Overview of the ATLAS Electromagnetic Compatibility Policy

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Abstract

The electromagnetic compatibility of ATLAS electronic equipments must be insured to achieve the required 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.

I. THE ATLAS EMC POLICY

A. Scope of the Policy

The ATLAS electromagnetic compatibility (EMC) policy [1] addresses the compliance to CERN electrical safety rules, the immunity against conducted and radiated emissions present in the experimental area, and the control of those emissions for each system of the experiment.

The electromagnetic compatibility is a quality issue that aims the proper operation of a system in a given environment. It is also a risk management tool to identify potential problems and to provide preventive and corrective solutions as appropriate.

B. Implementation

The EMC policy is based on three procedures, applied to each system of the experiment, that target the approval and documentation of the systems from a safety, compatibility and maintenance points of view.

First, the electrical safety is addressed in a document that describes the grounding scheme, the power distribution and the compliance of equipment to the CERN safety rules (Table 1) [2,3].

Then, the electromagnetic compatibility of the system is addressed by parameters that define the working condition limits. Specific emission and immunity measurements are carried out following the procedures defined in the policy (Table 2).

At last, the commissioning phase of each system is checked for compliance to the safety rules and to the established working limits.

Table 1: System Installation Report

- Identification of EMC contact persons.
- Description of equipments, parts and components.
- Identification of CE marked equipment.
- Identification of non CE marked and custom made equipment to be approved by the safety Commission.
- Description of interconnection of equipments, including the grounding scheme.
- Description of fault conditions and protection devices.
- Identification of the routing paths for the cables.

Table 2: EMC Report

- Definition of the noise parameters and the working limits associated to it.
- Identification of key parameters such as operating frequency and bandwidth, thresholds, cable lengths and properties, power supplies topologies, codifications.
- Measurements of conducted noise in power supply cables.
- Measurement of susceptibility to common mode noise.

II. ELECTRICAL SAFETY

The electrical safety aspects that are addressed by the policy are the compliance of equipment and installations with the AC and DC power distribution schemes and with the use of adequate protection devices.

The AC power is distributed with a separated protective earth conductor in a so called TN-S configuration (figure 1) [4]. This configuration requires overcurrent protection devices or ground fault interruptors.

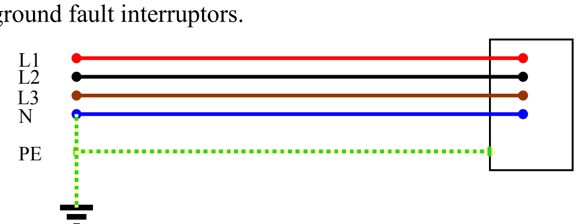

Figure 1: AC power distribution scheme.

The DC power is distributed with a protective earth conductor that is either separated from the return conductor or common with it to allow for proper safety grounding of the faraday cages of some detectors (figure 2-a,b,c). These configurations, known as TN-S and TN-C [4], require overcurrent protection devices.

A floating DC power distribution scheme, know as IT [4], is allowed for critical systems such as magnets (figure 2-d). This configuration requires a permanent isolation controller to detect the first ground fault, and an overcurrent protection device.

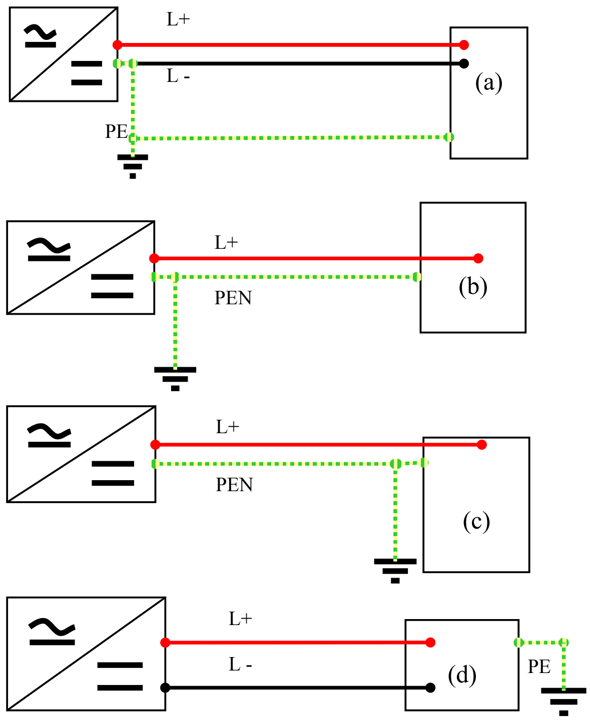

Figure 2: DC power distribution schemes, TN-S (a), TN-C (b,c) and IT (d).

The metallic structures, faraday cages and other systems in the experimental area are all grounded to the protective earth (PE) [5,6,7]. The meshed ground formed in this way defines an equipotential network that provides a return path for the common mode currents and prevents them from entering sensitive front end electronics systems.

III. Electromagnetic Compatibility

1) Electromagnetic environment.

The electromagnetic environment in the cavern is contributed by the experiment itself. By means of system reviews and measurements, the policy maps the conducted and radiated noise environment.

The use of faraday cages and shielded enclosures in the ATLAS systems allows to control the radiated emissions from the front end electronic boards. The use of long cables to connect the front end boards to the power supplies and other equipments at remote locations are identified as the major source of near field and far field radiated noise.

The electromagnetic far field produced by an electrically short section of cable pair is mostly contributed by the common mode current [9,10] because the fields induced by differential mode currents are oppositely directed while the fields induced by common mode currents just add up (figure 3). In ATLAS, all cables are electrically long and must be modeled as multiconductor transmission lines (MTL). The common mode current and its surrounding field propagates at a given velocity along the cable. The far fields attenuate at a rate of 1/d with a constant ratio E/H of 377 Ω.

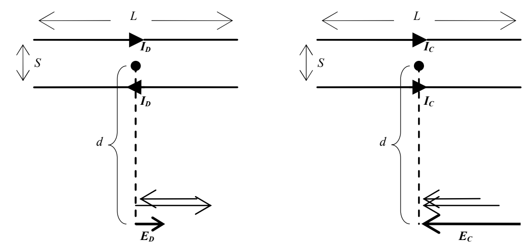

Figure 3: far fields induced by DM currents tend to cancel (left) while those induced by CM currents add up.

Given the high density cabling of ATLAS and the confinement of cables inside well defined trays and routing paths, the dominant coupling takes places between cables in the near field region inside the tray. Electromagnetic interferences in the near field region can be electric (high impedance field) or magnetic (low impedance field) and are defined by the wave impedance E/H. Current transients in power supply cables are mainly magnetic sources of interferences, and the coupling is due to mutual inductance. Voltage transients in digital links are mainly electrical sources of interferences, and the coupling is to stray capacitances. The electromagnetic environment of the ATLAS systems is therefore simplified to the near field interferences along these cable trays, that are mainly contributed by the common mode noise carried by the cables that they contain. The dominant component of the near field attenuates at a rate of $1/d^3$.

The power supplies and DC/DC converters, the feeding of frequency variators for pumps and motors and the digital copper links (fieldbuses) are identified as the major sources of interferences and common mode current. The main frequency range of those interferences sits below 40 MHz. Other sources of radiated interferences exist at upper frequencies (figure 4).

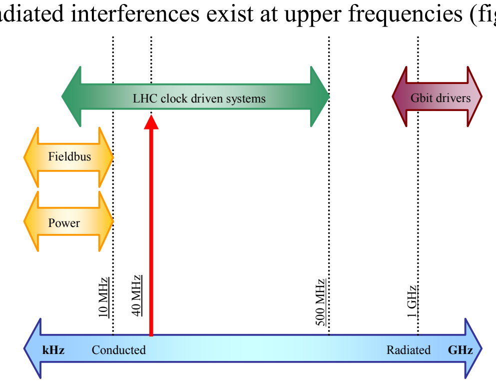

Figure 4: EMC environment of ATLAS.

The front end analogue electronics has a bandwidth that is usually lower than 20 MHz and is sensitive to interferences in this range, mostly coupled to cables in form of common mode current. Above 40 MHz, interferences are mostly radiated; systems sensitive in this range are protected from the radiated interferences by the grounded enclosures where they sit.

The frequency range of interest in the ATLAS EMC Policy is comprised between 10 kHz and 500 MHz, which includes the 40 MHz LHC clock and its harmonics. The measurements are focused on the conducted noise in long cables, caused by the near field electromagnetic pickup in the above mentioned frequency range, and because it is the dominant source of electromagnetic interferences in the experimental area.

C. A model for CM currents propagation.

A model for the common mode current path in the ATLAS systems is shown in figure 6 The impedance of the ground connections and of the stray capacitances are the key parameters to address the EMI problems due to CM currents [5,7,8,9,10]:

- Long copper cables are modeled as multiconductor transmission lines (MTL).
- Ground straps are modeled as inductors of straight wire in free space, with typical inductances of 1 µH/m [9,10].
- Faraday cages and grounded systems are linked together through stray capacitances. For large surfaces, the typical capacitance is 0.9 nF per square meter separated 1cm away.
- The common mode current returns to its source through the least impedance ground network.

ATLAS is made from several large dimensions detectors that are electrically isolated between them (figure 5). These systems are usually located very close one of each other, and the interfaces between them are made on large surfaces. The detectors structures are grounded to the experimental area grounding network through ground cables. At high frequencies, these connections are bypassed by the stray capacitances between detectors.

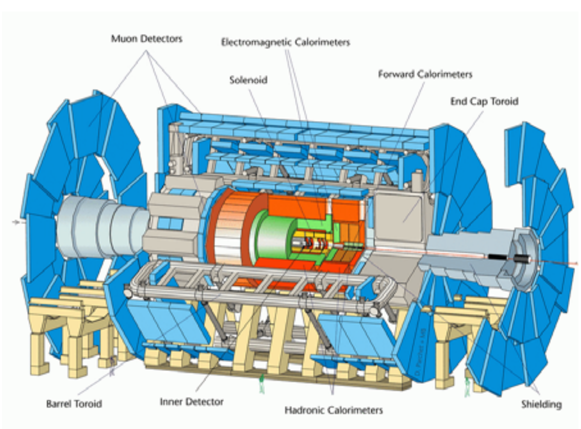

Figure 5: The ATLAS detector.

The systems will effectively stay at a potential with respect to ground that is a function of the entering CM current, of the input cable characteristic impedance, of the system load and of the frequency response of stray capacitances and ground inductances [11]. Resonant frequencies can show up under given conditions. Through stray capacitances, CM currents can couple to a neighbouring system and cause malfunctions. Typical parameters for the ATLAS systems are ground inductances greater than 10 µH and stray capacitances between systems greater than 10 nF.

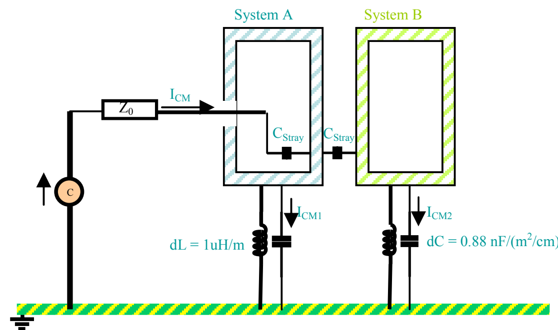

Figure 6: CM circuit model for large systems.

The systems must evaluate their immunity to common mode currents in a setup as similar as possible to the final one. The EMC Policy defines the measurement setup, methods and instruments to get consistent results. The improvement of the immunity can only be achieved by reducing the inductance of ground connections; it can also be achieved by proper shielding of cables (to reduce emissions and decrease the pick up) and by proper separation of noisy and low noise cables [5,9,10]. The stray capacitances cannot be reduced, as they are intrinsically linked to the mechanical implementation of the systems. For systems still in the design process, CM and DM filters can be installed at the entry point of the cables.

D. Compatibility limits.

The compatibility limit is defined as the maximum amount of noise that a system can tolerate to achieve the required level of performance. It must be defined for a complete system, that is with its power supply and DAQ system connected, under power and taking data.

The common mode currents degrade the noise performance of the systems. The correlation between CM current and system noise must be established, and the maximum amount of CM current that a system can sustain must be measured. The noise is defined in the measuring units that suits best each system, such as RMS voltage, current or charge pedestals, average or baseline hit rate. The compatibility limit can be expressed also in terms of data transmission error rate for communication links.

E. Installation and routing of cables.

The cables are installed inside grounded cable trays and share tens of meters inside of it. Depending on its geometry and construction, the cable tray provides some level of shielding and it allows to contain the electromagnetic interferences along a grounded path. Also, it provides a common mode return path along the cables, reducing this way the CM circuit loop and the associated emissions.

The coupling between cables mainly happens in the near field region in the form of induction and capacitive couplings. It 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 cables are grouped in terms of their sensitivity or contribution to electromagnetic interferences. The separation between power and data equipment and cables must be provided.

F. Shields.

The shields are effective against electric field couplings if grounded at least at one end; they are however of limited effect against magnetic induction coupling, which is particularly important in power circuits. The most effective technique to minimize induction couplings between cables is the *distance*, in particular for power circuits.

Still, the magnetic near field emitted by power cables can be reduced if a shield is provided for the common mode return current. For this, the shield must allow the current to flow back and must therefore be bonded to ground at both ends with a low inductance connection. The equal and opposed currents produce magnetic fields that cancel out, therefore reducing the emissions of the cable.

The shielding effectiveness depends of the shield geometry. The aluminium foil and the copper braid are the basic configurations used for the cables of ATLAS. The foil is the most basic configuration and works up to 1 MHz. The braid is mechanically stronger and works up to 10 MHz. In some places both shields are used, improving the effectiveness but not the frequency range.

IV. MEASUREMENTS METHODS AND INSTRUMENTS.

A. Measurement setup.

The correlation between CM current and system noise requires the measurement of both parameters on a setup that reflects the final configuration, including the power supplies, data acquisition systems, cables and other pieces of equipment required to operate the detector

. The observed system noise strongly depends on the path followed by the CM current. Therefore, the measurements shall be done either on the testbeam setups or in the experimental area,, with the cables laying inside the grounded trays. Measurements at other places or without grounded supports and trays require the addition of a ground plane floor.

B. Instrumentation.

The EMC measurements shall be carried out with appropriate instrumentation. The noise is recorded by an EMI receiver with standard input filters. The common mode current is measured with calibrated current probes. An injection probe and an RF generator are required for immunity tests.

C. Conducted noise measurement.

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 (figure 7).

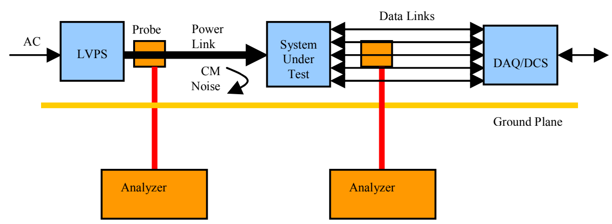

Figure 7: Conducted noise measurement setup.

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 line impedance stabilization network (LISN) to normalize the AC plug impedance and allow for reproducible measurements independently of the plug used.

D. Immunity tests.

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 (figure 8).

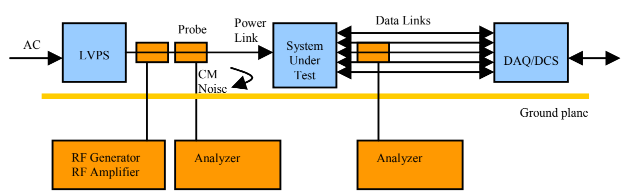

Figure 8: Immunity test setup.

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 continuous 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 sensitive 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 reproducible measurements independently of the plug used.

V. Conclusion

A policy was defined in the frame of the ATLAS Technical Coordination that establishes the methods and procedures to insure the systems electromagnetic compatibility in the experiment environment.

The electrical safety is addressed to insure conformity to safety rules, and to identify the power distribution and the grounding schemes.

The major noise sources are the common mode currents in electrically long copper links used by power equipment and digital links. The dominant coupling takes place between cables inside the trays in the near field region. Electrically long cables in ATLAS propagate magnetic or electric electromagnetic interferences as a function of the line impedance, its terminations and the noise source properties.

To achieve the best performance, shielded cables are required with at least one side grounded for effective protection against high impedance near field waves. Physical separation between noise sensitive cables and noisy cables must be provided, in particular with low impedance wave sources (power cables). Low impedance noise waves can be contained inside properly grounded shielded cables.

The compatibility limits must be defined for each system to evaluate in a consistent way the correlation between the observed physics noise and the common mode noise in the cables.

The common mode emission and immunity measurement methods and instrumentation are defined to achieve reproducible results. Setups on the testbeam areas and in the experimental area are defined for valid measurements. The systems must characterise their immunity to common mode currents and must measure the amount of emitted noise in their cables.

VI. References

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