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A Burn-in Test Station for the Transformer-Coupled Buck Converter Boards within the Low Voltage Power Supplies of the ATLAS Tile Calorimeter

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A comprehensive quality-assurance testing procedure has been developed to ensure the reliability of transformer-coupled buck-converter boards ("Bricks") used in the ATLAS hadronic Tile Calorimeter (TileCal). With the impending Phase-II upgrades of the TileCal, which will contribute to the success of the forthcoming High-Luminosity Large Hadron Collider, ensuring the reliability of the Bricks in the TileCal's Low Voltage Power Supply (LVPS) system is essential. There are 256 LVPS Boxes within the TileCal, each equipped with eight Bricks that step down 200 V DC power received from the off-detector electronics to the voltage required by the on-detector front-end electronics. As part of the Phase-II upgrades in South Africa, our team plays a significant role in production by manufacturing half of the required Bricks. Access to the Bricks is limited to once per year during the Year-End Technical Stops due to their location within the inner barrel of the ATLAS detector. Consequently, if a Brick fails, it may remain offline for up to one year, during which the front-end electronics it powers will also be non-operational. Establishing a Burn-in test station is essential for subjecting LVPS Bricks to accelerated aging, thereby stimulating potential failure mechanisms and screening out defective units that could compromise detector performance. By ensuring the reliability of the final population of Bricks installed, we minimize instances of the front-end electronics being offline, thus improving detector performance and data integrity.

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1. Introduction

The Large Hadron Collider (LHC) [1], located in Switzerland at the European Organization for Nuclear Research (CERN), forms the largest particle accelerator in the world. The LHC is a 27 km underground ring straddling the border between Switzerland and France, built to accelerate and collide beams of particles, primarily protons or heavy ions, at near light speeds. The primary collision of interest for this study is proton-proton (pp) collision events of a significant size, as they will be the cornerstone of new physics discovery and applicable to the main mission of the ATLAS detector. The LHC operates with two particle beams traveling in opposite directions in separate beam pipes, maintained under ultra-high vacuum. The beams intersect at four predetermined points corresponding to the four major detectors. The four primary detectors consist are ATLAS [2], CMS [3], LHCb [4], and ALICE [5].

The ATLAS detector is a large multi-purpose instrument at the LHC for observing high-energy collisions. The detector consists of several subsystems, each responsible for capturing the detector's response to particle collisions. As particles go through the detector, they have unique properties (type, energy, and trajectory), which produce unique signatures that can be accurately reconstructed. The TileCal is a sampling calorimeter and a central component of the ATLAS experiment's hadronic

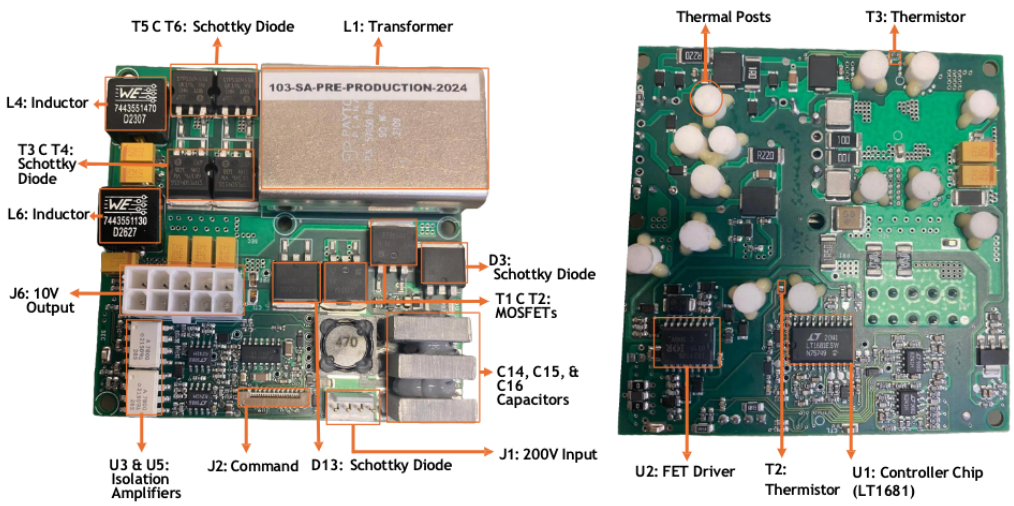

Figure 1: The South African V8.6.0 pre-production buck converter board with the top (left) and bottom (right) perspectives.

calorimetry, designed to measure hadrons, jets, and hadronic τ-lepton decays, as well as missing transverse energy. It also aids in muon identification and provides critical input to the Level-1 calorimeter trigger system. The High-Luminosity Large Hadron Collider (HL-LHC) is set to commence operations in 2030 with the goal of drastically increasing the LHC's luminosity. The high rate particle collision environment requires new electronics developments inside and outside the detector to maintain performance levels due to unavoidable increases in pile-up and radiation which consequently justifies the ATLAS TileCal Phase-II upgrades [6].

Figure 2: The current view of the Wits Burn-in test.

2. Quality Assurance Testing of Buck Converter Boards

To mitigate the risk of buck-converter board failures during ATLAS operation, a Burn-in test station has been implemented to identify and remove faulty units. Figure 2 shows the Burn-in stations used for this process.

2.1 Burn-in Testing

Latent defects that would normally appear only after extended use can be induced earlier by deliberately stressing the boards. The boards are subjected to operating temperatures of 60°C, with a constant load of 6 A, for 8 hours. The test temperature exceeds the typical TileCal operating range of 30 – 40°C, revealing thermal stresses early in the test, including factors such as solder fatigue and component drift. The load of 6 A is the maximum operating current, stressing the power regulation circuitry and associated protection features. The duration of the burn-in test of 8 hours, although much shorter than the multi-year TileCal operation, corresponds to an accelerated-aging factor. Using thermal acceleration models (Arrhenius law) we can estimate that running at 60°C for 8 hours is equivalent to several weeks of normal running at 35°C.

2.2 Temperature Monitoring During Burn-in

The pre-production buck converter boards shown in Figure 3 underwent an 8-hour burn-in test, during which two relevant temperatures T_2 and T_3 were monitored. These temperatures, measured using thermistors as shown in Figure 1, represent the thermal behavior of the board under evaluation. While they were comparable to one another, T_2 and T_3 are slightly different locations on the fLVPS board; T_2 is connected to the circuit over temperature protection (OTP) protection set at 70°C to prevent damage to board components. T_3, located at the PCB edge between the thermal posts of the T_5 and T_6 Schottky diodes, is used to monitor temperature variation.

The Burn-in station is designed to accommodate up to eight buck converter boards; however, in some burn-in testing cases, as shown in Figure 3, only six boards were tested per 8-hour burn-in due to maintenance on some channels on the Burn-in station. In Figure 3, the burn-in test records did show the temperature at T_2 and T_3 starting around 40°C, and rising subsequently, stabilizing around the 20-minute mark at which they reach their burn-in temperature. This thermal profile was maintained through the duration of the test. The burn-in test was closely monitored to observe any unusual tripping or issues that could push the testing temperature outside of the OTP thresholds.

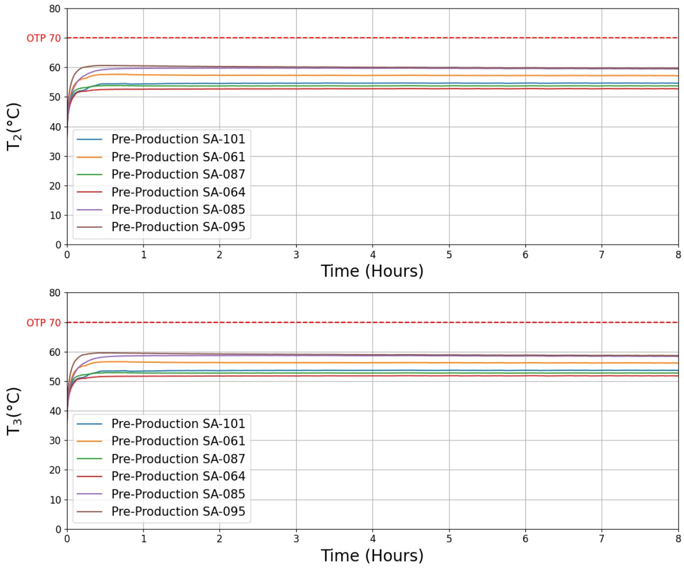

Figure 3: The T_2 (top) and T_3 (bottom) temperature monitoring of 6 pre-production LVPS boards undergoing burn-in simultaneously.

3. Conclusions and Outlook

We have made substantial progress in testing and assessing the buck converter boards. The purpose of the Burn-in test was clearly defined, demonstrating its importance in assessing the reliability of the buck-converter boards. During the pre-production phase, 104 units were subjected to near-maximum loads in extended Burn-in tests, which gave us the opportunity to monitor how they behaved under significant stress of which will be applied during the main production with more than a thousand units.

Two Burn-in stations are currently operational at the University of the Witwatersrand in preparation for the main production phase of the buck converter boards towards the end of 2025.

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