The development of test stations for the ATLAS Tile Calorimeter Low Voltage Power Supplies

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Abstract. This paper describes the development of test stations at the University of the Witwatersrand for the ATLAS Tile Calorimeter Low Voltage Power Supplies (LVPS) of the Large Hadron Collider (LHC). As part of the phase II cycle, South Africa will produce and test, half of the LVPS bricks that will power up the front-end electronics of the detector. We describe procedures and parameters used to verify the functionality of the LVPS bricks using the Test and Burn-in stations. The upgraded LVPS bricks have improved reliability, reduced noise which reduces the trips due increase in luminosity. The Test station is functional, while the Burn-in station development still in progress.

1. Introduction

The expected elevated radiation from higher luminosity of a factor of five on the Large Hadron Collider (LHC) [1] and the reduction of the lifespan of the current electronics in the detectors indicates that all electronics of the Hadronic Tile Calorimeter (TileCal) must be upgraded as part of the Phase II upgrade cycle [3]. The TileCal [2] of the ATLAS experiment [3] is designed to measure the energy and time of arrival of hadronic jets and isolated single hadrons that are produced in the detector from proton-proton collisions at the LHC CERN. The calorimeter is constructed from long wedge-shaped modules, as shown in figure 1. Each module is composed of alternating layers of steel absorber and scintillating tiles as the active media. Light produced in the scintillators is routed to photo-multiplier tubes (PMTs) using wavelength-shifting fibers. The PMTs reside in the outer section of each module called drawers as shown in the lower part of figure 1, which also contain the front-end electronics, digitizers, and read-out electronics. Generally, there are 45 PMTs in each drawer, although the number varies depending on location. The power supplies that provide power for the drawer electronics are mounted at the end of the drawer, as shown in figure 1. The TileCal is designed as a 6-m-long barrel section with each mechanical module containing two electronics drawers, and two 3-m-long extended barrel sections with each module containing one electronics drawer. Each section contains 64 independent modules in azimuth, for a total of 256 electronics drawers. The drawer electronics are powered by full-custom switching power supplies, called the Finger Low Voltage Power Supply (fLVPS or LVPS).

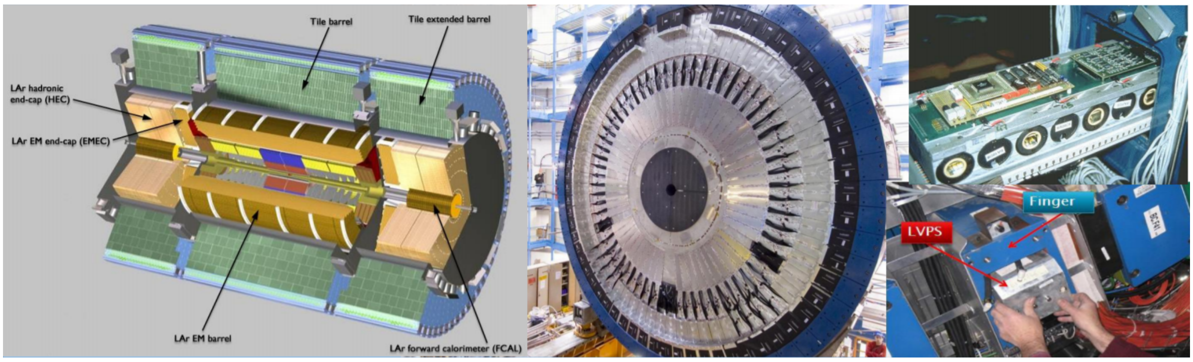

Figure 1. Shows the cross sectional view of the TileCal, modules, electronic drawer and the fLVPS [5].

1.1. Readout Architecture

Replacement of the readout electronics is mandatory because the current readout architecture is not compatible with the new fully digital Trigger/DAQ (Data AcQuistion) system of ATLAS. Figure 2 shows the upgraded readout architecture which will be suitable to sustain the higher trigger rate (> 1 MHz) and the larger event buffer (latency $> 10\mu s$). Some main guidelines were adopted: move buffers and pipelines off detector, read out data at 40 MHz (LHC bunch-crossings frequency), and improve reliability through redundancy to limit the impact of component failures. A total of 9852 PMTs are used to readout the TileCal cells. The PMT signals are amplified, shaped, and digitized at 40 Msps (Mega Samples Per Second) using a clock synchronous with the LHC beam crossing. The analogue signals are converted to digital signals using the Analogue Digital Converter (ADC) on the main board (MB). The digitized data are sent to a Daughter Board (DB). The MB also provides the control of the High Voltage. The DB synchronizes the digitized data and sends them to the Pre-Processor (PPr) via optical links [6].

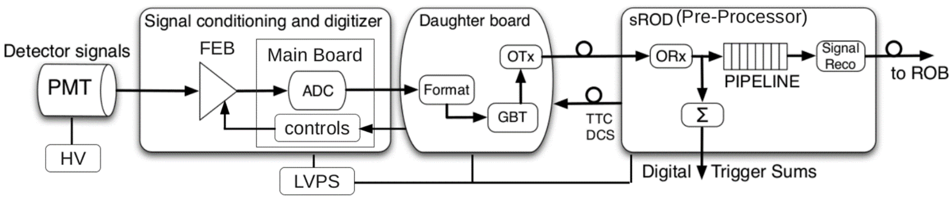

Figure 2. Block diagram of the TileCal readout architecture at the HL−LHC [7].

2. Low Voltage Power Supply for the TileCal

The power supply bricks that were installed on the detector functioned well up until there was a rise in the luminosity, the system showed sensitivity to trips at a rate that

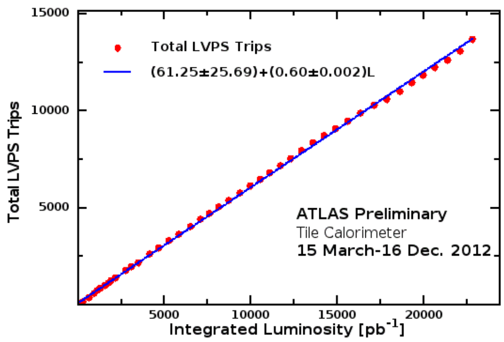

Figure 3. Number of power supply trips observed versus delivered luminosity [8].

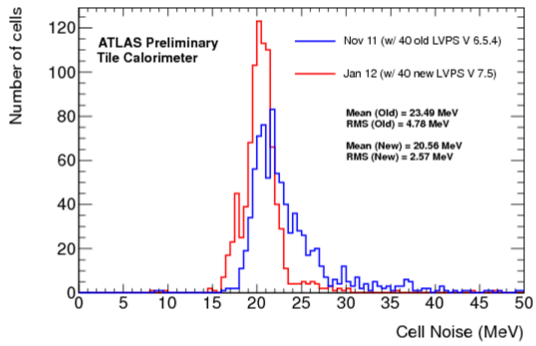

Figure 4. RMS of the electronic noise for all cells noise in relation to the LVPS bricks [9].

scales with the luminosity of the beam. A plot of the observed trips versus luminosity during 7.5 months of operation in 2011 is shown in figure 3. In these cases, an individual LVPS box trips off, it's then restarted after a period of 2 minutes. Most often the recovery is automatic through software control, but sometimes the recovery required human intervention. These trips are usually not debilitating, but do cause a loss of data from that particular module for several minutes. Also, a great deal has been learned about the low-voltage power system and the performance of the bricks, and we will take this opportunity to implement other improvements to the design. From figure 4, it clearly shows that there is a significant decrease in the RMS noise cells on the new LVPS bricks compared to its predecessor.

3. LVPS Production testing

As part of the Phase II upgrade, South Africa is responsible for producing and testing half of the LVPS bricks, which will power the ATLAS detector electronics. For a prototype of LVPS bricks see figure 5 - produced in South Africa and tested, where small issues were encountered and resolved for the next production phase. LVPS system consists of eight identical power supply (bricks). The combination of the harsh operating environment (radiation hardness) and the high reliability necessitated the custom design of a switching power supply. Because of the environment in which LVPS is located in, LVPS must remain radiation hardened to single-event upsets and total dose accumulated over several years. LVPS also contains custom designed magnetic components to operate reliably within the magnetic field of ATLAS. The LVPS bricks which step down 200 V to 10 V to power all the detector electronics are nominally rated at 100 W each. Additional control circuitry (with a quick response time) has been synthesized outside of the main controller to shut down the brick in any event of over current, over voltage or temperature.

3.1. Testing Station

The test station in figure 5 is controlled by a custom-based computer software (LabVIEW) figure 6, which controls and performs readout of certain parameters to

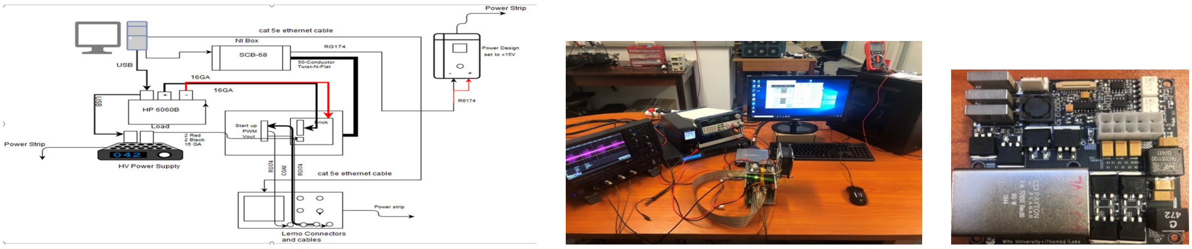

Figure 5. Functional block diagram of the LVPS test station (left), Test station setup at Wits (middle), and LVPS prototype manufactured in South Africa (right).

accomplish tests. The station consists of a high voltage power supply, oscilloscope, electronic load and personal computer. The only custom component is a metal case that acts as brick support and administers the interface to the computer and the ground connections. The data is acquired primarily through a data acquisition card connected to the computer using a Peripheral Component Interconnect interface. A few noticeable metrics which we are measuring are the system clock and its jitter. A presence of clock in LVPS can alter system stability and scale down the functioning domain of the system duty cycle. The stations authenticates the protection circuitry of the LVPS brick shield in contrast to over voltage, temperature and current. A testing program procedure is in place, which provides us a guideline to examine the functionality of an LVPS brick. In all there are 11 tests that each brick has to pass in order to be deemed good enough to passed to another testing station (burn-in). The figure 6 shows a testing program developed using the graphical programme framework called LabVIEW. The following list shows the tests that need to carried out:

- Minimum Stable Current
- Minimum Output Voltage
- Output Over Voltage Trip Point (validates fail safe features of the Bricks.)
- Output Over Current Trip Point (validates fail safe features of the Bricks)
- Output Analysis (more metrics)
- Start-up Verification (turn-on delay)
- output Voltage / Voltage input monitor vs Trim (feedback signal: slope, offset, linearity)
- output Voltage / Current input monitor vs Load (feedback signal: slope, offset, linearity)
- Input Voltage Monitor (Validates feedback signals used for remote monitor)
- Input Current Monitor (Validates feedback signals used for remote monitor)
- Temperature Measure

3.2. Burn-in Station

During the burn-in process, components are exposed to harsh settings whereby both temperature and load are high. These settings stress the electronics under test and

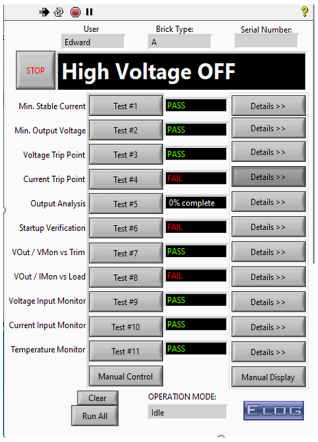

Figure 6. LabVIEW testing program framework for the test station.

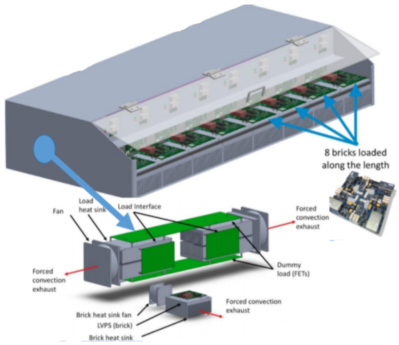

Figure 7. Burn-in Station and its components.

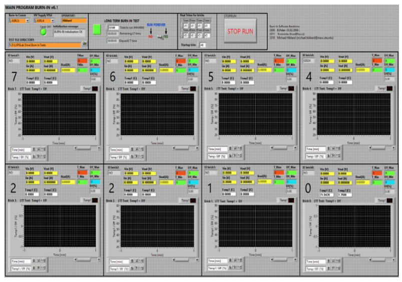

Figure 8. Front graphical panel of the LabView program for burn-in station.

causes components that would fail prematurely, to deteriorate rapidly during the duration of this test before they can be manufactured and installed on the TileCal, where there is limited space to access them if they fail during the operation of the detector. The previous Burn-in station used a cooling circuit, to lower the temperature of the bricks by reducing capacity from the load of eight bricks. With the new model, the electronic load uses a forced-convection cooling mechanism to maintain temperature of the bricks compared to the previous model which used a water circuit. Also in this new model, each brick has its own heat sink, that's forced-convection cooled to regulate temperature independently for each brick.

Duration	8 hours
Temperature	$60°C$
Brick load	$100\ W/10.5\ A$, nominal is $2.5\ A$
Start-up Cycles	30+

Table 1. LVPS Brick Burn-in operating parameters.

The burn-in station in figure 7 and 8 consists of a desktop PC with software that controls eleven compartmentalized microprocessors placed within the burn-in station. A LabVIEW software program [4] is used to control and do the test on the LVPS bricks.

The high voltage power supply will power up the burn-in station populated with eight bricks with 1kW while supplying 200 V voltage across all the bricks. The high voltage power supply is controlled by the LabVIEW software using a VISA communication link over Ethernet. The infant mortality stage will be used to detect early failures on the components and this needs to be done in a timely manner. It's ideal to conduct the test above $40°C$, and marginally below the lowest maximum temperature of any device on the brick, which is assumed to be $60°C$. The parameters in table 1 will be implemented to test the bricks on the burn-in station and the following measurements are used to indicate the behaviour of the bricks: temperature, efficiency, input and output voltages and current.

4. Summary

The TileCal Phase II upgrade design is well advanced and a prototype for the LVPS has been tested and it shows improved reliability and reduced noise levels compared to the previous design. The prototypes manufactured in South Africa have been tested using the developed Test station situated at Electronics Lab, University of the Witwatersrand. The development of the Burn-in station will commence shortly after all the technical details are finalised. This station will play a vital role when South Africa go to a mass production of LVPS bricks in 2021.

5. References

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