Performance of a Remote High Voltage Power Supply for the Phase II Upgrade of the ATLAS Tile Calorimeter

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ABSTRACT: The experience gained in the operation of the present High Voltage system of the Tile calorimeter in the ATLAS detector and the new HL-LHC constraints, in particular the increase of the radiation, lead to the proposal of changing the currently embedded regulation system to be a remote system in the counting room, by adding easily new functionalities. The system described in this note is using the same regulation scheme as the current one and distributes the individual High Voltage settings with 100 m long multi-conductor cables. The tests show that it reaches the same good performance in terms of regulation stability and noise, while allowing a permanent access to the electronics.

KEYWORDS: ATLAS, Tile Calorimeter, LHC Upgrade Phase II, Remote HV.

Contents

1. Introduction	1
2. Review of the present TileCal scheme and performance	2
3. HV specifications for the Phase II upgrade	2
4. Design of the remote HV system and performance	3
5. Conclusion and next steps	7

1. Introduction

The current HV power supply of the Tile Calorimeter (TileCal) of the ATLAS detector [1,2] must supply 9852 photomultipliers (8-stage Hamamatsu PMTs) by adjusting individually the HV of each PMT. It is made of two parts: an embedded system for the individual regulation of the voltages and an external HV source which supplies the regulation electronics. The embedded electronics was designed in order to fit both the requested performance of the voltage stability of every channel (better than 0.5 V) and the radiation tolerance of electronic components in the LHC context. Its use during the Run 1 LHC fits very well the required specifications.

The Phase II upgrade of TileCal sets new constraints on the number of channels per card and on the radiation environment. Besides, much was learned from the operation of the present system during Run 1 LHC that can be incorporated in the design system for Phase II.

2. Review of the present TileCal scheme and performance

In the present HV system supplying the Tilecal PMTs, the HV regulation system is located inside mechanical supports (called Drawers) that host the front end electronics. It is accessible only when the detector is open while its DCS (Detector Control System) is fully controlled by an external system. The Drawers are configured in pairs as Super-Drawers; the HV distributors are made of 5 types of components as shown in Figure 1.

Figure 1: Location of the HV cards in a Super-Drawer.

These HV boards are:

- One HV Opto card per Drawer which provides the individual regulation of 24 channels.
- One HV Micro card which manages the two HV Opto cards of a Super-Drawer and hosts a micro-controller Motorola MC68376.
- Two long and stiff HV Bus cards which support the HV Opto cards and the HV Micro card, and which distribute the adjusted voltages to the PMTs. The external and internal cards are different.
- A short flexible HV Bus card which links the external and the internal HV Bus cards.

Connectors provide the High and Low Voltages on the external HV Bus card. The common HV source is located in the counting room, while the required Low Voltages are provided by electronics bricks embedded inside the TileCal Modules. CANbus is the standard protocol for DCS communication, compatible with the micro-controller interface.

The key point of the electronics scheme is the HV regulation loop (Figure 2) the main element of which is the high voltage opto-coupler.

Figure 2: Part of the electronics scheme of the current HV regulation loop.

Intensive radiation tests (NIEL, TID and SEE) lead to this scheme with 2 transistors from each side of the opto-couplers in order to balance the radiation induced gain loss of the opto-coupler transistor.

There is one regulation loop per channel. In a given channel, the opto-coupler ensures a high voltage output in the range ($HV_{in} - 360 \text{ V}$, HV_{in}), where HV_{in} is the voltage delivered by the external HV source, common to the 48 channels (maximum) of a Super-Drawer. The uncertainty on this range is $\pm 24 \text{ V}$.

From the LHC run 1 data, the mean HV stability over all the channels is close to 100 mV (for a mean applied HV of 690 V), with only 0.6% of problematic HV channels.

3. HV specifications for the Phase II upgrade

The HV specifications for the Phase-II upgrade are based on the specifications of the current detector. Additional refinements are suggested by the experience gained during the TileCal operation and from the new constraints coming from the upgraded design and the harsher environment of HL-LHC. New constraints are coming from the decision of making independent Mini-Drawers (one Mini-Drawer is half-long a current Drawer) which has a double impact:

- A grouping of 12 channels maximum per Mini-Drawer, instead of 24 for present Drawers.

- The electronics independency of Mini-Drawers inside their mechanical association inside a Super-Drawer will increase the working reliability.

Besides, the passive Dividers that share the voltages in between the photocathode, the 8 dynodes and the anode of the PMTs are replaced by active Dividers (shown in Figure 3) in which transistors (and diodes) equip the last 3 stages.

Figure 3: Active Dividers.

In case of a short-circuit somewhere in the Super-Drawer, it is proposed to have the possibility to switch off every channel individually. Depending on the types of components, on their locations in the most irradiated position and on the considered radiation, the ATLAS Radiation Policy sets bigger constraints on the radiation tolerances, even though Safety Factors were relaxed on the Monte Carlo simulations of the radiation levels. The serviceability of the HV system can be affected by both the HV system itself and external systems which supply or control it, like the HV source, the LV Power Supplies and the DCS. Other constraints could also affect the operation, such as the humidity level, the cleanliness of the environment, the stray magnetic field, the protection of the electronics and bad manipulations. The ultimate goal is to build a fully reliable system that meets the performance requirements of the experiment. Obviously, the cost of the whole HV system is an important parameter in its design and in its making that prevents the choice of too expensive commercial products.

Two options are developed within the Tile Calorimeter system: an evolution of the current embedded design by the ANL Argonne team and the remote system by the LPC Clermont-Ferrand team.

4. Design of the remote HV system and performance

It is proposed to have a remote HV system located in the electronics room. Therefore the radiation hardness of the electronic components is not a concern anymore and there is a permanent access to the HV regulation electronics. The electronics will be similar to the current one, with four main modifications:

- The individual regulation of channels is no longer embedded but implemented in dedicated crates in the counting room.

- The individual adjusted voltages are distributed by multi-conductor cables, with one cable per Mini-Drawer. These cables are about 100 m long to reach the ATLAS cavern.
- The HV distribution to the PMTs is made through passive HV Bus cards equipped only with the “noise killers” which suppress some grounding loop effects coming from the readout electronics. The noise killers are made of one $k\Omega$ resistor on each individual HV power and return line.
- The regulation loop is revised.

The lay out of the system and a photo of the crate prototype are shown on Figure 4 (Top and bottom.)

Figure 4: Top) Lay-out of the remote HV system, Bottom) regulation crate.

In this R&D study, the HV crate hosts the present HV Opto and HV Micro cards, as described in Section 2. Additional base boards support these cards and distribute properly the voltages to the channels: 1-12 for HV Bus 1, 13-24 for HV Bus 2, 25-36 for HV Bus 3 and 37-48 for HV Bus 4.

There is a base board per every HV Opto card and another one for every two HV Micro cards. These base boards do not exist in the current TileCal HV system.

The Low Voltage Power Supplies are in the rear part of the crate, whereas the CANbus link and the long multi-conductor cables are connected to the front part. The common HV Power Supply (not yet inside the crate) is the usual TileCal HV source system.

Figure 4 (bottom) shows the HV regulation crate of a single Super-Drawer made of 4 Mini-Drawers, but in fact this crate can host the electronics for 4 Super-Drawers. The HV Bus cards are made of 4-layer printed circuits. The external layers act as shielding over their whole area, the internal layers distribute the HVs through the noise killers. Every HV Bus card has 12

channels. Figure 5 shows this card with the connections to the PMTs, the noise killers and the cable tray which hosts the internal multi-conductor cable.

Figure 5: HV Bus board on a Mini-Drawer. Figure 6: HV connectors outside the detector.

In our tests, the individual HVs are distributed by multi-conductor screened cables with twisted pairs, available in the CERN Stores catalog. Twelve twisted pairs, with 0.6 mm diameter conductors, are screened by a tinned copper braid, itself covered by a blue poly-olefin sheath. Their external diameter is of 1.12 cm. There is one twisted pair per HV channel. HV connectors connect each long cable multi-conductor cable to its internal multi-conductor cable supplying the corresponding Mini-Drawer (Figure 6). These connections are made outside the Detector.

The most significant aspect in validating the performance of this new remote HV system is the regulation of the control loop while maintaining low noise operation.

As said above, the PMTs will use active voltage Dividers with transistors. It is expected that the association of the Divider transistors with the long cables will increase the HV noise and this effect would be enhanced if the regulation loops has the current scheme with 2 transistors per loop. For these reasons, systematics tests were made by comparing many set-ups, leading to a regulation scheme without these transistors, as shown on Figure 7.

Figure 7: Regulation loop for the proposed Phase II upgrade

Intensive tests were performed at LPC Clermont-Ferrand and at CERN. Figures 8 and 9 show the set-up at CERN in the building 175 where the Drawers were operated outside and inside the dedicated black box.

Figure 8: CERN set-up in the open space.

Figure 9: CERN set-up in the black box with PMTs and a complete readout.

The main results are:

- The HV noise at the PMT input is always lower than 2.5 mV for a voltage of 700 V. Its relative variation with respect to the applied HV is practically constant, at a level of $2.6\text{-}2.7 \cdot 10^{-6}$, within the allowed HV range of 300 V (see Figure 10).
- The impact of the HV noise at the readout level (ADC output downstream the PMT) has been measured from pedestal data taken without and with applied HV: it is negligible, within the ADC data uncertainties, as shown in Figure 11.
- The HV regulation stability at the PMT level during run durations of at least 13 hours is better than 90 mV, as shown in Figure 12.

Figure 10: Noise variation with respect to the applied HV.

Figure 11: HV Noise contribution to the readout noise for the low and high readout gains (Negative values mean that the noise with HV off can be measured as being higher than measured with HV on, giving an estimate of the systematics).

Figure 12: HV stability during a 13 hours long run at CERN.

5. Conclusion and next steps

The proposed HV remote system fulfills all the specifications of the Phase II upgrade, in terms of noise and regulation stability. Being permanently accessible in the ATLAS electronics room, it offers a full working reliability, in a zone without radiation and other possible disturbing conditions (Magnetic field, humidity, etc.). In the next evolution of the regulation crate, it is proposed to put one passive jumper on every HV channel output and to improve the overall organization of the remote crate (Regulation loops, Low and High Voltages, slow control). Obviously, it will be not useful to have base boards as it is in the crate prototype. The final choice of the long multi-conductor HV cables must be performed and their routing from the electronics room to the detector must be studied. Performance in the ATLAS test beam in 2015 and 2016 will be analyzed in order to take a final decision for the Phase II upgrade.

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Reference

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