Electromagnetic Compatibility Tests for CMS Experiment.

F.Arteche*, C.Rivetta**, F. Szoncso *

*CERN,1211 Geneve 23 Switzerland; **FERMILAB, P.O Box 500 MS222, Batavia Il 60510 USA
(Principal contact: rivetta@fnal.gov, fernando.arteche@cern.ch)

Abstract

Electromagnetic compatibility (EMC) is concerned with the generation, transmission and reception of electromagnetic energy. These three aspects form the basic framework of any EMC design.

CMS experiment is a very complex system. Millions of low-cost acquisition channels using very low-level signals have to work inside magnets and under radiation. This front-end electronics constitutes the sensitive receptor in the EMC model [1]. Noise can be coupled to the sensitive electronics through conductive or radiation paths, being the former the most important coupling mechanism.

Some EMC tests are necessary to qualify the immunity of the different parts of the front-end electronics. Among them, measurement of the common mode (CM) noise and differential mode (DM) noise sensitivities of the front-end electronics and the immunity to transient perturbations are the most important. This paper presents a description of basic tests to be performed on FEE prototypes and power supplies before they are committed for final production.

I. INTRODUCTION

Electromagnetic compatibility (EMC) among different electronic sub-systems of the CMS detector is an important goal for the integration of the detector. It involves the study of sensitivity and immunity of FEE circuits and the emission level of power supplies, cables and FEE. It is important to describe the EM environment of CMS to determinate in advance and solve problems related with electromagnetic interference (EMI). Part of this study is based on EMC tests on final electronics prototypes to define the emission and immunity of the different parts to be integrated into the detector.

Due to the level of signals involved and the acquisition clock frequency of 40Mhz, signals that will interfere with the front-end electronics have a frequency spectrum lower than 40Mhz. This makes both the conductive and near EM field coupling mechanisms the fundamental one to generate interference among the different electronics systems. To address the conductive noise coupling, common mode (CM) and differential mode (DM) tests are going to be performed on the front-end electronics and power supplies, while the near EM fields are going to be characterised by transient tests.

The aim of the CM and DM noise injection tests is to get threshold levels in the front-end electronics for all the frequency range. In this test, DM and CM noise signals at different frequencies are coupled through the power supply cables and signal cables and the output noise is measured using the acquisition system. It is important to perform the tests based on a reduced system with a configuration as close as possible to the final one. A complementary test is the measurement of CM and DM conductive noise of power supplies that feed the front-end electronics. To make compatible both tests, especial care will be taken on the common impedance connecting both parts: the front-end electronics and the power supply. In general, this common impedance is estimated or measured and included in the circuit under test using a line impedance network stabilisation (LINS) especially designed based on the above information. All these tests constitute the basis to characterise the compatibility of the system operating in steady state, without considering dynamic load variations or transients.

To qualify the compatibility of the system under dynamic or transient conditions other set of tests are necessary. Transient emission can induce in the FEE not only signal degradation or lost of data but also catastrophic failures. To characterise the immunity of the electronic system to transients, electrical fast transient and voltage drop tests are performed on the power supply cables of the FEE. The procedure to be followed during these tests is close to the one recommended by the IEC 1000-4 standard and the signal level to be applied will depend on the environment conditions surrounding the electronic sub-system.

The proposed methodology constitutes only a part of the EMC analysis to be performed before the detector integration. Additional studies about grounding and shielding, cabling grouping and layout are necessary to address the vast number of compatibility issues. The number of EMC problems involved in the integration of CMS presents a challenge in the characterisation of each electronic subsystem and, at the present, surpasses the possibility of conclusive studies for the entire detector.

II. COMMON IMPEDANCE – LISN-CDN

The general layout for the EMC test has to be as close as possible to the final one. The common impedance between the power supply units and the FEE plays an import role in these tests. There are two different kinds of common impedance, Line Impedance Stabilisation Network (LISN) and Coupling De-coupling Network (CDN).

The goal of using LISNs is to standardise the measurement of all tests. The values of the LINS components are estimated from measurements of the power cables parameters, as it is the common impedance between the power supply units and the FEE. The LISN presents stable and well-defined impedance (CM and DM impedance) for all the desired frequency range. At high frequency the common mode and differential mode impedance of the LINS approaches to the CM and DM characteristic impedance of the lines. As an example, the layout of the LISN for HCAL sub-system is depicted in figure 1.

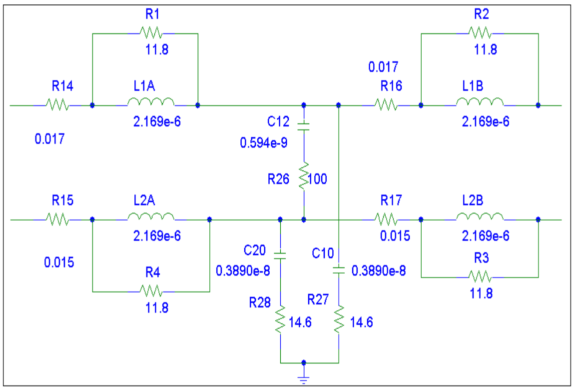

Figure1: Layout of HCAL LISN

The CDN is an electrical circuit, interconnected between the equipment under test (EUT) and the auxiliary equipment (AE), to force the injected signal to flow through the EUT preventing the damage or malfunction of the AE. The component values of this impedance are specified by the standards [2] [3]. The layout of the CDNs, which is used for surge immunity tests, is depicted in figure 2

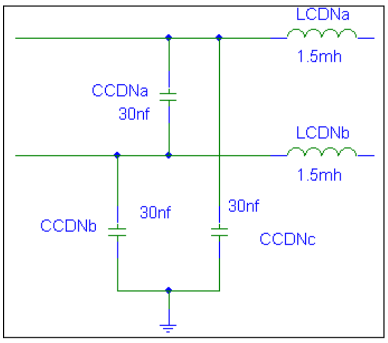

Figure 2: CDNs for surge immunity test.

III. EMC TESTS

Six different tests are proposed for the EMC plan. Two of them are focused on studies of the conducted emission and four tests on studies of conducted susceptibility.

A. *Emission Test*

1) *Harmonics.*

All loads connected to the 400Hz-distribution system are non-linear. They generate harmonic currents that interact with the distribution system impedance and produce distortion in the sine wave voltage. Harmonics are prejudicial because they over heat equipment, radiate noise, induce malfunction in sensitive equipment, etc. Operating at 400Hz, harmonics can extend up to 25 kHz. Harmonic standards for 400Hz systems are more strict that standards limiting harmonics in 50/60Hz systems.

The goal of this test is to measure the harmonics generated by the AC-DC converters and the transformers. All equipment to be installed has to comply with the limits imposed by CMS.

2) *Conducted emission test*

The goal of this test is to measure the conducted emission level of power supplies and FEE. There are two different kinds of conducted emission, common mode and differential mode. The former is generated between a group of conductors and ground or other conductors. The differential mode takes place between conductor pairs that form a conventional return circuit. It is the direct result of the fundamental operation of the power supply or FEE [5].

To perform this test, the system topology has to be as close as possible to final one. A LISN is used as common impedance between FEE and power supplies [7]. Conducted emission measurements are performed at both the input and the output cables of power supplies. Figure 3 depicts the basic set-up for this test. It is carried on using a wide-band current probe and a spectrum analyser as it is suggested by the military standard MIL-STD-461 [6] and IEEE 1515 [10].

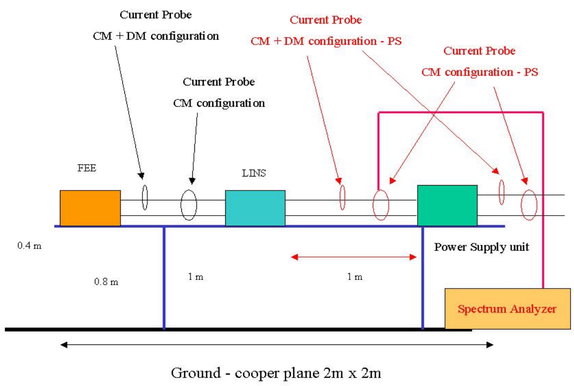

Figure 3: Layout of emission test

The common mode current and both individual currents are measured at the input cord of the power supply. Measurements are performed in the frequency range between 9KHz and 50 MHz. As an example, the measurement of the positive input current of a DC-DC converter for HCAL sub-system is depicted in figure 4. The current measured is converted to volts using a normalised 50 ohms resistor to compare the result with the standard EN-55022. In this case, an input EMI filter has been used to attenuate both differential and common mode noises to fulfil the standard.

Other than the MIL-STD-461 (Class C3 UM-5) [5], there is no specific standard to define the conducted noise level emitted by the output cables of power supplies. In our case, we are defining those limits based on immunity levels obtained from measurements performed on the specific FEE system. Similarly, to the input cables, output current measurements are performed between 9KHz and 50MHz.

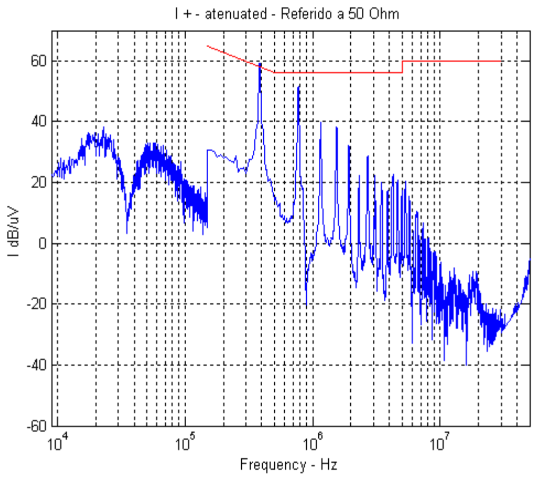

Figure 4: Input current spectrum of DC-DC converter

B. *Immunity test*

The electromagnetic immunity is the ability of a device, equipment or system to perform without degradation in presence of electromagnetic disturbances. The goal of these tests is to fix the immunity level of FEE and power supplies to conducted disturbances. The results from these tests are classified in terms of loss of function or performance degradation of the equipment. These tests are; Immunity to RF disturbances, burst immunity test, surge immunity test and voltage dips.

1) *Immunity to conducted radio frequency disturbances*

These tests are complementary of the one described in A.2 The goal of these tests is to measure the immunity level of the FEE to radio frequency interferences. The basic idea is to inject a perturbing signal to the FEE and measure the output noise of the FEE to analyse its effect and evaluate the performance of the FEE operating under such a perturbation. These tests follow the directives given by the norm EN-61000-4-6 / IEC-1000-4-6 [4]. The level of the injected signal levels varies according to the sensitivity of the FEE under test. The immunity level of the FEE to common mode currents at low and high frequency, as well as to differential mode current is determined by these tests.

Current probes and insulation transformers are used to inject noise to the system [8], while a current transformer, a differential voltage probe and a spectrum analyzer are used to monitor the current injected and the bus voltage. The output noise of the FEE is measured by its own adquisition system. The common impedance between the FEE and power supply is extremely important. LISN is used in these tests to maintain a similar configuration to the final one. These tests are important to qualify the robustness of the FEE to conducted emission, to define threshold levels where the performance of the FEE is deteriorated and also to define the conducted emission levels for the power supply outputs.

As a summary of the tests described in A.2 and B.1, figure 5 depicts measurements of conducted noise at the output cables of a switching power supply feeding a FEE system. The set-up used is similar to the one shown in figure 3. In this case, figure 5a shows the current spectrum at low frequency, while figure 5b shows the spectrum of the common mode current at high frequency. This spectrum is coincident with the spectrum of the output current of the positive terminal. This power supply presents an extremely low noise at high frequency with levels that comply with military standards.

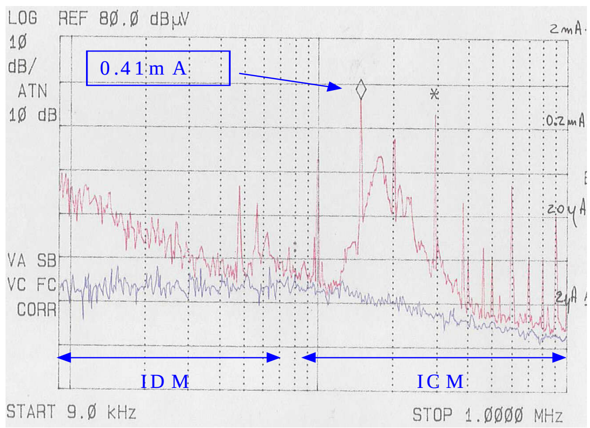

Figure 5a: Spectrum of the output current of HCAL PS unit. (Positive terminal, Ref: 80dBμV=2mA)

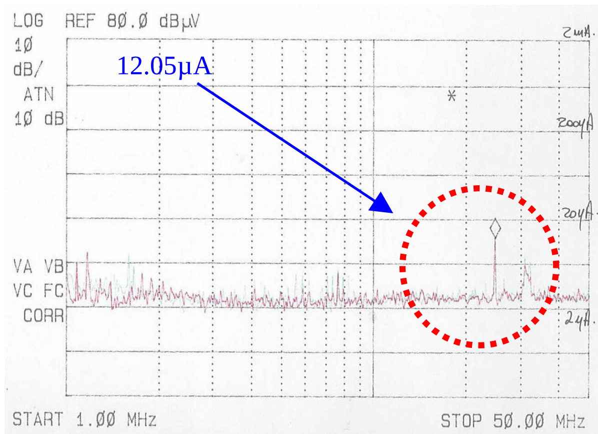

Figure 5b: Spectrum of the output current of HCAL PS unit (Common mode noise, Ref: 80dBμV=2mA))

Figure 5a depicts the spectrum of the output current of the positive terminal of the power supply. The spectrum between 9KHz and 60KHz corresponds to the noise current induced by the front-end electronics (differential mode, IDM), while the spectrum above 60KHz corresponds to common mode currents (ICM) due to the switching power supply. In these conditions, the FEE output noise was almost similar that the result obtained when the same FEE was powered-up by a linear power supply.

Testing other switching converters with the same FEE did not give the same output noise performance. The noise increased by 30%-50%. The difference among current spectrums was due mainly to an increment in magnitude of the common mode components in the frequency range between 3MHz and 20MHz. The FEE is very sensitive to common mode components at high frequencies

2) Surge inmmunity test

The goal of this test is to determinate the susceptibility of the equipment to damage by over-voltage. Over-voltages can be generated by short circuits, load changes (power consumption of the FEE), faults to earth in power distribution cables, surge voltage transient, etc.

In general the test follows the standard EN-61000-4-5 / EIC-1000-4-5 [3]. The system under test is in a configuration as similar as possible to the final one. A LISN and CDN is used as a common impedance. The last impedance insulates auxiliary equipements from the injected pulse. In figure 6 is shown the set-up used in this test.

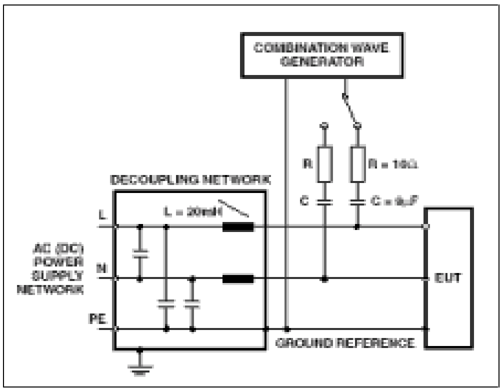

Figure 6: Set-up for surge immunity test

Figure 7 shows the standard waveform for the surge test, which is a single unidirectional impulse specified by two waveforms at the same time. A 1.2/50 µs voltage impulse in open-circuit and a 8/20 µs current impulse into a short circuit, leading to its common name: *"the combination wave"*. When testing main inputs (at input of the power supplies), the surges are applied at all zero-crossings and the peaks in cycle of mains waveform. The time between pulses is 1 minute. The internal impedance of the pulse generator is 2 Ohms.

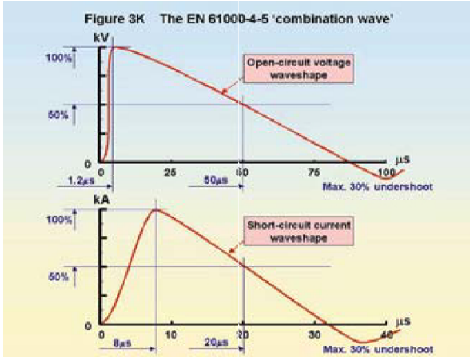

Figure 7: Waveform for the surge immunity test.

A coupling network is used to transfer the energy from one circuit to another. This network is specified by the standard. The components of this network are a capacitor of 18 µf (line-line test) or a resistance of 10 ohms and a capacitor of 9 µf (line-ground test).

The magnitude of the impulse to be used during this CMS test is still under discussion. According to [3], all the power cables reaching to the detector can be classify as either class 3 or 4. In this case, positive and negative pulses of amplitude equal to 2 kV (Line - Line) and 4 kV (Line - Ground) will be applied. However, it is not very clear what class is the CMS system between the power supplies and the FEE. The selection of this class will have a big influence in the selection of protections, perfomance, reliability and cost.

Some simulations of the surge immunity test conducted on the HCAL sub-system shows the problematic of this kind of phenomenon. Figure 8 depicts the surge inmmunity test for HCAL sub-sytem using different test levels.

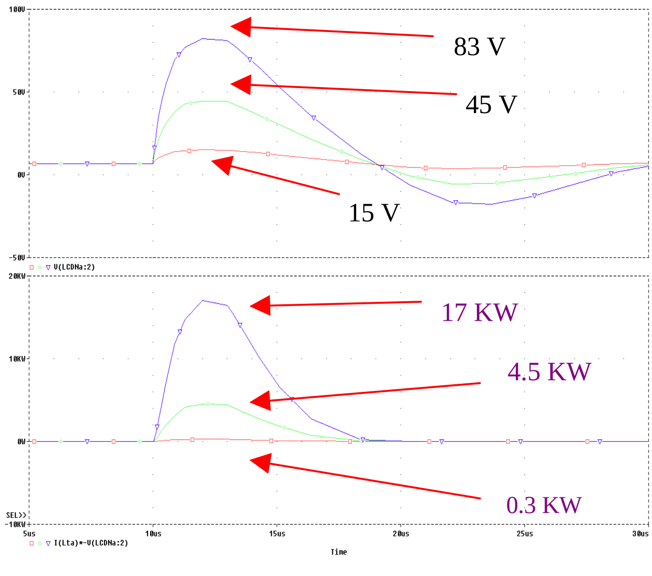

Figure 8: Overvoltage and power dissipated by the protection device for the surge immunity test of HCAL subsystem. Input levels: 1KV, 0.5KV and 0.1KV.

A protection device has been placed on FEE at the power supply input to protect the equipment. The input level was set to 1KV, 500V and 100 V. The power dissipated by the trans-absorber in some cases was around several kW. The over-voltage at the distribution bus of the FEE reached a peak voltage of 83 V for 1KV input impulse. This over-voltage magnitude is not acceptable. It is very difficult to find in the market a device that could deal with this amount of power and the same time clamp the voltage within the maximum limit of the FEE. The selection of a lower class increases the risk of failure due to transients. However, the election of a higher level could increase the cost of the equipment. The final selection of test levels has to be based on these preliminary studies and simulations and the impact on reliability and cost of the detector electronics.

3) Electrical fast transient or burst immunity test

The goal of this test is to define the susceptibility of the equipement to damage by over-voltage originated by swiching transients. These over-voltage are generated by interruptions of inductive loads and contact relays. The test follows the standard EN-61000-4-4 / EIC-1000-4-4 [2].

Figure 9 shows the standard waveform for the burst test. It consists of a single unidirectional impulse (double exponential pulse-5ns / 50ns) repeated at 5 kHz rate in burst lasting 15 msec each, with three burst per second. The internal impedance of the pulse generator is 50 Ohms.

The fast transient burst is a wideband phenomenon with spectral components up to hundreds of MHz, and therefore as others RF test , layout is very important for repeatibility. The coupling of the burst is strongly dependent on the FEE stray capacitance to its sorroundings. So especial attention should be paid with the test layout.

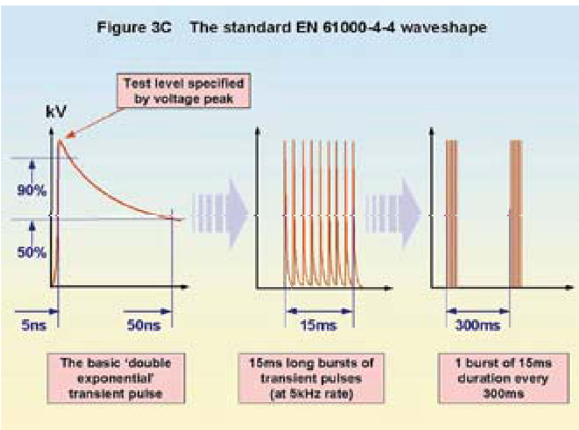

Figure 9: Waveform for the surge immunity test.

LISN and CDN are used as a common impedance to protect the auxiliary equipment from this transient. A capacitor of 33 nf is used to transfer the energy from pulse generator to the circuit under test. The test set-up is shown in figure 10.

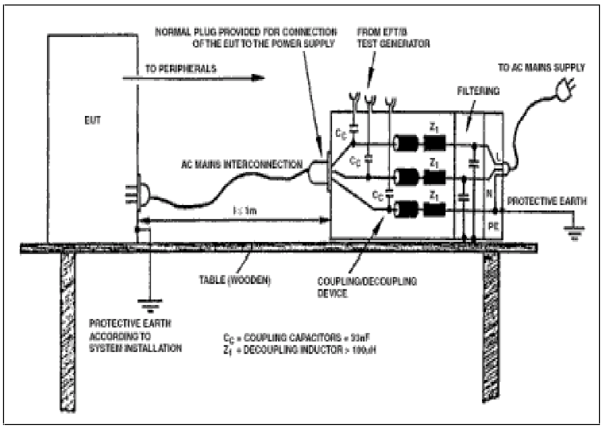

Figure 10: Set-up for burst immunity test

The voltages for the HCAL FEE during a burst test for several values of RF-capacitor (5nf, 500nf and 5000nf) on board are shown in figure 11.

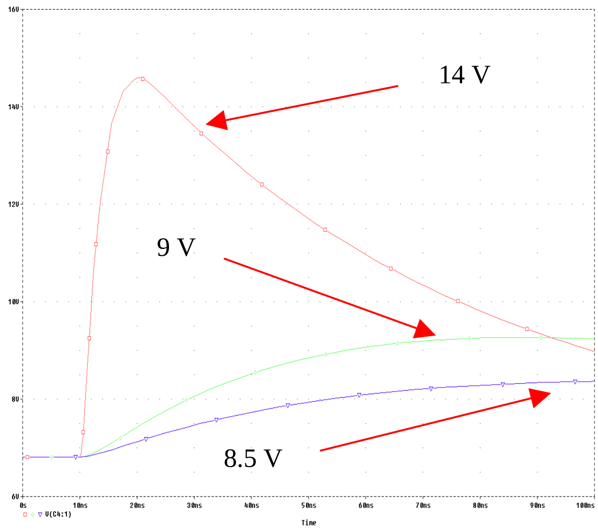

Figure 11. Overvoltage at FEE in the fast transinet inmunity test

4) Voltage dips and short voltage interruptions test.

Electrical and electronic equipment may be affected by voltage dips, short interruptions or voltage variations of power supply.

Voltage dips and short interruptions are caused by faults in the network, in installations or by a sudden large change of load. These phenomena are random in nature and can be characterised in terms of both the deviation from the rated voltage and the duration. Voltage dips and short interruptions are not always abrupt, because the reaction time of rotating machines (400Hz system) and protection elements connected to the power supply network.

The goal of this test is to determinate the susceptibily of the equipement to short voltage interruptions and voltage variations of the primary power supply. Short interruptions and voltage variatios are applied to the FEE and power supplies and the degradation of the FEE performance and lost of adquired data is evaluated. Voltage dips test will be only applied to the power supplies. The test follows the standard EN-61000-4-11/ EIC-1000-4-11 [9]. The waveforms for these tests are shown in figure 12.

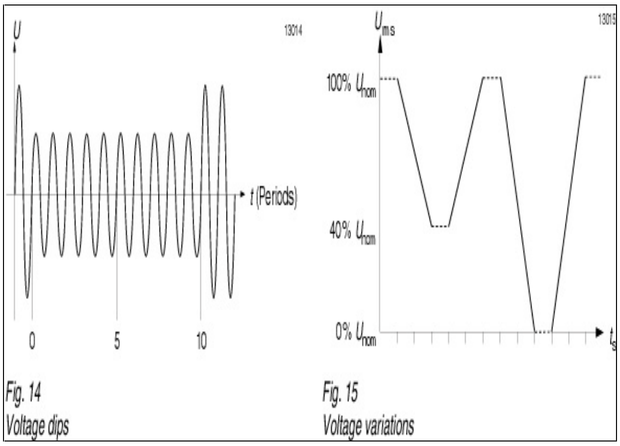

Figure 12. Voltage dips and short interruptions

IV. CONCLUSIONS

The new generation of calorimeters for high-energy physics experiments demand, for successful integration, to conduct EMC tests to the electronic systems before installing them. This paper presented an EMC test based on international standards and rules applied successfully by aerospace agencies. We have adapted existing EMC standards to the HEP electronics systems by defining new limits for emission and susceptibility tests. The final selection of those limits could be based on these preliminary studies, simulations, reability and cost of the detector electronics.

V. ACKNOWLEDGEMENTS

The authors would like to thank to Antonio Ciccollela and Philippe Laget from EMC & Antenna Measurement Section of European Space Agency for the help during the development of these studies. Also, one of the authors (C.R.) wants to thank to Fermilab PPD-EED for the support to complete this work. This work was performed under contract # DEACO2-76CH03000 with the Department of Energy – USA.

VI. REFERENCES

[1]- F.Szoncso " EMC in High Energy Physics" in *Proc Fifth Workshop on Electronics for LHC Experiments*, 20-24 Sept 1999 (http://s.home.cern.ch/s/szoncso/www/EMC/)

[2]- International Standard - IEC - 61000-4-4 "*Electromagnetic compatibility (EMC) - Testing and measurement techniques – Electrical fast transient/burst immunity test*" Basic EMC publication (Ed. 1995)

[3]- International Standard - IEC - 61000-4-5 "*Electromagnetic compatibility (EMC) - Testing and measurement techniques - surge immunity test* " Basic EMC publication (Ed. 2001)

[4]- International Standard - IEC - 61000-4-6 " *Electromagnetic compatibility (EMC) - Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*" Basic EMC publication (Ed. 2000).-

[5]- C.R. Paul, *Introduction to Electromagnetic Compatibility* NY:Wiley-Interscience,1992, ISBN-0-471-54927-4

[6]- T. Williams *EMC for Product Designers*, 1997, ISBN-0-7506-2466-3

[7]- A. Ciccolella, T, Blancquaert, J. Verniolle "Power interface characterisation between the Russian module and the ESA automated transfer vehicle" *(Pre-print, Private communication).*

[8]- Goedbloed, Jasper J. *Electromagnetic Compatibility*, 1990, ISBN-0-13-249293-8

[9]- International Standard - IEC - 61000-4-11 "*Electromagnetic compatibility (EMC) - Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity test*" Basic EMC publication (Ed. 1995).

[10]- IEEE-Std 1515-2000. *"IEEE Recommended Practice for Electronics Power Distribution Subsystems: Parameter Definitions, Test Conditions and Test Methods".*