Low Voltage Power Supply production, hardware upgrade and testing for the ATLAS TileCal Front-End Electronics system

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Abstract. The large-scale production of the LVPS bricks will involve the complete replacement of all power supply "bricks" in the TileCal (Tile Calorimeter) front-end electronics for the LHC-HL upgrade. A total of 1024 LV bricks (half needed for the entire detector) will be produced by the University of the Witwatersrand. Such an operation comprises of several steps which include the development of two new custom quality assurance test stations. The initial test station will quantify a multitude of performance metrics of a LVPS brick, whereas the Burn-In test station would perform an endurance type test and subject the LVPS brick to a stressed environment. Both these custom test stations ensure the reliability and quality of a new LVPS which will power the next generation of the upgraded hardware system of ATLAS at CERN.

1. Introduction

At the European Laboratory, CERN, the ATLAS detector is a general-purpose proton-to-proton collider designed to exploit the full discovery potential of the Large Hadron Collider (LHC) [1]. The Tile Calorimeter is the hadronic calorimeter of the ATLAS detector, based on an iron scintillator and provides coverage in the central rapidity region ($|\eta| < 1.7$) behind the electromagnetic calorimeter [2]. The Tile Calorimeter 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 a super-drawer. Each section contains 64 independent modules for a total of 256 electronics drawers. The electronics of the super-drawers are powered by a switch-mode power supply and referred to as a Low Voltage Power Supply (LVPS) [3]. Eight LVPSs are mounted inside an aluminium box to supply power to a super-drawer. The LVPS box provides stable power to the front-end electronics of the super-drawer and interfaces with a Distributed Control System (DCS) for remote monitoring and control [3].

2. Overview of the Tile Calorimeter readout system

The LVPS system supplies power to all the front-end electronics of the ATLAS TileCal and

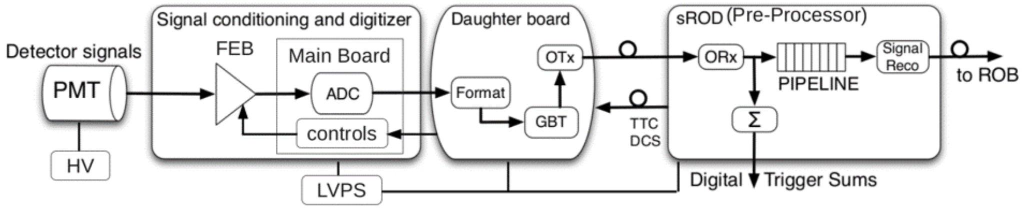
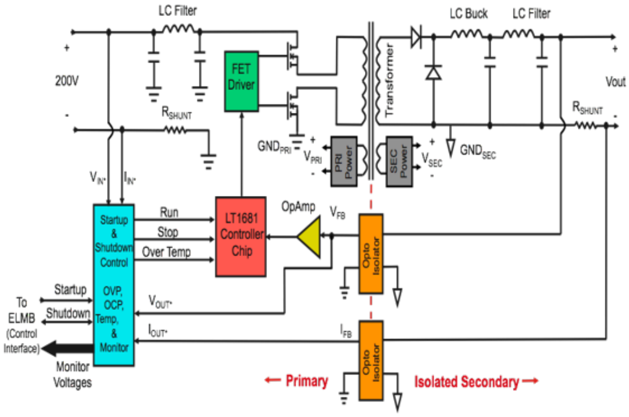


Figure 1: Upgraded TileCal readout architecture [2].

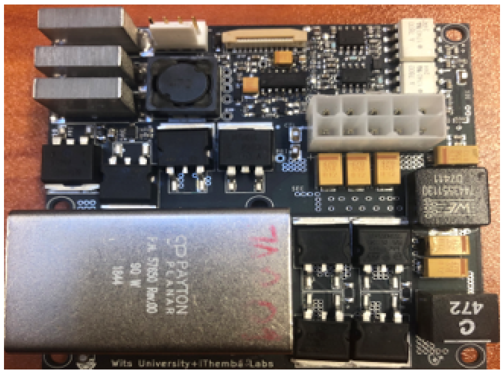
provides feedback through a monitoring system. The power for each super-drawer is supplied by one LVPS box which powers up to four mini-drawers of one module of the TileCal. Modules of the long barrel have 4 mini-drawers powered from the LVPS box, and modules of the extended barrel have 3 minidrawers powered from the LVPS box. In total, there are 256 LVPS boxes in the TileCal, which consists of eight or six individual power supply boards called bricks (for boxes located in long barrel and extended barrel, respectively), a fuse board, and a monitoring/control board [4]. The fuse board has filtering elements for the 200 V DC line and individual fuses for the individual bricks [5]. There is also a cold plate that runs laterally through the middle of the LVPS box to provide water-cooling for the bricks. Compared to the design used in the initial TileCal, the Phase-II design is different in two important ways (see Figure 1). Each LVPS box will consist of eight bricks supplying 10 VDC through a step-down transformer that needs a forward converter and buck regulator with negative feedback control.
The main boards and daughterboards have two independent sides and a left right symmetry so that in case of the failure of the electronics on one side, the other side is still operational. Each side is served by a separate brick. Each calorimeter cell is read out by two photo-multiplier tubes (PMTs) [5] and both PMTs are connected to the two opposite sides of the front end electronics. Therefore, in case of loss of one side of the front end electronics or brick, the other side is still active and the calorimeter cell is still read out by one PMT. A second redundancy is envisioned in case one brick fails. With the help of fast fuses and diode-OR circuit located on the main board the role of a failing brick can be taken over by the brick serving the other left/right side. In this situation the remaining brick sees its load increase from 3 A to 6 A. For this reason, the bricks are required to be able to deliver 3 to 6 A. The LVPS box specifications contain additional fail-safe and redundancy electronics to still provide power if certain bricks fail.

3. Detailed Functional Description and Specification

The brick Printed Circuit Board (PCB) is a 6 layer board with dimensions of 80.26 mm by 80.26 mm and has mounting holes for attachment to the cooling plate inside the LVPS box. A shielded transformer is produced by PAYTON following our custom specifications. The transformer is used to step down an alternating high voltage produced from the forward controller depicted in Figure 2a to a lower an alternating voltage for DC-DC regulation. Ceramic cylinders made from Aluminium Nitride, called thermal posts, are used to transfer heat from brick components to the cooling plate. The metallized cylinders have one metallized face, which will be in contact with the pad of the switches and diodes on the PCB. A 4 pin connector is used to receive the 200 V DC from the fuse board, with two pins for +200 V and two pins for return. There is a 10 pin output connector to deliver the 10V output of the brick to the Harting connector on the LVPS box. (see Figure 2b). The is also a small 20 pin connector, which connects the brick to the Embedded Local Monitor Board (ELMB) motherboard with a ribbon cable. This connector is used to receive the control signals from the ELMB motherboard, and send the monitoring signals in Differential Analog format to ELMB motherboard.



(a) LVPS schematic [2]



(b) Wits Low Voltage Power Supply brick

Figure 2: (a) LVPS block diagram control system illustrating the LT1681 forward controller operating at 300 kHz, (b) Wits LVPS brick manufactured in South Africa.

3.1. Low Voltage Power Supply monitoring system

The brick is an isolated switching DC-DC converter, that converts the 200 V input to a 10 V output. The isolation is provided by a step-down transformer, which also has additional windings for other auxiliary power supplies on the brick, required for control and monitoring purposes [2]. A summarized schematics of the converter with the transformer is given in Figure 2a. The switching frequency of the brick is constant at 300 kHz, and it benefits from a two switch Forward converter topology. The brick measures six analog signals and sends them to the ELMB motherboard, which includes input voltage and current, output voltage and current, and the temperature readings from two points on the brick (primary and secondary side switches), measured using thermistors. The brick receives an Enable signal and a start-up pulse from ELMB motherboard. The start-up pulse provides temporary power to the control circuits of the brick to power it on. When the Enable signal is high, the brick will power on after a short delay after receiving the start-up pulse. The brick provides a nominal output current of 3 A, should be able to provide twice of the nominal current (6 A), and has built-in automatic over current protection (at 10.5 A) and over temperature protection (at 70°C), in addition to over voltage protection (at 12 V). Each brick will be tested according to a specific procedure and must pass different criteria. Table 1 also lists this criteria for the LVPS bricks.

3.2. Development of the Wits test-station for LVPS Production

Pre-production and production of the bricks will entail testing and subsequent testing. Testing procedures will take place at the University of Witwatersrand School of Physics, High-throughput lab. The testing ensures that bricks meet the criteria listed in Table 1. Bricks that pass these test procedures will then be shipped for assembly at CERN, and for further radiation testing of the LVPS components. The ‘Wits test-station’ quantifies a multitude of performance metrics of a LVPS brick. This station would also verify protection circuitry of the LVPS brick, to guard against over temperature, over current and over voltage. Custom PC based software was synthesized to perform the tests and graphically display and record onto file these performance metrics [5]. The desktop PC is connected to the data acquisition using a National Instrument (NI) and B-type USB to the electronic load as well as the high voltage power supply. The Data Acquisition uses a 50 pin ribbon cable twist and flat to connect to the brick as can be seen in Figure 3. Coaxial cables will be used for the start up and voltage output of the LVPS and recorded.

Parameter	Minimum	Maximum
Frequency Standard Deviation	0	1000
Duty Cycle Standard Deviation	0	0.1
Frequency Max	350000	290000
Frequency Min	250000	310000
Minimum Stable Load	2.1	2
Minimum Output Voltage	9.8	10.2
Over Voltage Protection Trip Point	11.5	12
Over Current Protection Trip Point	10.25	10.75
Output root mean square Voltage	0	0.5
Output Peak to Peak Voltage	0	0.5
Clock Duty Cycle Average	0	40
Clock Duty Cycle Standard Deviation	0	0.15
Start-up Delay (Max)	0.2	0.08

Table 1: Minimum and maximum of testing parameters. Parameters are used in the test station software to test individual bricks.

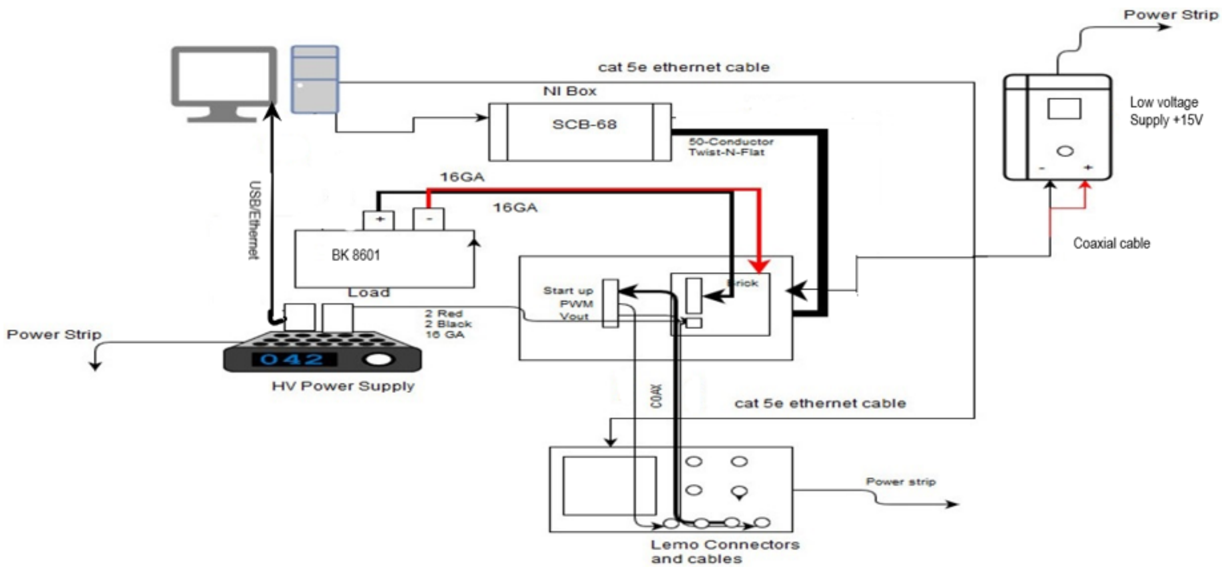


Figure 3: Wits test-station block diagram.

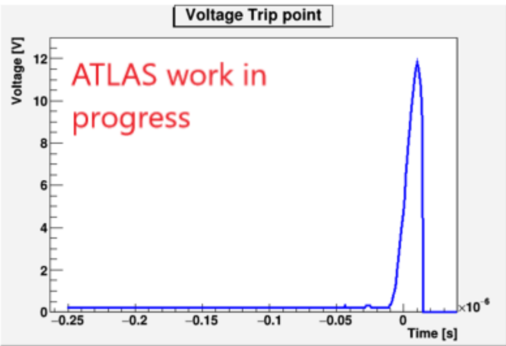
4. Quality Assurance test results

The testing ensures that bricks meet the criteria listed in Table 2. So far sixteen bricks were assembled and produced in South Africa. We have already done a rigorous analysis using sophisticated LabVIEW software programs developed by the University of Texas and Arlington (UTA) group. The feasibility of the design regarding electrical parameters of specification was verified using a test-station that was assembled at the University of the Witwatersrand. The test stand performs several tests on the bricks to ensure all of the parameters are according to the specification [5]. Various tests determine whether the protection circuitry of the LVPS are functioning correctly. In the test results as can be seen in Figure 4b the over-voltage protection and the current trip point are assessed. Similarly to the protection circuitry results, we also monitor the output voltage range and a function of output voltage settings operating at nominal

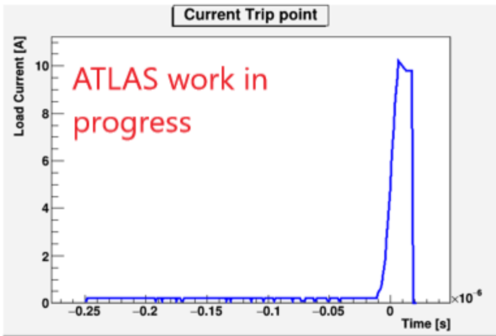
Parameter	Value	Status of test
Minimum stable current (0.5-2A)	1.700A	Pass
Minimum Output voltage (9.8-10.2V)	10.0484V	Pass
Voltage trip point (11.5-12V)	11.8092V	Pass
Current Trip point (10.25-10.75A)	10.1901A	Fail
Voltage input Monitor(0.95-1.05V)	1.04901V	Pass
Current Input monitor(-0.015 -0.005A)	-0.01032A	Pass
Temperature monitor(10-93°C)	57°C	Pass

Table 2: Test status and summary of voltages and currents for the different brick types.

load as can be seen in Figure 5b.

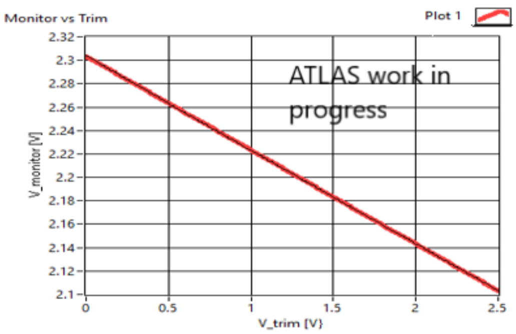


(a) Voltage trip point of the Wits LVPS brick.

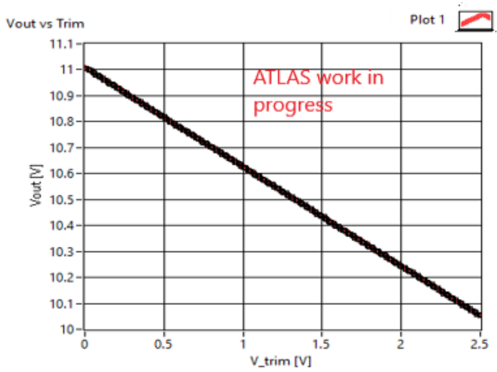


(b) Current trip voltage of the Wits LVPS brick.

Figure 4: (a) While operating at minimum stable load, the output voltage is increased by decreasing the trim voltage, until the built-in over voltage protection shuts down the brick. (b) The load current is increased, until the built-in over current protection shuts down the brick



(a) Voltage monitoring and trim voltage.



(b) Output voltage and trim voltage.

Figure 5: Operating at nominal load, the trim voltage is changed to change the output voltage. Then, a linear plot is produced to show the output voltage vs trim voltage.

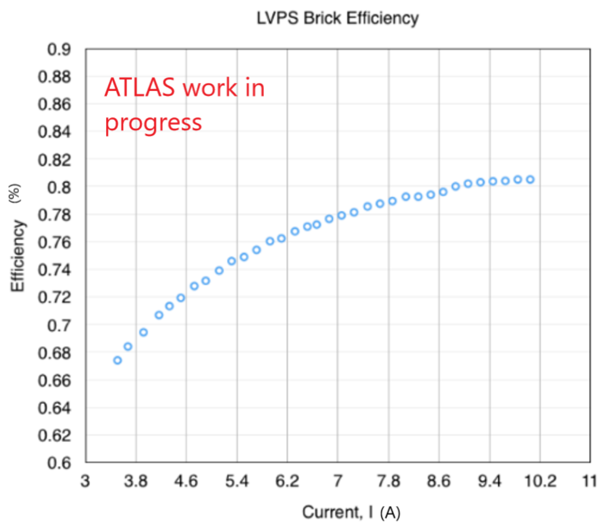


Figure 6: The total losses of the brick is 19.7 W, while supplying 100 W on the output. The measured efficiency of the brick operating at 10.19 A is 80.5%.

5. Overall performance and reliability analysis

We have undertaken a project to develop a test-station according to UTA's design requirements. We are manufacturing half of the bricks in South Africa for the next run. The primary goals are to improve noise performance, reliability, and tolerance to single-event upset, while retaining the physical layout, interface to the detector control system, and other infrastructure. There are various efficiencies in power supplies as a function of output load that meet manufacturer specifications input/output conditions,The LVPS prototype guarantees over 80.5 efficiency at 10A load at 200V / 55Hz input and able to withstand harsh environments from the overall design.The total power loss and efficiency of the LVPS can be seen in Figure 6.

6. Summary and Outlook

We have built and tested the LVPS bricks which are manufactured in South Africa and tested at Wits (using the Wits LVPS test-station). The reliability and stability of the system has been visibly improved with respect to the previous design [2]. A few notable metrics we are measuring is the efficiency of the brick operating at nominal load (see Figure 6). The analyses that follow assume that the bricks are in the normal operating portion of the lifetime curve, where components exhibit a constant failure rate as a function of time. The calibration systems of the ATLAS TileCal have been presented, analysis of the LVPS bricks can be used to gain detailed insight in what causes variations in detector response. Once a brick passes the Quality Assurance tests from above it will be sent to component stress testing on the 'burn-in' test-station which elevates the temperature of the bricks to 60°C for 8 hours.

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