	ATLAS EMC Technical Note

ATLAS EMC Policy

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Abstract

Electromagnetic compatibility of ATLAS electronic equipments must be insured to achieve the expected level of performance of the experiment. The ATLAS EMC Policy covers the electrical safety aspects of the front end and racked installations, and aims the proper operation of the experiment in the electromagnetic environment that it creates. For this, the policy defines a set of procedures to document and approve the installations from the safety, compatibility and maintenance points of view.

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History of Changes

Version	Date	Page	Description of Changes
DRAFT.3	**14 June 04**		**First draft. Submitted at EB in July 04.**
1	**21 July 04**	**7**	**Edited section 1.4.**
		9-10	**Edited section 2.3.1. on power distribution schemes to accommodate grounding close to the detectors, in agreement with SC rules.**
		11	**Added sections 2.3.1.5 and 2.3.1.6 about sense wires and common grounds.**
			Edited section 2.3.2 about cable trays.
		22	**Added reference number 21.**
2	**04 August 04**	**18**	**Added section 3.7.2 about installation of cables and power/data separation.**
3	**01 March 05**	**22**	**Added section 3.11 to 3.13 about harmonics emissions, power factor and voltage transients.**

1. Introduction

1.1. Scope of the Policy.

To achieve the expected level of performance of the ATLAS experiment, the electromagnetic compatibility (EMC) of the electronic installations must be insured. Three topics must be covered:

- Compliance to electrical safety rules applicable at CERN.
- Immunity against conducted and radiated emissions present in the experimental area.
- Measurement of conducted and radiated emissions of each installation in the experimental area.

The compliance to electrical safety rules is mandatory at CERN and is insured by the Safety Commission. The characterisation of emissions and immunity of each system is necessary in order to identify EMC hot areas or incompatibilities between neighbouring equipments. The main reference documents of this policy are the ATLAS Policy on Grounding and Power Distrubution [1], the IEC 61000-5-2 technical report on EMC [2], the LHC Technical Note “Liaisons equipotentielles et protections electromagnetiques” [3] and the French Low Voltage Code NF C 15-100 [4]. The information relevant to this policy can be found at the ATLAS EMC site:

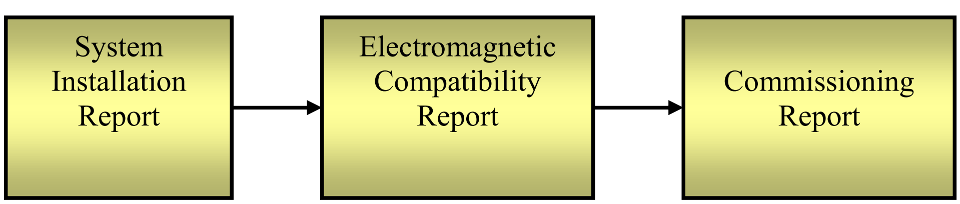
http://atlas.web.cern.ch/Atlas/GROUPS/FRONTEND/EMC/

1.2. International standards.

Pieces of equipment acquired from industrial vendors shall comply with the international standards for *industrial environment*, in particular EN 61000-6-2 and EN 61000-6-4. The level of immunity required (immunity criterion) shall be established on a case by case basis. Compliance to international standards isn’t required for custom made equipment, however their EMC performance must be evaluated.

1.3. Policy implementation.

The EMC policy is implemented as a set of three procedures that target the approval and proper documentation of the installations from a safety, compatibility and maintenance points of view. The systems targetted by this policy are described in Annex 1. The documents associated with it are stored in EDMS and are available at the ATLAS EMC web site.



1.3.1. System Installation Report.

The systems and associated front-end and racked electronics which form an *installation* must comply with mandatory electrical safety regulations of CERN. This first document, whose content is detailed in Table 1 is required for:

- Approval of the installation by the Safety Commission
- Documentation of the installation.

System Installation Report.
▪ Identification of contact person for safety and EMC procedures. ▪ Description of equipments, parts and components that compose the installation. ▪ Identification of commercial CE marked equipment and report of their conformance to international standards. ▪ Identification of non CE marked and custom made equipment to be approved by the Safety Commission. ▪ Description of how the equipments must be installed and interconnected to be operated safely, including grounding aspects. ▪ Description of the fault conditions and protection systems. ▪ Description of the cables routing paths and identification of the next neighbours on this path. ▪ Definition of a checklist that allows to crosscheck that the installation is done properly. ▪ Definition of a procedure to clear electrical faults.
Approval of this document by the ATLAS EMC coordinator and by the Safety Commission is mandatory.

Table 1: System Installation Report

1.3.2. Electromagnetic Compatibility Report.

The equipments, components and parts that form a system installation as described in the System Installation Document, do not require to comply to any specific international EMC standard because of the particular EMC environment of the experiment. However, their EMC behaviour must be known. Therefore, measurements shall be carried out and an EMC Report is still necessary:

- To understand and define the limits of good operation of the system.
- To identify the levels of emissions of the system.
- To draft afterwards a map of emissions in the cavern that will allow to set the electromagnetic compatibility level of the system at its location.

<u>Electromagnetic Compatibility Report.</u> ▪ Definition of working and non working limits of the system and the parameters to evaluate the margin to these limits. ▪ Identification of key parameters such as operating frequencies, bandwidths, transmission methods, thresholds, power supplies topologies, cables lengths and properties, electronic noise. ▪ Measurement of conducted emissions in cables and ground straps. ▪ Measurement of CM susceptibility through power supply cables. ▪ Definition of a check procedure that allows to cross check at installation the performance of the system according to the EMC Report. *Approval of this document by the ATLAS EMC coordinator is mandatory.*

Table 2: Electromagnetic Compatibility Report.

The type and quality of cables shields shall be explicitely defined. The ways shields are terminated shall be defined, together with the type of backshells, connectors and frontpanels selected. Grounding of shields at one or both sides of the cable shall be explained.

The type and quality of enclosures that are used for the electronic boards shall be defined. Enclosures are susceptible to resonate at given frequencies. When possible, those modal frequencies shall be defined.

1.3.3. Commissioning Report.

Once installed in the experimental area, a final crosscheck must be carried out :

- To insure the compliance of the system to its System installation Document.
- To insure the compliance of the system to its EMC Report.

The crosschecks should be made according to the check procedures established in the installation document and in the EMC Report.

<u>Commissioning Report.</u> ▪ Electrical safety crosscheck report. ▪ EMC compliance report. ▪ Measurement of final performance of the system: working limits parameters and margin to non working limit. *Approval of this document by the ATLAS EMC coordinator is mandatory.*

Table 3: Commissioning Report

1.3.4. Measurements and Support at CERN.

The following measurements are mandatory and will be carried out with the support of the CERN Safety Commission and/or the ATLAS EMC responsible:

- Grounding scheme conformity for each installed equipment and system.
- Emissions and immunity of installed front end electronics and their associated power supplies.

Assesment on good EMC practices at board design level and system integration is available through the ATLAS EMC coordinator.

Technical support, in form of standard equipment and expertise to carry out specific measurements is available through the ATLAS EMC coordinator.

1.4. ATLAS Policy on Grounding and Power Distribution.

The preliminary guidelines for grounding and power distribution in ATLAS are defined by the ATLAS Policy on grounding and power distribution [1]. The systems shall be designed in order to be electrically isolated between them and from ground.At installation time, the detectors are to be grounded to the safety network of the cavern in a controlled manner and according to the power distribution schemes defined in section 2.3 of this document.

2. Electrical Safety.

The applicable standard at CERN is the CERN Electrical Code C1 [5], which refers to the french national code, known as NFC 15-100 [4].

2.1. Voltage Domains.

The voltage domains for installations as defined by the IEC are described in the Safety Instruction 33 [6].

Equipment and installations in ATLAS are not provided with double or reinforced insulation, and therefore they must be grounded to a protective earth conductor. In general, equipment and installations shall be implemented in a way that provides protection against direct and indirect contacts when the involved voltages are above 50VAC(rms) or 120VDC :

- Protection against direct contact with live conductors. This is achieved with insulated active parts or enclosures.
- Protection against indirect contacts, that is contacts with conductive parts that might become active under fault condition. The protection is in form of ground fault interruptor and/or overcurrent interruptor.

2.2. Equipment.

Electrical and electronic equipment that provide a *direct function* which is CE marked shows conformance to the applicable EU Directives, including the Low Voltage Directive 89/336/EEC on which is based the french code. Components and equipment with *no direct function* do not require to be CE marked.

Electrical and electronic equipment that provide a *direct function* which isn't CE marked or is custom made may be authorised to operate on CERN premises by the Safety Commission. The assessment is on low voltage electrical safety, fire risk and nuisance to the immediate neighbours. A documentation folder must be submitted to the Safety Commission for approval, containing:

- Schematics including power and earth paths;
- Cable lengths and sections;
- Possibilities of direct contact;
- Protections (fuses or others);
- Capability of power sources involved;

2.3. Installations.

The ATLAS electrical and electronic *installations* are combinations of front end detectors with their supports, services (pipes for gases and fluids), cables and cable trays, racks and crates with electrical, electronic, computing and communication equipment. These *installations* must be built with pieces of equipment which are either CE marked or approved by the Safety Commission. The overall setup must comply with the CERN Electrical Safety Code C1.

2.3.1. Power Distribution.

2.3.1.1. AC TN-S configuration

The AC network that distributes the power to the ATLAS experiment is in TN-S configuration (Figure 1): the neutral is earthed at the secondary star point of the main transformer, the earth conductor is routed separately from the neutral conductor, and the cases of the equipments are connected to the earth (PE) conductor. A ground fault differential interruptor is to be placed at the power input of each installation and will open the circuit with the first ground fault. The fault current rating has to be specified according to the load.

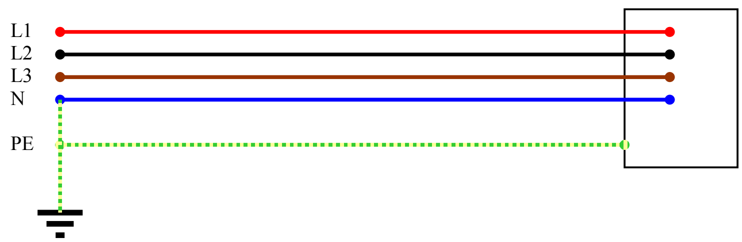


Figure 1: AC TN-S configuration.

The power distribution of the ATLAS front end systems is done in DC. It must be noted that ground fault *differential* interruptors are not required on DC networks, and protection is insured with overcurrent protection devices or fuses. The power supplies that deliver the DC power from the AC power network are located in racks off-detector and are either regulated or switched-mode power supplies. Specific international standards apply to these units (see annex 2). The DC distribution network can be implemented in TN-S, TN-C or IT configurations:

2.3.1.2. DC TN-S configuration.

In a DC TN-S configuration, a protective earth conductor PE is routed parallel to the power return line. The PE conductor is earthed at the rack and connects to the front end cases. A fault between L+ and PE or L- will cause a short circuit condition. The protection can be implemented as trip down feature of the power supply or an overcurrent protection device (fuse or equivalent).

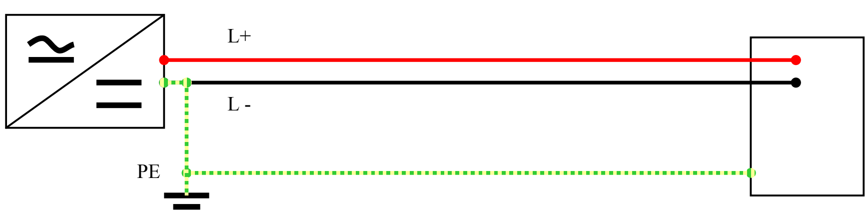


Figure 2: DC TN-S Configuration.

2.3.1.3. DC TN-C configuration.

In a DC TN-C configuration, the power return is earthed at the rack level and connects to the front end cases; here, the case is the return conductor of the front end equipment. The power return is the protective earth conductor (PEN). A fault will cause a short circuit condition. The protection can be implemented as trip down feature of the power supply or an overcurrent protection device (fuse or equivalent).

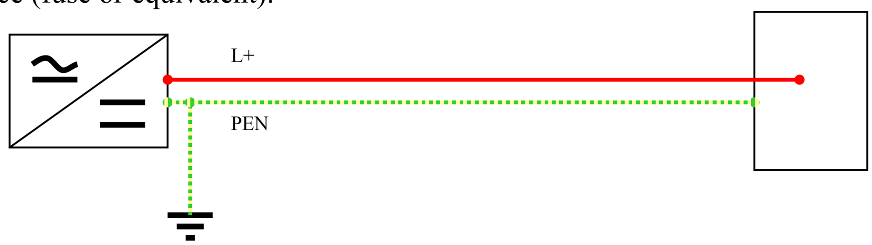


Figure 3: DC TN-C Configuration.

A variant of the TN-C configuration, with the grounding connection made close to the load rather than close to the source, is accepted (Figure 4). If a ground fault between the power return and the ground appears at the source, an alternative short circuit return path through ground is provided, but difficulty detected. In this configuration, the ground connection (wire cross section, connectors and mechanical links) must be able to sustain the short circuit currrent if a ground fault appears at the load too.

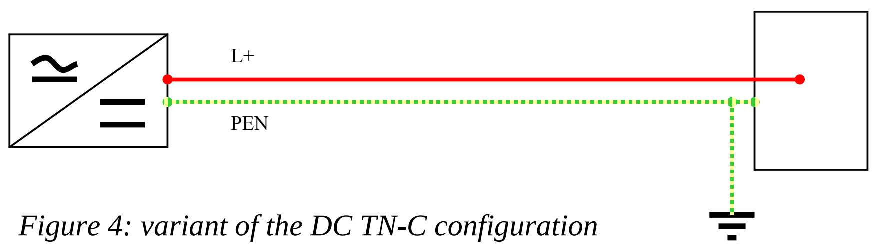


Figure 4: variant of the DC TN-C configuration

2.3.1.4. DC IT configuration.

In a DC IT configuration, the outputs are left floating. However, the front end case has to be earthed. The first ground fault condition will not create a hazard by itself (a leak current will be created through stray capacitances only), however provisions must be made to prevent hazards in case of a second ground fault. The protection must be implemented in form of permanent isolation controler (CPI) that will monitor the impedance between L+- and earth at the source, together with a safety procedure to clear the fault. The first ground fault must be detected and an alarm must be raised in the DCS system so that the fault can be identified and cleared. The second ground fault can cause a short circuit condition: for this, overcurrent protections are required in form of fuse or trip down.

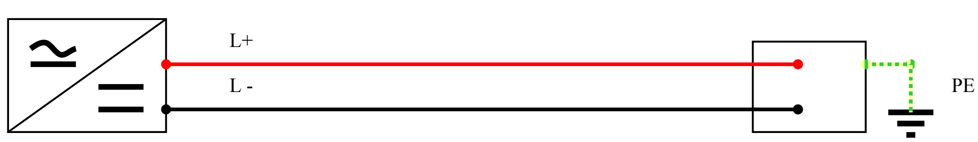


Figure 5: DC IT Configuration.

2.3.1.5. Sense wires.

In agreement with Safety Instruction IS48 [21], the sense wires used to regulate at the source the voltage delivered at a remote load must be provided with current limiting devices such as resistors or fuses, in order to limit the eventual fault currents. The current limiting devices shall be installed on both wires, as close as possible to the sense connections at the load.

2.3.1.6. Common returns.

Power supplies providing mulltiple outputs with a single common return line are not allowed, unless provisions are made so that the cabling is capable to handle the full short circuit current.

The derivation of a power supply output from an equipment such as a crate to power a remote load is not allowed, as a short circuit condition might create a fire hazard in the remote load and its cable. In these cases, auxiliary power supplies shall always be used.

2.3.2. Cable trays.

All cable trays are earthed with a PE conductor bonded inside the tray and must be installed in agreement with Safety Instruction IS48 [21]. Multiple levels of trays are bonded together at regular intervals. The racks supplying the cables to the tray must be earthed to that tray . Meshed trays by themselves cannot be used as PE conductors.

In order to reduce the electromagnetic emissions of cables, they shall be laid as close as possible to the tray surface [3]. Cables shall be grouped in terms of power and sensitivity to disturbances, and appropriate separation between those groups shall be provided [3]. Power cables shall be routed on the tray surface and as close as possible to the PE conductor.

From the EMC point of view, cable trays act as a *ground plane* for the system.

2.3.3. Services.

Pipes for gases and fluids are to be earthed for safety purposes. However, they cannot be used as protective earth PE conductors.

2.3.4. Supports.

The structural conductive parts are to be earthed to the nearest ground connection for safety reasons. However, they cannot be used as protective earth PE conductors. The front end systems installed on these structures must be earthed by means of an adequate PE conductor.

Grounding all conductive parts will provide a meshed ground structure that will improve the EMC proformance of the front end systems [2,3]. Cables shall be laid on grounded structures and trays to reduce emissions.

Aluminium structures that are bolted shall be connected to the safety ground mesh with a dedicated copper wire. Electrical continuity across bolted aluminium parts shall be checked at installation for EMI control purposes.

2.3.5. Earth connections in UX15.

Earth connections are provided *exclusively* by means of 120 mm2 copper wires, directly bonded to the electrical distribution PE conductor. All safety ground connections require a specific ground wire. For EMI control purposes, passive structural elements shall be bonded to the grounding network, but cannot be used as safety ground connection point.

The steelwork and beams of the UX15 experimental area building are grounded at surface. A meshed ground network is welded to the cavern steelwork. This network is grounded to the USA15 grounding network through the TE galleries, and is directly bonded to the secondary star point of the transformer. The HO and HS structures are grounded as well to the cavern grounding network.

The HO and HS structures located inside UX15 are made of painted beams that are either soldered or bolted together. Because of this, the ground continuity cannot be insured as is. The main beams of those structures are bonded to the safety ground mesh. The other beams of the structure will be indirectly grounded through the bolts; when the quality of the connection is iinsufficient, ground starps shall be added.

2.4. Installation verification.

The installation must be done in a way that it allows to cross check its safety grounding. The verification method must be documented in the System Installation Document.

Specific and independent measurements to insure the proper grounding of metallic structures and installations will be carried out by the Safety Commission. Additional measurements shall be requested to the ATLAS EMC responsible.

2.5. Safety procedures.

To clear the ground faults in any of the configurations described above, a procedure must be documented in the System Installation Document. This is particularly important in the IT configuration.

3. Electromagnetic Compatibility.

3.1. Electromagnetic environment.

As an underground facility, the ATLAS experimental area is up to some extent shielded against electromagnetic fields that are usually present at surface: broadcast radio, TV signals, and satellite radio signals. The fields present underground will be contributed mostly by the CERN radio services and by the experiment itself. Some radio signals are however broadcasted inside the cavern:

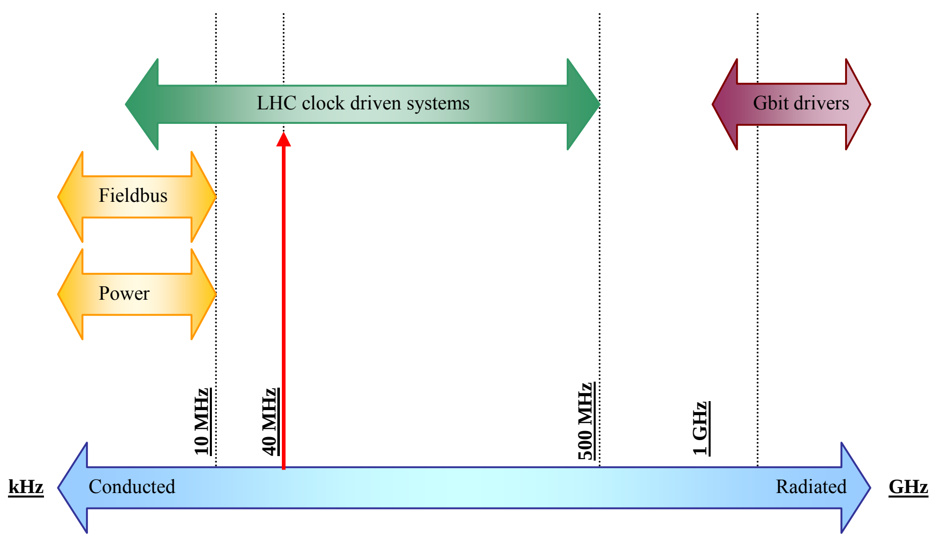
- Voice radio bands (151MHz, 155MHz, 161-169MHz, 174MHz, 451-462MHz).
- Radiocontrol for the UX15 cranes, occupying the 433MHz and 869MHz bands.
- GSM radio (886-942 MHz) is broadcasted by two antennas. .
- Wireless LAN occupying the 2.4-2.484 GHz band.

The EMC Policy aims to insure the proper operation of the experiment in the electromagnetic environment that it creates. Because of this specific statement, the compliance with international EMC standards that are applicable for industrial and commercial equipment do not represent a guarantee of proper operation for the experiment, and might set too stringent or to loosy constrains on the front end electronics. However, in sake of consistency, the parameters for *immunity* and *emissions* measurements have to be defined for the ATLAS environment, and the measurement methods must be specified. A front end system must be implemented so that it is *immune* to the fields created by its neighbours; on the other hand, each front end system must limit its emissions at a level that is compatible with the operation of its direct neighbours. The reference to international standards is useful to settle down the measurements methods, but a full compliance for underground equipment is not mandatory in ATLAS.

On the other hand, equipment located at the surface will be exposed to the full spectrum of electromagnetic fields, and therefore the compliance to the EMC international standards for the equipment installed at this level is strongly encouraged. The basic EMC standard applicable in ATLAS is the IEC-61000 standard. The measurement techniques and instrumentation is contained in the IEC harmonized standard CISPR 16; for information technology equipment, the measurement techniques and instrumentation is contained in the harmonized standard CISPR 22.

The electromagnetic disturbances are conducted through cables and are radiated to the environment in form of electrical and magnetic fields. The nature of those disturbances depend of the involved coupling paths and frequencies. Several groups are identified that will contribute to most of the electromagnetic environment in the ATLAS experimental area:

- Switched mode power supplies, with switching frequencies from few kHz up to few MHz. Taking into account the frequency content of the transient switching waveforms, the SMPS will contribute to noise up to few MHz. At these frequencies, conducted noise will dominate.
- Fieldbus links, with baud rates up to 1 Msps and taking into account harmonics of digital waveforms, will contribute to conducted noise in the range of few kHz up to few MHz.
- LHC clock driven systems, will contribute to conducted and radiated noise in frequency ranges from few hundreds of kHz (for systems running at lower frequencies derived from the main 40MHz clock) up to few hundreds of MHz for harmonics of digital waveforms running at the main 40MHz clock. As those systems use mainly optical links for the transmission of information, radiated noise from the front end systems and from the readout crates will dominate.
- RF frequency of the LHC machine (400 MHz) might show up in the experimental area.
- Gigabit links: the data links drive the optical signals in the Gbps range. The SerDes chips of these links operate in the GHz range and are susceptible to radiate locally high frequency noise.
- Magnetic field fluctuations at startup and shutdown of magnets, specially during quenching.
- 50 Hz and harmonics of AC power rectification circuits, for instance of magnets power supplies (LHC magnets, toroid magnets, solenoid).
- Particle showers are themselves noise sources in the RF spectrum [12].



Because the analog front end electronics bandwidth is limited to a maximum of 40 MHz, it can be seen that the conducted noise from power and fieldbus systems will be the most critical one because it is susceptible to impact directly on the resolution of physics data. LHC clock driven systems and Gigabit links drivers, usually located in crates or in front end faraday cages, will radiated locally and can be at the origin of unexpected error rates or intermittent failures. The LHC clock driven systems will be at the origin of coherent noise all over the experiment. A gap in the range of hundreds of MHz will exist due to the lack of systems operating in this range of frequencies.

The conducted noise dominates and will take the form of common mode noise, that is current flowing in the same direction toward a system, with the return path being the ground (conductor or surrounding conductive elements). This common mode current can be at the origin of electromagnetic fields if the circuit loop is large, and contribute in this way to the radiated EM environment of the experimental area.

To control the electromagnetic environment of the experiment, the Policy focuses on two major work lines:

- Measurement and mitigation of conducted emissions of systems and equipment.
- Survey of radiated emissions in the experimental area.

3.2. Use of radio emitters.

The usage of radio controlled equipment is regulated at CERN. The installation of radio transmitters in the experimental area must be autorized by the ATLAS EMC responsible and by the IT division, who maintain a database of emitters to avoid interferences between systems.

3.3. Compatibility limits.

A system is considered to be working in its environment if it is able to resolve the smallest signal with the minimally required resolution. A loss of resolution is interpreted as a degradation in the RMS value of the measurement, or as the inability to digitze and/or transmit the result through the data links. A system is disturbed through cables (conducted susceptibility) and through interferences (radiated suscpetibility). The compatibility limits must be defined for a complete system, that is with its power supply and DAQ system connected, under power and taking data. The evaluation of the RMS values of pedestals and error rates of data links are usually sufficient to set the compatibility limit condition. Other specific parameters can be defined for each system if needed.

Compatibility limits parameters: analog circuitry

- Analogue variable to monitor: X
- Intrinsic noise: ΔX
- Compatibility limit: ΔX_{MAX}

Compatibility limits parameters: data links

- Intrinsic error rate: ε
- Compatibility limit error rate: ε_{MAX}

Compatibility limits parameters: specific parameters

- Other specific parameters and limits may be defined if needed.

Table 4: Compatibility Limits

3.4. Basic measurement instrumentation.

The EMC measurement must be carried out with appropriate instrumentation as described in Table 5. The ATLAS EMC Policy is mainly focused onto the dominant conducted emissions in the range comprised between 10kHz and 500MHz.

Instrumentation for conducted and radiated noise tests
▪ EMI receiver 9kHz-1.5GHz minimum, or: ▪ Spectrum analyzer with quasi peak detector and appropriate IF input filters. ▪ Current probes for conducted emissions measurement , up to 100MHz minimum. ▪ Injection current probe for immunity test, up to 100MHz minimum. ▪ RF Generator and amplifier, for immunity test. ▪ Line Impedance Stabilization Network (LISN) for AC powerline emissions. ▪ Loop antenna for magnetic field emissions, up to 30MHz. ▪ Monopole antenna for electric field emissions, up to 30MHz. ▪ Dipole antenna for electric field emission, above 30Mz and up to 1GHz. ▪ Ground plane.

Table 5: Instrumentation for conducted and radiated noise tests.

3.5. Use of ground planes.

Cables in ATLAS are routed in grounded cable trays that act as a ground plane for the installation. The use of grounded cable trays is of great importance for EMI control because it provides the return path for common mode currents in a contained loop. Therefore, emissions measurements in lab or at testbeams shall always be done with cables either laying on a grounded copper plane when trays are not used, or alternatiivelly with cables routed in grounded trays or structures. In all cases, and in particular for measurements done at testbeam areas, the equivalent ground plane shall be provided.

For large installations such as testbeams or the ATLAS experimental area where a ground plane cannot be inserted, the cabling shall be done in grounded cable trays or along grounded strautures. Structures and cable trays shall be interconnected. In this configuration, the CM currents follow a controlled least inductive path.

3.6. Line impedance stabilization networks.

Measurements of conducted emissions on power lines done in laboratories require the usage of line impedance stabilization networks (LISN) to normalize the measurements. However, measurements done in situ (i.e. at testbeam areas or in the experimental area), do not require the usage of LISN as the setup is the final one.

3.7. Shielding and Installation of Cables.

3.7.1. Shields.

Because of the cabling density of the experiment, all copper links (power and signal) are closely packed together inside grounded cable trays. The length of the links can be rather long. All cables are to be considered as potential electromagnetic radiators and at the same time as antennas. As radiators, the near field will depend on the cable topology and transported energy. As antennas, the induced voltage will be a function of the near field and of the cable topology. To minimize the coupling between closely packed cables, shields shall be used. There are several types of shields, of coupling mechanisms and of ways to connect the shields: this subject is extensively covered in the litterature [13]. The performance of a shield is evaluated by its transfer impedance. In ATLAS, shielded cables shall always be used.

The most commonly used shields are the aluminium foil and the tin plated copper braid. The shielding effectiveness is a function of the frequency but also of the way the shield is connected at its ends. Aluminium foils are usually laminated on polyesther foils to improve their mechanical strength. The aluminium layer is usually very thin, and this results in a low mechanical strength and high DC resistance. The resulting transfer impedance is usually about 100 mΩ/m. This type of shield is however close to the ideal tubular shield, which is of interest at high frequencies. In order to improve the DC resistance, a drain wire is usually supplied. Because of its fragility, when bended and stretched during installation, some gaps can be created in the foil, and affect the resulting shielding effectiveness.

The braided shield is mechanically much stronger, and it offers better transfer impedance, around 10mΩ/m. The shielding effectiveness is limited at high frequencies by the shield topology. Typically, the transfer impedance start to degrade at around 1MHz. The cutoff frequency is a function of the optical coverage, which shall not be less than 85%. To improve the performance at higher frequencies, aluminium foils can be wrapped inside the braid, and a drain wire issually added.

The shield is an electromagnetic barrier. When grounded on one side, it forms an equipotential that protects the circuits against electric field couplings. Because the current cannot flow, it does not provide any protection against magnetic field couplings. In order to provide some degree of protection against near magnetic fields, both ends of the shield shall be grounded, allowing current to flow [13]. In all cases, a shield will only behave properly if no impedance is added in series to ground; at most, a capacitive connection to ground can be tolerated at expense of DC shielding effectiveness. Resistive connections shall be avoided, because they will develop voltages in the shield and impeach the energy to flow to ground, and therefore it will flow through sensitive circuits.

The shielding effectiveness is vastly affected by the way it is grounded at its ends. Metallic backshells, with 360 degree contact around the shield shall be used with the connectors. It is demonstrated that pigtails limit the shielding effectiveness to few kHz.

3.7.2. Installation of cables.

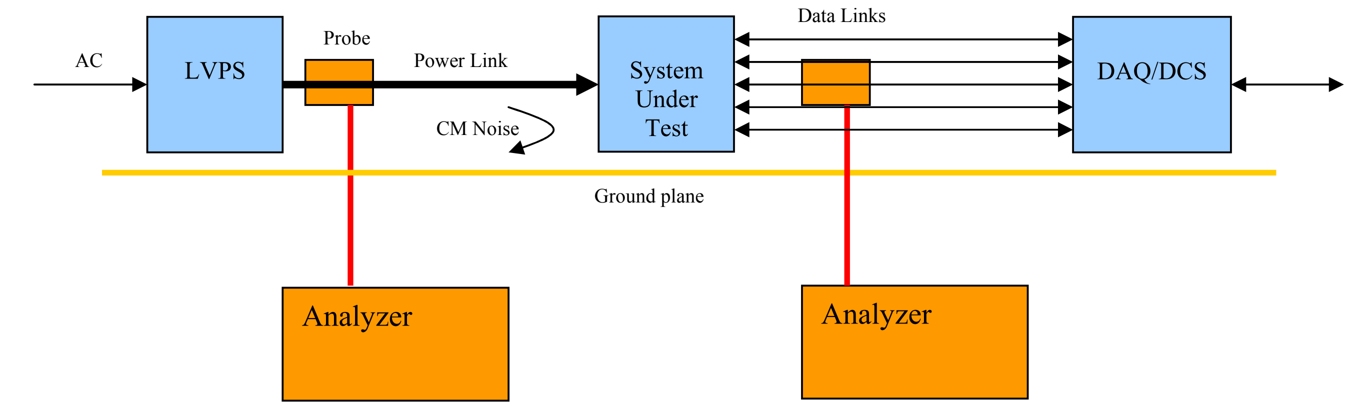
In addition to the rules defined in section 2 about cables trays, services, supports and earth connections, the routing of cables shall be made in order to minimize couplings across them. The rules that apply to the installation of cables are detailed in the IEC 61000-5-2 technical report on EMC [2]. The coupling between cables is proportional to the coupling path length they share, to the current they carry (magnetic field surrounding the cable), to the voltage they carry (electric field coupling), to the transients speeds, and is inversely proportional to the separation between them. The shields are effective against electric field couplings if properly grounded; they are however of limited effect against magnetic field couplings, which is particularly important in power circuits. The most effective technique to minimize magnetic couplings between cables is the *distance*. The guidelines are summarized as follows:

- The cables must be grouped (and bundled) in terms of their sensitivity to interferences and contribution to noise:
  - Very sensitive: sensors, front end and trigger signals.
  - Sensitive: slow control signals, low speed serial and parallel links, for voltages below 24VDC.
  - Noisy: 220VAC lines, relay and switch lines without protection.
  - Very noisy: lines that feed AC and DC motors, switched power supplies, frequency variators for AC motors.
- Separate the different groups and bundles of cables:
  - Noisy bundles and sensitive bundles should be routed in separated, grounded metallic trays, and when possible on different paths.
  - When noisy and sensitive cables share the same tray, the distance between them in the tray must be maximized.
  - When power and noise sensitive cables have to share a common tray over distances greater than 15 meters without separation between them, both cables shall be shielded and grounded *at both ends*.
- Minimize the circuit's loop area:
  - The coupling is proportionnal to the area exposed to magnetic fields, therefore the return lines shall follow the same path as the live lines of a given circuit.
  - The insertion of switches and interlocks in a control line must be done so that it does no increase significantly the loop area of the circuit.
- Minimize the length of antennas:
  - Circuits provided with switches at the source and normally opened form antennas that feed the detector with picked up interferences. Therefore, those circuits shall be provided with common mode filters at the interface to the detector.
  - When possible, the switches should be located close to the detector to reduce the antenna length when disconnnected.

In practice, power equipment should be grouped in a given area, and the asssociated cables are bundled together and routed on power trays, far away from sensitive equipment, which is usually installed in a separated area, with the associated sensitive cables bundled together and routed on signal trays. Both trays and sets of cables will come together close to the detector (less than 15m). In this way, the coupling length is minimized and the volume of the trays is efficiently used.

3.8. Emissions tests and mitigation.

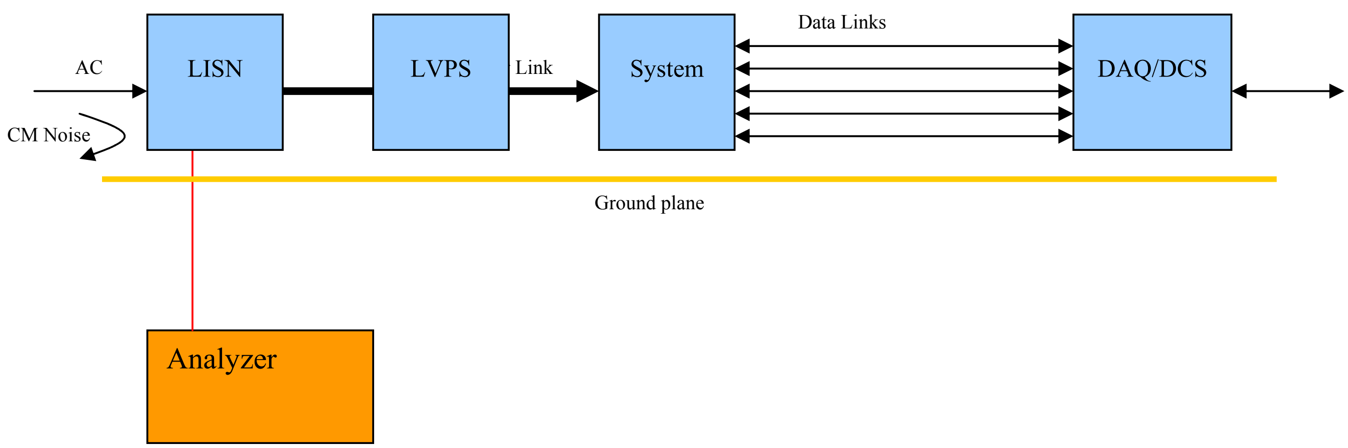
Conducted emissions tests carried in laboratories shall be done on appropriate ground planes, or at least with grounded cables trays or with cables laid on grounded structures, with calibrated current probes and with an EMI receiver or spectrum analyzer equipped with quasipeak detector.



The conducted emission measurement shall be done for spectrums comprised between 10kHz and 100MHz. The main peaks frequencies shall be recorded together with their amplitude. The spectrum diagram shall be reported in the EMC Report.

Emission on AC powerline done in laboratories shall be carried out with an appropriate LISN to normalize the AC plug impedance and allow for repeatible measurements independently of the plug used.

Emissions of commercial power supplies must comply with the standards and the systems powered by those units must be capable to withstand the level of noise created by them. Emissions of custom SMPS must comply with the compatibility level of the system it is intended to power.



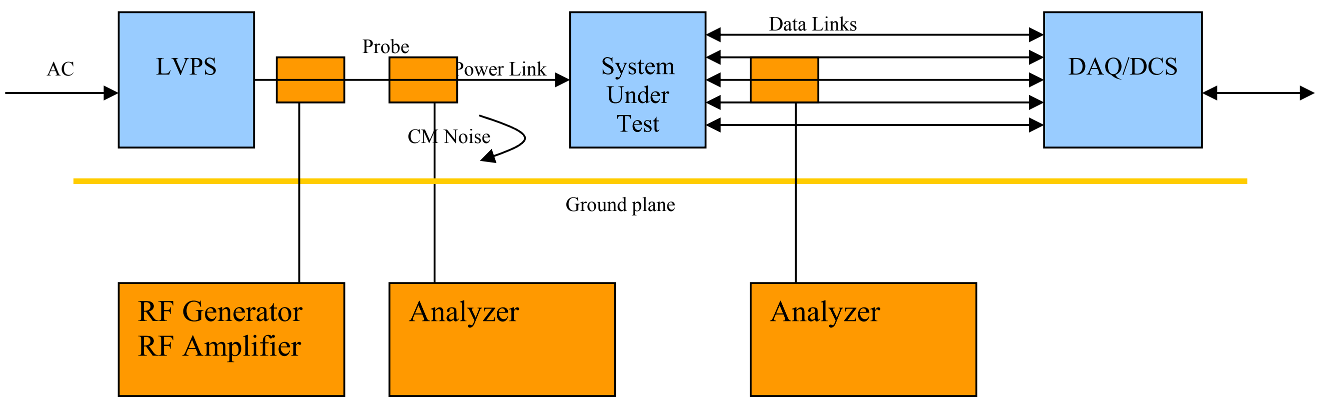
Whenever possible, the systems should implement mitigation techniques to reduce as much as possible their conducted emissions. This is achieved with:

- Cables carried into grounded cable trays.
- Structural and surrounding metallic elements grounded.
- Control of power loops and common mode loops.
- Addition of EMI filters and ferrites on cables to either filter out or block CM noise.
- Usage of isolation techniques on data links.
- Usage of balanced transmission lines and differential signalling.

3.9. Immunity tests.

Conducted common mode (CM) noise is a fact in ATLAS: systems must be designed to cope with it. The ways CM noise is converted into differential mode (DM) noise is widely described in the litterature. The CM noise will enter a system through all the cables (power, input and output) and returns to its source through ground. The immunity of systems with respect to common mode noise must be checked to insure its compatibility with the specified compatibility level.

Conducted emissions immunity tests carried out in laboratories shall be done on appropriate ground planes, with the same setup as for emission tests with the addition of an injection current probe driven by an RF amplifier.



The immunity test shall be done for spectrums comprised between 10kHz and 100MHz. The most sensitive CM frequencies must first be identified. For this the DAQ system must run continous calibration runs and record the RMS values and error rates defined in the EMC Report, for each frequency step at fixed amplitude. An automated test setup is strongly recommended in order to cover as much as possible the whole spectrum. The CM injected onto the cable shall be monitored to insure that a constant intensity is injected over the whole spectrum. From this, a diagram of the RMS values or Error Rates versus frequency is obtained. The most critical frequency is retained.

In a second phase, the RF generator is set at a fixed frequency corresponding to the most sensitive one, and amplitude is swept up until the compatibility limit of the system is reached.

The initial tracking spectrum, the most sensituve frequency, and the CM current compatibility limit are reported in the EMC report.

Tests on AC powerline shall be carried out with an appropriate LISN to normalize the AC plug impedance and allow for repeatible measurements independently of the plug used.

3.10. Electromagnetic survey.

The electromagnetic environment of the experimental area will remain unknown until the experiment is fully commissioned. Then, it is not possible to set radiated immunity limits beforehand. On the other hand, it sounds unpractical to establish arbitrary radiated emissions limits for systems whose immunity is difficult to measure due to its large dimensions: radiated emissions and immunity tests shall be done in anechoic chambers, which is unrealistic. Also, because shielded cables and faraday cages are extensively used, and because the frequency range of emissions won't exceed 500MHz (excepting gigabit link drivers and receivers with limited radiated coverage), it can be stated that a system is subject to the radiated emissions it creates.

Therefore, measurements carried out on testbeams can be assimilated to system level radiated immunity tests. Emission measurements cannot be performed because of lack of appropriate anechoic chambers.

Still, for longer term, it will result extremely useful to *know* the electromagnetic environment of ATLAS, in particular for maintenance and upgrade of the systems, and for future experiments. For this, an electromagnetic survey will be carried out at fixed places in the cavern, with monopole and dipole antennas.

3.11. Emissions of harmonic current.

The harmonics in the load current drawn from the mains is a source of disturbance for the electrical distribution network and for other users:

- Harmonics currents cause an excess of losses (heat) in the transformers, reducing their lifetime. The transformers installed in the experimental area are not derated to cope with high level of harmonics, and therefore the harmonic current emissions must be controlled.
- Harmonic currents cause voltage distortion on the electrical lines, which in turn can be at the origin of reduced lifetime or malfunctions of other user equipment connected to the same network. To avoid nuisances to neighbouring equipment, all users equipment must limit the emissions of harmonic current on the mains.
- Harmonic currents are a source of interferences at low frequency, that should be avoided in experimental areas. Below 2kHz linear regulators must be used to filter away the induced noise.

For these reasons, the control over harmonic current emissions is required [22] and user equipment shall comply with harmonic emissions standards:

- EN-61000-3-2: Limits for harmonic current emissions for equipment whose input current is less than 16A.
- EN-61000-3-4: Limits for harmonic current emissions for equipment whose input current is greater than 16A.

The limits are specified as absolute RMS currents for harmonics up to order 40.

3.12. Power Factor.

The power factor is defined as the ratio of the measured active input power to the product of the supply voltage (r.m.s.) and the supply current (r.m.s.). The ATLAS electrical distribution network is rated for:

- Power factor greater than 85%.

Active power factor correction shall be implemented within the user equipment if the above limit cannot be achieved y use of passive filters.

3.13. Voltage transients.

The ATLAS electrical distribution network is designed in compliance with EN-61000-2-4. User equipment shall be protected to cope with voltage transients in the power distribution system mainly caused by mains faults, lightning strikes, switching of power devices, inrush currents and external dropouts [22]:

- Peak mains surges: 1200 Volts for 200 µs.
- Mains overvoltage: 50% of U_N for 10 ms.
- Voltage drops: 50% of U_N for 100 ms.

4. References

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LHC-EM-ES-0001 rev 2.0.
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Annex 1: Systems.

1. Pixel detector.
2. Semiconductor Tracker (SCT).
3. Transition Radiation Tracker (TRT)
4. Central Solenoid.
5. Endcap Toroid.
6. Barrel Toroid.
7. Liquid Argon Barrel Calorimeter.
8. Liquid Argon Endcap Calorimeters.
9. Tile Calorimeter.
10. Muon Drift Tube Chambers.
11. Cathode Strip Chambers.
12. Resistive Plate Chambers.
13. Thin Gap Chambers.

5. Annex 2. About international standards.

Equipment purchased within the EU shall be compliant to some of the following standards depending on the type of equipment (non exhaustive list).

EN 50081-2	Electromagnetic Compatibility – Generic emissions standard - Part 2: industrial environment. (superseeded by EN 61000-6-2).
EN 50082-2	Electromagnetic Compatibility – Generic immunity standard - Part 2: industrial environment (superseeded by EN 61000-6-4).
EN 55011	Industrial, scientific and medical (ISM) radio-frequency equipment - Radio disturbance characteristics - Limits and methods of measurement.
EN 55022	Information technology equipment – Radio disturbance characteristics - Limits and methods of measurement.
EN 61000-2-4	Electromagnetic compatibility (EMC) -- Part 2-4: Environment - Compatibility levels in industrial plants for low-frequency conducted disturbances.
EN 61000-3-2	Electromagnetic compatibility (EMC) -- Part 3-2: Limits - Limits for harmonic current emissions (equipment input current up to and including 16 A per phase)
EN 61000-3-4	Electromagnetic compatibility (EMC) -- Part 3-4: Limits - Limits for harmonic current emissions (equipment input current above 16 A per phase)
EN 61000-4-1	Electromagnetic compatibility (EMC) -- Part 4-1: Testing and measurement techniques - Overview of IEC 61000-4 series
EN 61000-4-3	Electromagnetic compatibility (EMC) -- Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
EN 61000-4-6	Electromagnetic compatibility (EMC) -- Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
EN 61000-6-2	Electromagnetic compatibility (EMC) -- Part 6-2: Generic standards - Immunity for industrial environments
EN 61000-6-4	Electromagnetic compatibility (EMC) -- Part 6-4: Generic standards - Emission standard for industrial environments
EN 60950	Safety of information technology equipment
NF C 15-100	Low voltage french standard.

The standards are available on the CERN Library.