

Noise Susceptibility Measurements of Front-End Electronics Systems

B. Allongue^a, F. Anghinolfi^a, G. Blanchot^a, F. Faccio^a, C. Fuentes^{a,b},
S. Michelis^{a,c,†}, S. Orlandi^a, A. Toro^b

^aCERN, 1211 Geneva 23, Switzerland

^bUTFSM, Valparaiso, Chile

^cEPFL, Lausanne, Switzerland

georges.blanchot@cern.ch

Abstract

The conducted and radiated noise that is emitted by a power supply constrains the noise performance of the front-end electronics system that it powers. The characterization of the noise susceptibility of the front-end electronics allows setting proper requirements for the back-end power supply in order to achieve the expected system performance. A method to measure the common mode current susceptibility using current probes is presented. The compatibility between power supplies and various front-end systems is explored.

I. INTRODUCTION

The developments of new particle detectors for the LHC and the sLHC experiments are setting increasingly demanding requirements to the front end electronics that reads out and processes the physics data that they produce, with the aim to achieve high levels of performance in terms of resolution and accuracy. This performance is limited by the system intrinsic noise, but also by external sources of disturbances. The use of modern microelectronic technologies with lower operating voltage, with higher clock speeds and more dense input-output connectivity make the front-end electronics systems more sensitive to these disturbances. A more comprehensive and systematic approach of the electromagnetic compatibility issues that affect the front end systems becomes necessary so that the expected detector performance is achieved [1][2].

The power supplies have been identified, at many occasions during the commissioning phases of the LHC experiments, as a dominant source of disturbances that affect the resolution of the front-end systems [3]. However, the compatibility between a power supply system and a front-end system is better addressed at the design stage, with the characterization of the susceptibility of the front end system to external noise [4], as part of a coherent development strategy [1]. Knowing beforehand the noise susceptibility of a system allows implementing optimal corrective actions while the establishing the EMC requirements for a compatible power supply system.

The characterization of the conducted noise susceptibility of a system is achieved using well documented measurement techniques [5][6]. However, this measurement requires the use of particular instruments to allow the coupling of reference disturbances into the system. Also, physical

constraints of the tested system often make the coupling difficult. Front-end power converters emit also near field radiated noise; a simplified method to explore the front-end susceptibility to radiated noise is proposed. The methods are applied to the front-end electronics of the absolute luminosity monitor for ATLAS (ALFA) and on the TOTEM detector front-end. Susceptibility curves are obtained and the dependencies between the noise and the system are interpreted. On the basis of the susceptibility figures, the noise properties of the power supplies can be set for each system.

II. NOISE COUPLING INTO FRONT-END SYSTEMS

The front-end systems are exposed to electrical disturbances of different kind, i.e. electrostatic discharges, overvoltage or undervoltage fast transients on all the input and output ports, conducted noise carried by all the cables, and radiated noise incident to the system (Figure 1). To achieve a robust and reliable system, its design has to take into account these disturbances, within a well defined electromagnetic compatibility plan that sets the limits that the system must be able to tolerate [1][2].

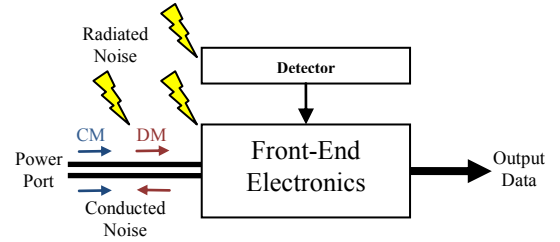


Figure 1: Noise coupling paths.

III. TESTING FOR CONDUCTED SUSCEPTIBILITY

A. Bulk Injection Method.

The front-end systems are exposed to common and differential mode noise voltages and currents on all their interconnection ports. They transfer each of these noise contributions into system noise through susceptibility transfer functions (in the frequency domain) associated to each disturbance for each port (Eq. 1).

$$n(f) = I_{CM}(f) \cdot H_{CM}(f) \quad [\text{Eq. 1}]$$

The common mode currents have been identified at many occasions as being a dominant source of noise that degrades the performance of a front-end system [2][3]. These common mode currents often find their way into the system through the power ports.

[†]S. Michelis has been supported by a Marie Curie Early Stage Research Training of the European Community's Sixth Framework Programme under contract number MEST-CT-2005-020216 – Elacco.

They propagate deep inside the front-end circuitry, where they can become a significant source of disturbance when switched mode power supplies are used.

The measurement of the front-end susceptibility to conducted noise is carried out with the injection of known common mode or differential mode currents in the tested ports over a given frequency range using bulk injection probes and appropriate arrangement of the cables [2][6]. The disturbance is coupled inductively (Figure 2), and the magnitude of the injected current is a function of the circuit impedance. At low frequencies, the inductive coupling is weak, while at large frequencies the circuit inductance limits the injected current. Because of this, large voltages are often needed to drive the bulk injection probe in order to get the desired current, sometimes using specialized radiofrequency power amplifiers. Using a high purity RF generator and a suitable bulk probe, non distorted disturbances can be applied over a broad frequency range at constant amplitude. The injected current has to be monitored, typically with a second calibrated current probe.

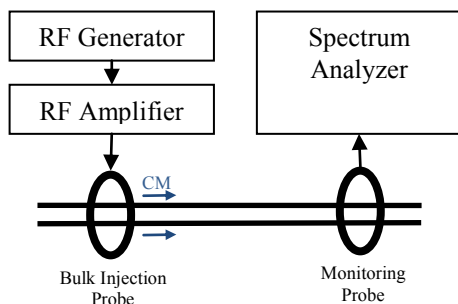


Figure 2: Injection of conducted noise.

The ratio between the output system noise and the injected current sets the system susceptibility at the tested frequency. The full susceptibility figure is obtained in the frequency domain sweeping the test frequency from 100 kHz to 100 MHz at constant current.

B. Susceptibility of the ALFA Prototype.

The described measurement method was exercised to determine the common mode susceptibility of a front-end prototype of the absolute luminosity monitor for ATLAS (ALFA) [7]. This system is composed of a matrix of 5x5 front-end photomultiplier modules (PMF). The PMF incorporates a front-end ASIC (MAROC2) [8] that perform the pulse shaping, amplification and discrimination of 64 pixels according to configurable gain and threshold settings (Figure 3). The dynamic range of each MAROC preamplifier is set to 5 pC (30 p.e.) with a declared noise of 5 fC (ENC), that allows for single photoelectron resolution using a fast unipolar transimpedance shaper with a peaking time of 20 ns. The signals are acquired and transmitted to the motherboard by an FPGA embedded in the PMF. The motherboard packs and transmits the data through a GOL link (Figure 4).

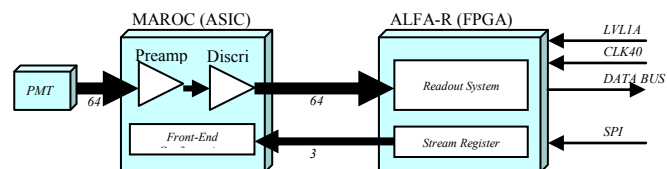


Figure 3: ALFA front-end diagram.

Three electrical ports are found on the ALFA motherboard (Figure 4):

- 12VDC input power, feeding the motherboard auxiliary circuitry.
- 5VDC input power, feeding the FPGAs and the front-end ASIC in the PMF through linear regulators.
- CANbus interface for the ELMB, isolated with optocouplers.

The two power ports are fitted with common mode and differential mode filters with an insertion loss optimized between 10 MHz and 100 MHz.

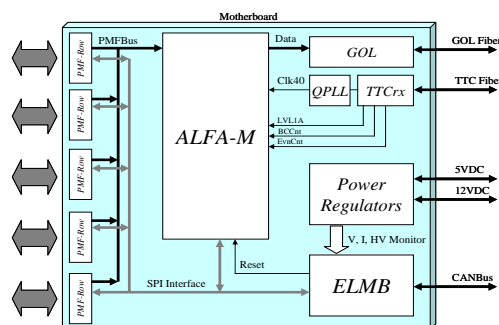


Figure 4: ALFA motherboard diagram.

The sensitivity of the PMF against noise is first determined by means of a threshold scan that delivers an S-curve of the front end ASIC (Figure 5). The sixty-four front-end pixels cross the noise threshold for a DAC setting comprised between 89 and 94. The susceptibility curves must be obtained for that range in order to observe the threshold effect on the susceptibility characteristic.

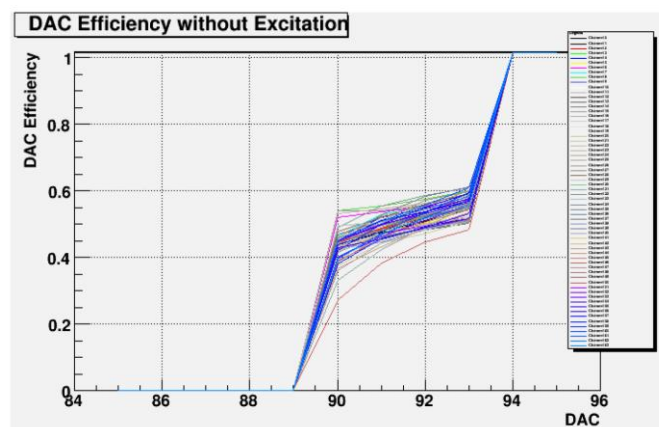


Figure 5: ALFA front-end intrinsic noise versus threshold.

A threshold is then set and common mode currents are injected (Figure 2) using an ETS-Lindgren-91256 probe, with amplitudes up to 10 mA and frequencies comprised between 150 kHz and 100 MHz, first on the 12V port, and after on the 5V port. The injected current was monitored with an ETS-Lindgren 91550-1L probe (Figure 2). The characterization is made at a nominal gain of the MAROC2 preamplifiers, set to 10 for different threshold settings.

The injection on the 12V power port did not reveal any susceptibility to common mode currents in the whole frequency range for the maximum amplitude of 10 mA. However, non negligible system noise was observed when injecting common mode currents on the 5V port that powers the front-end ASICs. The conducted noise develops the largest disturbance at the source of the detector signal, before its amplification, at the MAROC2 inputs.

The susceptibility characteristic is obtained at a constant current, sweeping the frequency from 150 kHz to 100 MHz. For each frequency, for each threshold setting, and for each pixel in the tested PMF the noise hits are counted for 10^4 events. The resulting figure, obtained for a current of 10 mA and a threshold DAC of 89 allows putting in evidence a susceptibility peak at 25 MHz (Figure 6), in agreement with the frequency response of the transimpedance front-end preamplifiers that has a peaking time of about 20 ns. The measurements are repeated for different values of the injected common mode current.

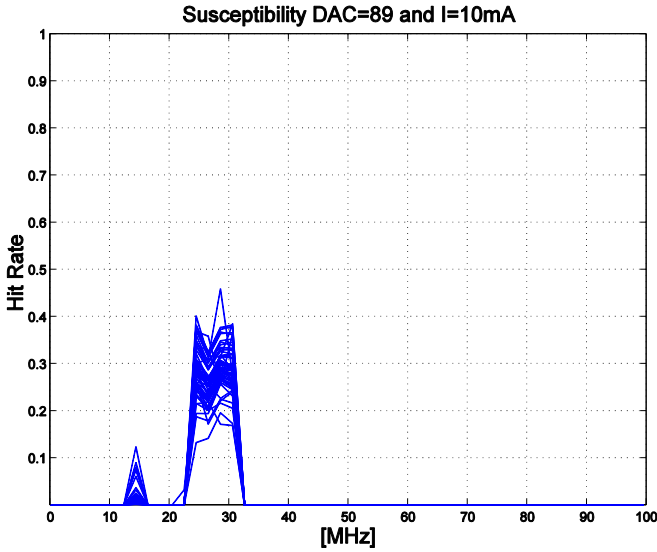


Figure 6: Conducted susceptibility.

Having identified the frequency at which the peak of susceptibility occurs, the dependency of the observed noise with respect to the injected current and to the threshold is estimated (Figure 7). The system is sensitive to common mode currents greater than 7 mA for thresholds settings greater than 88. The susceptibility at critical frequencies can be explored at nominal threshold and gain conditions, for different amplitudes of the noise current (Figure 8).

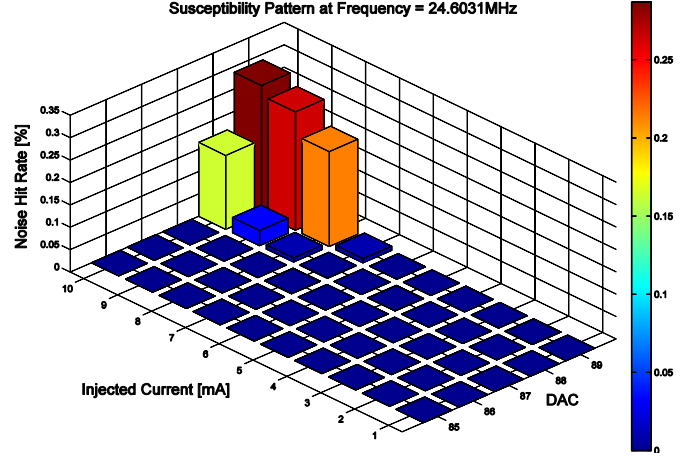


Figure 7: Conducted susceptibility versus threshold and current.

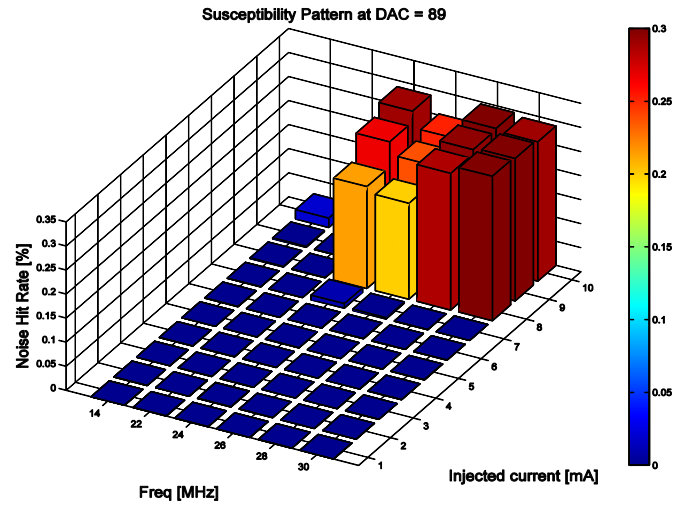


Figure 8: Conducted susceptibility versus frequency and current.

The physics requirements set the gain and threshold settings together with the maximum acceptable noise rate. With these parameters in hands, it is possible to extract the maximum common mode current that a power supply is allowed to emit into the system and select it (or filter it) accordingly, for instance with a limit of 7 mA between 10 MHz and 35 MHz in the ALFA front-end system.

IV. TESTING FOR RADIATED SUSCEPTIBILITY

The electric and magnetic fields radiated from devices in the vicinity of the front-end circuitry, located inside their shielding envelope, expose those to radiated near field couplings that degrade the system performance. The accurate measurement of radiated susceptibility requires the use of complex instrumentation that is often unavailable to the front-end designers. A simple method to qualitatively explore the front-end susceptibility to radiated near fields is presented. The methods are exercised on the production test setup of the TOTEM front-end.

A. The TOTEM Front-End.

The detector module used is part of the silicon strip TOTEM detector designed for luminosity monitoring. The front-end strips are coupled to four VFAT2 ASICs that shape, amplify and discriminate the strips signals. The discriminated signals are packed and transmitted by the hybrid board as LVDS signals. A test board [9] allows testing the hybrids prior to their installation. The test system is controlled by a dedicated software tool that configures the detector and analyzes the transmitted data.

The system has been exposed to electric and magnetic field sources with the aim to understand its compatibility with DC to DC converters located in the front-end area [10].

B. Susceptibility to Magnetic Field.

A major concern when embedding DC to DC converters is the magnetic field emitted by the coils at the switching and harmonic frequencies that can introduce noise in the preamplifier inputs. Electromagnetic simulations carried out with Ansoft Maxwell indicate that the magnetic field emitted along the axis of a coil decays very fast with the distance [11], being reduced by two orders of magnitude at 10 mm of the coil edge. To verify this, an air coil (Coilcraft 538 nH air core) was driven with a 0.5A, 1 MHz signal, pointing at different locations and angles around the front-end system (Figure 9). At these locations and angles, the S curves parameters were evaluated by the test platform for every channel. The dispersion of the slopes is used to estimate the susceptibility to the magnetic field at a nominal and fixed threshold.

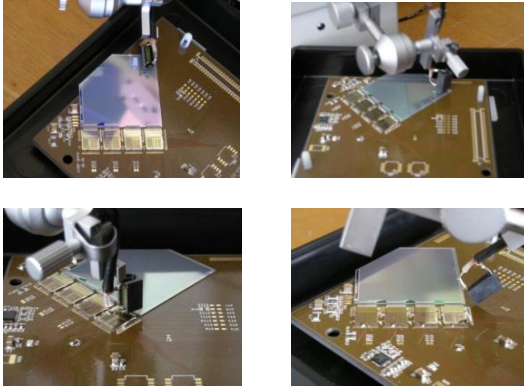


Figure 9: Magnetic field coupling test setup.

When exposing the bondings of the VFAT chips, an alternating noise pattern is observed, that is correlated with the staggered arrangement of the bonding on the hybrid. When exposing the strips, the VFAT channels develop large noise along a pattern that is centred along the coil axis. In both cases (Figure 10), large noise amplitudes are observed for the channels exposed to the fields (VFAT#1).

The coupling between the coil and the strips decays fast with the distance, becoming negligible beyond 20 mm. Similarly and as in the case of conducted noise, the coupling between the coil and the front-end inputs is function of the frequency (Figure 11). However, the coupling is strongly reduced by the addition of a shield, either around the coil

(Aluminium foil) or in the form of a copper plane between the coil and the sensitive area (Figure 12).

VFAT#	Nominal Noise	Bondings		Sensor		Far distance [mm]	
		Oblique	Straight	Parallel	Straight	50	30
1	1.76	2.3	12.87*	10.05*	4.14	1.78	1.79
2	1.81	2.14	3.96	3.97	2.35	1.78	1.80
3	1.68	1.88	2.20	2.94	1.84	1.59	1.72
4	1.56	1.70	1.87	2.18	1.65	1.63	1.67

*not an Scurve anymore

Figure 10: Magnetic coupling noise summary. The noise is expressed as the average slope dispersion of the S curves of all channels for each VFAT.

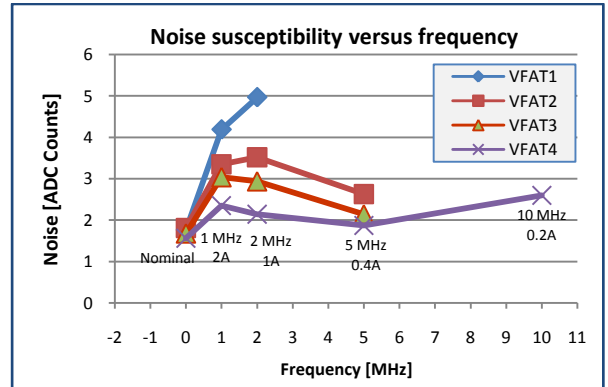
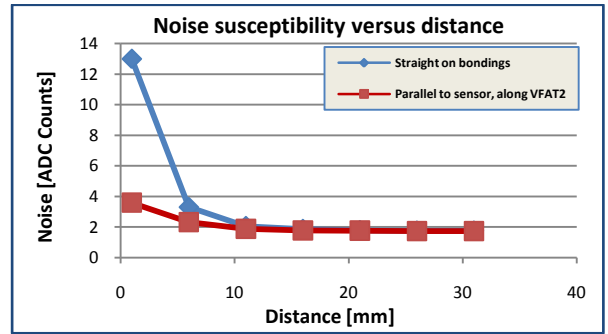


Figure 11: Distance (top) and frequency (bottom) dependency of magnetic field susceptibility.

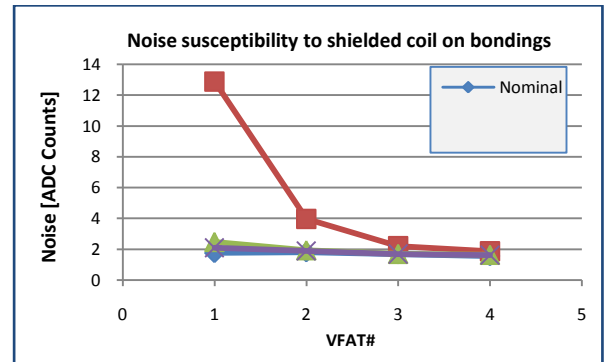


Figure 12: Shielding effectiveness of magnetic field coupling.

The voltage developed between the coil pins is a noise source that radiates electric field towards the system: complementary tests to evaluate the susceptibility to electric field must complement the magnetic field susceptibility test described here.

C. Susceptibility to Electric Field.

A reference signal of 3.4V at 1 MHz was applied to different geometries to expose the front-end system to electric fields, through capacitive coupling (Figure 13). The applied signal is referred to the ground level of the front-end system. The use of a shield provides a significant but not complete reduction of the coupling (Figure 14).

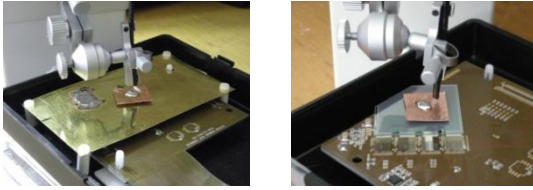


Figure 13: Shielded (left) and unshielded (right) coupling test setups.

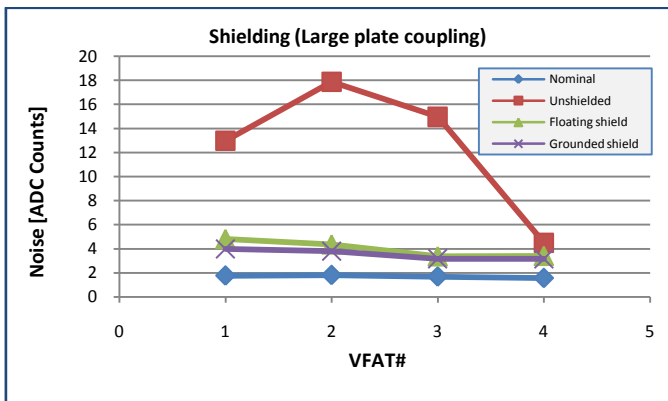


Figure 14: Shielding effectiveness against electric field couplings.

D. Compatibility with a power converter.

The observations concerning the electric and magnetic field couplings made on the TOTEM front-end predict a low sensitivity to noise sources at distances greater than 20 mm. The same system has been exposed to the conducted and radiated noise emitted by a DC to DC converter (46 dBμA peak CM at 1 MHz) used to power the front-end hybrid (Figure 15).

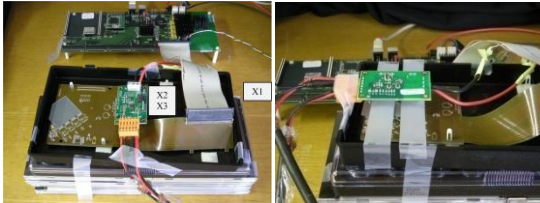


Figure 15: Powering the TOTEM hybrid with a DC to DC converter at the vicinity of the hybrid (left) and straight on the VFAT chips (right).

The system was found to be insensitive to the combined emissions at three different locations in the close vicinity of

the bondings and of the strips (X1, X2 and X3 on figure 15). An increase was only visible when the converter was placed straight on the top of the detector at about 15 mm, and only on the VFAT chip under the unshielded inductor.

V. CONCLUSIONS

The noise susceptibility of front-end systems is a key parameter that can be evaluated with accurate measurements. The characterization of the conducted susceptibility provides accurate results that can be used to set up appropriate filters and to specify a compatible power supply system. The radiated susceptibility can be evaluated with simple setups, allowing to qualitatively discriminate between electric and magnetic couplings and to set geometrical compatibility boundaries. The method allows exploring the effectiveness of shields.

VI. REFERENCES

- [1] "EMC Phenomena in HEP Detectors: Prevention and Cost Savings", F. Artech, C. Rivetta, Int. Symposium on the Development for Particle, Astroparticle and Synchrotron Radiation Experiments, Stanford, CA, USA, 3-6 Apr 2006, pp.0149.
- [2] "Overview of the ATLAS Electromagnetic Compatibility Policy", G. Blanchot, 10th Workshop on Electronics for the LHC and Future Experiments, Boston MA, USA, September 2004, pp. 205-209.
- [3] "Electromagnetic Compatibility of a Low Voltage Power Supply for the ATLAS Tile Calorimeter Front-End Electronics", G. Blanchot et al., 12th Workshop on Electronics for LHC and Future Experiments, Valencia, Spain, September 2006, pp. 384-388.
- [4] "EMC Diagnosis and Corrective Actions for Silicon Strip Tracker Detectors", F. Artech, C. Rivetta, 7th International Symposium on Electromagnetic Compatibility, Barcelona, Spain, September 2006.
- [5] IEC-61000-6-2:1999, Electromagnetic Compatibility, Part 6-2: Generic Standards – Immunity for industrial environment.
- [6] CISPR 16-2-4: Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements.
- [7] "System Design of the ATLAS Absolute Luminosity Monitor", G. Blanchot et al., Topical Workshop on Electronics for Particle Physics, Prague, Czech Republic, September 2007, pp. 173-177.
- [8] "MAROC: Multi-Anode Readout Chip", P. Barrillon et al., Topical Workshop on Electronics for Particle Physics, Prague, Czech Republic, September 2007, pp. 304-308.
- [9] "The VFAT Production Test Platform for the TOTEM Experiment", P. Aspell et al, Topical Workshop on Electronics for Particle Physics, Naxos, Greece, September 2008, to be published.
- [10] S. Michelis et al, "Inductor based switching DC-DC converter for low voltage power distribution in SLHC," TWEPP conference, Prague, 2007.
- [11] S. Michelis et al, "Air core inductors study for DC/DC power supply in harsh radiation environment", IEEE NEWCAS-TAISA conference, Montreal, June 2008.