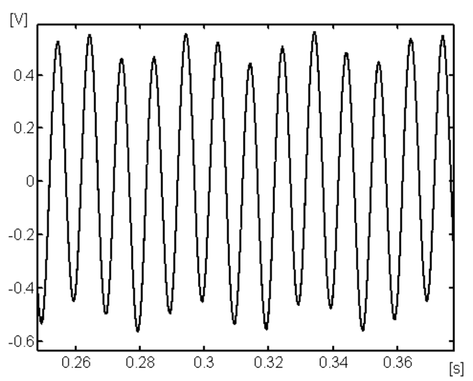

Fig. 11. Signal distorted by a 2 MHz CCW noise

On the whole, the executed tests bring to define some aspect to consider in the execution of CCW DAS immunity test:

(i) The CCW noise influences the operative working of DAS for each frequency in the range 150 kHz - 80 MHz. In particular, the CCW noise determines a sensible performance decrease if the disturbing frequency is close to the Nyquist frequency, whereas at higher frequencies the influence of CCW noise is less visible and it corresponds at an increase of noise floor. As consequence, the performance decreases can be estimated with two different frequency domain analysis: SFDR evaluation for disturbing frequency close to the Nyquist frequency and SINAD evaluation for disturbing frequency greater enough than the Nyquist frequency. The first approach is preferable for its greater simplicity, since the second one requires high spectral purity for the test generator.

(ii) Since the Nyquist frequency depends on the sampling frequency chosen, this last should be chosen equal to the maximum one allowed by the DAQ board. In fact, in this way the frequency range in which it is possible to make an SFDR analysis is the widest.

Concluding, the performed analysis give some practical indications useful to configure the set-up in DAS CCW immunity tests aimed to assure the reliability of the results. In particular a suitable procedure could be suggested. Denoting the frequency of the test signal with F_i, the sampling frequency with F_S and the amplitude of test signal with V_{pn}, the following recommendations can be given with the aim of obtaining the best sensitivity of DAS susceptibility analysis:

(i) V_{pn} = small with respect to the A/D full scale;

(ii) any F_i could be used even if low frequency values are preferred since they avoid problems connected to input signal generator non-idealities;

(iii) F_S = maximum achievable by the board under test;

(iv) SFDR or SINAD analyses can be used even if the former is easier to be applied.

3. PERFORMANCE COMPARISON BETWEEN DATA ACQUISITION BOARDS

In this section a comparison of susceptibility characteristics of DAQ boards placed in a standard Personal Computer, when interested by the previous described conducted noise, is reported.

The procedures proposed and detailed in the previous section are applied to evaluate the susceptibility of DAS under test. All the experiments were executed in the same configuration set-up, in terms of cable lengths and layout, PC, and location of the different DAQ boards inside the PC case, with aim of assuring reliability to the results.

The devices under test are two data acquisition boards of different manufacturers; one of this is featured by two possible connectors (passive and active) to cable the input signal. The main characteristics of the considered boards are summarised in Tab. I.

TABLE I – Main characteristics of the considered DAQ boards

	DAQ board A	DAQ board B
Number of Bits	12	12
Max Sampling Rate	500 kS/s	31.25 kS/s
Full Scale	± 10 V	± 10 V
Connector 1	Passive	Passive
Connector 2	Active	----------

3.1 EFT Susceptibility

The test parameters in terms of amplitude/frequency of test signal and sampling frequency were chosen in agreement with the procedure proposed in the previous section. In particular a 0.5 V amplitude, 66.66 Hz frequency test sinusoidal signal was considered. As far as the sampling frequency is concerned, two approaches were followed. In the first one, the maximum sampling frequency was fixed for both the DAQ boards (500 kS/s and 31.25 kS/s respectively), whereas in the second one the sampling frequency was fixed equal to 31.25 kS/s for both boards.

In Tab. II the corresponding results are reported. They highlight that DAQ board B shows saturation effects in presence of EFT noise, whereas an higher rejection is shown by board A, with similar behaviour for active and passive connectors, or even a better behaviour for the passive one.

In both the approaches, some aspects are evidenced:

(i) significant differences between the performance of DAQ A and DAQ B boards, since the EFT noise causes channel saturation of DAQ board B;

(ii) the electronic connector determines a more susceptible state with respect to a standard connector, for the higher sensitivity of electronic devices to EFT noise;

(iii) the higher the sampling frequency, the greater the V_{pEFT}/V_{pn} ratio, for the high dynamic of burst.

3.2 CCW Susceptibility

The test parameters in terms of amplitude/frequency of test signal and sampling frequency were chosen in agreement to the procedure proposed in the previous section.

In particular a 0.5 V amplitude, 100 Hz frequency test sinusoidal signal was considered. As for the sampling frequency, DAQ board B cannot be tested in a meaningful way by a SFDR analysis since its maximum sampling frequency is much lower than the minimum disturbing frequency suggested by the EN standard (150 kHz). The tests carried out on DAQ board A operating at its maximum sampling frequency (500 kS/s) and with a 200 kHz disturbing frequency highlights similar behaviour for active and passive connectors (SFDR equal to – 46 dB_c).

4. CONCLUSIONS

Typical conducted immunity tests (with reference to EN 61000-4-4 and EN 61000-4-6) were applied to a PC-based data acquisition system, in order to evaluate their influence on DAS performance approached as whole (PC and DAQ board).

Measurement procedures based on a time and frequency domain and aimed in highlighting the susceptibility of DAS without requiring a high-performance, high-cost signal generator were explored. Parameters influenced by the considered external noises were identified, and the most susceptible configuration set-up was identified (as recommended, by EN EMC immunity standards).

The proposed procedures were applied to DAQ boards of different manufacturers. The obtained results prove the suitability of these procedures in evidencing the DAS susceptibility to Electrical Fast Transient and Noise by Conducted Radio Frequency Field, highlighting the critical behavior that can affect DAQ boards when subjected to these disturbances.

TABLE II Comparison in the time domain between DAQ boards subjected to EFT noise

		DAQ A (connector 1)	DAQ A (connector 2)	DAQ B
Maximum frequency	V_{pEFT}/V_{pn}	3.62	3.85	20
Same frequency	V_{pEFT}/V_{pn}	2.80	3.01	20

REFERENCES

[1] W. Fireziyk, "Distrurbances of data acquisition systems caused by frequency converters", *in Proc. of IEEE Instrumentation and Measurement Technology Conference*, Venezia, pp. 999-1003, 1999.

[2] V. Haaz, A. Pistnek, "Influence of a Disturbing EM Field on the Real Number of Effective Bits of PC Plug-in Boards," *in Proceedings of XIV IMEKO World Congress-Int. Workshop on ADC Modelling*, Tampere, pp.183-186, 1997.

[3] M. Pokorny, J. Roztocil, "Influence of Magnetic Field on Measurements Using A/D Plug-in Boards", *in Proc. of IEEE Instrumentation and Measurement Technology Conference*, Ottawa, pp. 302-306, 1997.

[4] V.Haasz, J. Roztocil, "Testing of Dynamic Quality of AD Modules with Standard Interfaces and Problems Connected with it," in Proceedings of ICECS, Lisboa, vol. III, pp.461-464, 1998.

[5] V. Haasz, F. Pistinek, M. Purkert, "Disturbance Immunity of PC Plug-in Boards," *in Proceeding of 4th Workshop on ADC Modelling and Testing*, Bordeaux, pp. 166-169, 1999.

[6] G. Betta, D. Capriglione, C. De Capua, C. Landi, "EMC Characterization of PC-based Data Acquisition System", in *Proceeding of IEEE International Symposium on Industrial Electronics*, L'Aquila, vol. 2, pp. 548-553, 2002.

[7] IEEE Std 1241-2000 – *IEEE Standard for terminology and test methods for analog to digital converters*.

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