South African contribution towards the ATLAS Tile Calorimeter PreProcessor

M G D Gololo[1], F C Argos[1] and B Mellado[1,2]

[1] School of Physics and Institute for Collider Particle Physics, University of the Witwatersrand, Johannesburg, Wits 2050, South Africa

[2] iThemba LABS, National Research Foundation, PO Box 722, Somerset West 7129, South Africa

E-mail: mpho.gift.doctor.gololo@cern.ch

Abstract. Four major experiments for the High Luminosity Large Hardron Collider (HL-LHC) are upgraded to accommodate an increase in luminosity. ATLAS (A Toroidal LHC ApparatuS) is one of these four major experiments and it is upgraded to investigate a wide range of physics. The ATLAS detector is the largest and a general-purpose particle detector. The Tile Calorimeter (TileCal) is part of the ATLAS detector and is the central hadronic calorimeter. The detector is divided into one long barrel and two extended barrels. The main aim of the TileCal Phase-II upgrade is to completely redesign the on- and off-detector electronics. The TileCal PreProcessor (TilePPr) is one of the off-detector electronics and it is responsible for processing the detector data with a total data bandwidth of 40 Tbps. The University of the Witwatersrand is contributing 24 % to the total design and production of boards towards the TilePPr. The TilePPr is made up of numerous modules and the University of the Witwatersrand is responsible for TileCal GbE Switch and TileCoM modules.

1. Introduction

The Large Hadron Collider (LHC) collides proton beams at four interaction points where main experiments are located [1]. These are; ATLAS (A Toroidal LHC ApparatuS)[2], CMS (Compact Muon Solenoid)[3], ALICE (A Large Ion Collider Experiment)[4] and LHCb (Large Hadron Collider beauty)[5]. A major upgrade to the High Luminosity Large Hadron Collider (HL-LHC) will increase the instantaneous luminosity by a factor 5 compared to the operation of the LHC during Run 2. The complete redesign of replacement of on- and off-detector electronics for the ATLAS Tile Calorimeter Phase II upgrade is due to: radiation and time aging of the electronics; compatibility with full digital TDAQ and trigger processing at 40 MHz (L0) and; to fulfill Phase II radiation requirements. The new readout strategy for HL-LHC will transmit digitized data to the off-detector electronics at the HL-LHC frequency (40 MHz), which is approximately 40 Tbps to read out the entire detector.

2. ATLAS TileCal Pre-Processor for the Phase-II upgrades

Figure 1 shows the proposed redesign for the ATLAS Tile Calorimeter electronic readout chain where the on-detector electronics sends digitized data to off-detector electronics. The off-detector

ISBN: 978-0-620-97693-0

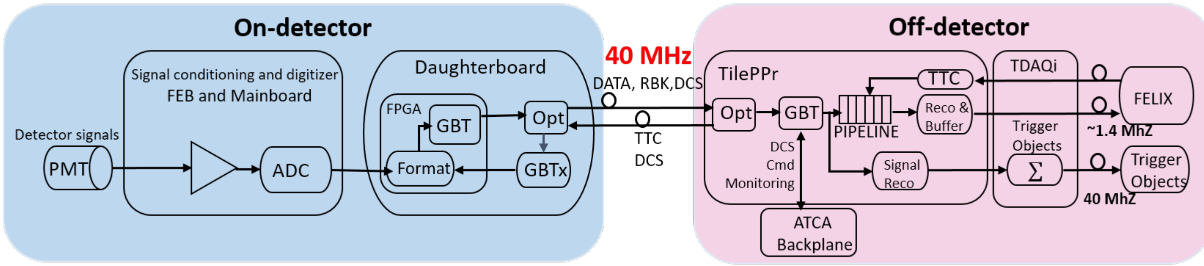

Figure 1. The ATLAS Tile Calorimeter electronic readout chain[6].

electronics receives these digital data using GBT protocol at the HL-LHC frequency, stores and processes these data in the Tile PreProcessor (TilePPr) modules. Figure 2 shows the components of the TilePPr which includes an ATCA Carrier Board, four Compact Processing Modules (CPM) and a Trigger and Data Acquisition Interface (TDAQi) module. The TDAQi provides preprocessed data to the ATLAS calorimeter and muon trigger systems. The TilePPr also includes mezzanine modules such as the TileCal Gigabit Ethernet (GbE) Switch, TileCal Computer on Module (TileCoM) and the Intelligent Platform Management Controller (IPMC). All the off-detector electronics are housed inside Advanced Telecommunication Computing Architecture (ATCA) shelves that can be controlled through remote communication. The IPMC is used for control and monitoring of the ATCA Carrier Base Board.

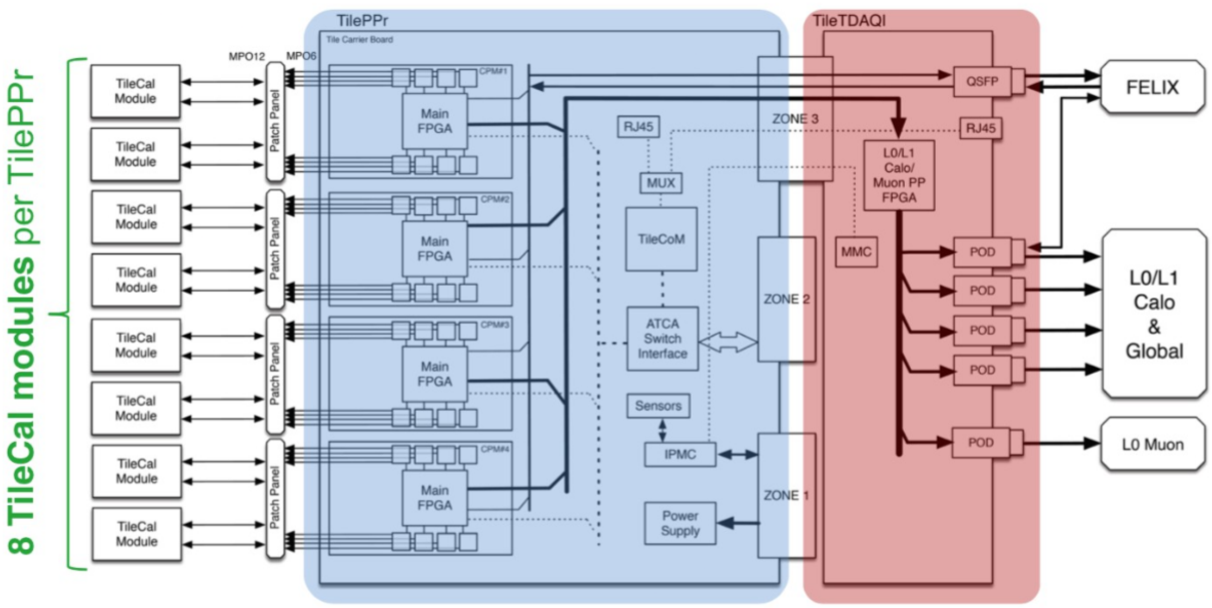

Figure 2. The ATLAS TileCal PreProcessor [7].

3. The South african contribution

3.1. Production of boards

The University of the Witwatersrand and iThemba labs are contributing towards production of boards from state-of-the-art companies in South Africa. The two mezzanine modules, TileCoM and TileCal Gigabit Ethernet (GbE) Switch, introduced in Section 2 are produced from South African companies. Figure 3 shows the TileCal GbE Switch, that will interconnect all the

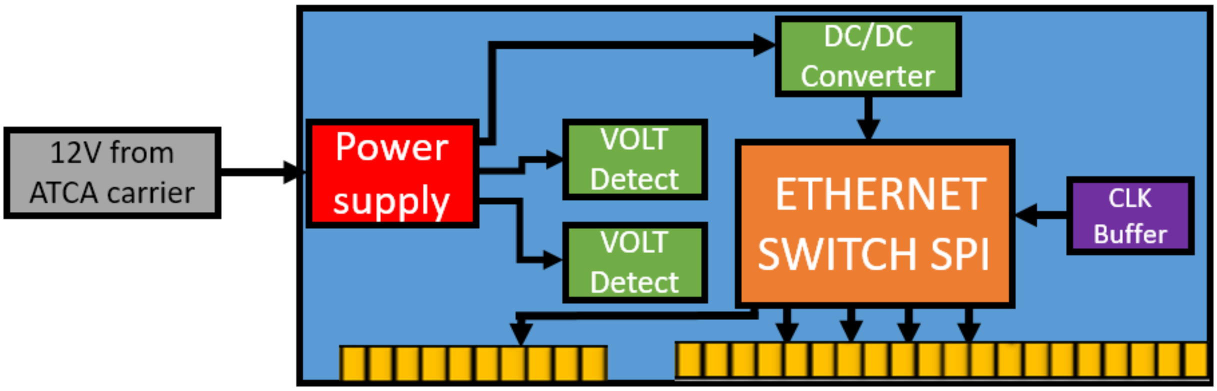

Figure 3. The TileCal Gigabit Ethernet switch card.

components in the TilePPr with an external ethernet network through the ATCA Base Interface located in the Zone 2 backplane on the shelf. The main component of this module is the Broadcom(R) BCM5396 which is a 16-port GbE switch with 16 1.25G-SerDes/SGMII port interfaces for connecting to external Gigabit PHYs or fiber modules. The Tile GbE switch provides communication to the CPMs and TDAQi.

This module consists of the interface connector to communicate with external components connectors and power regulators responsible for stepping down the 12V input voltage to the required voltages. Six boards have been produced from South African companies and these modules have been tested with the TilePPr modules. The produced TileCal GbE switch module has passed electrical and communication tests with TilePPr modules. The TileCoM functionalities detailed in subsection 3.2 are implemented and tested with TileCal GbE switch module and other TilePPr modules.

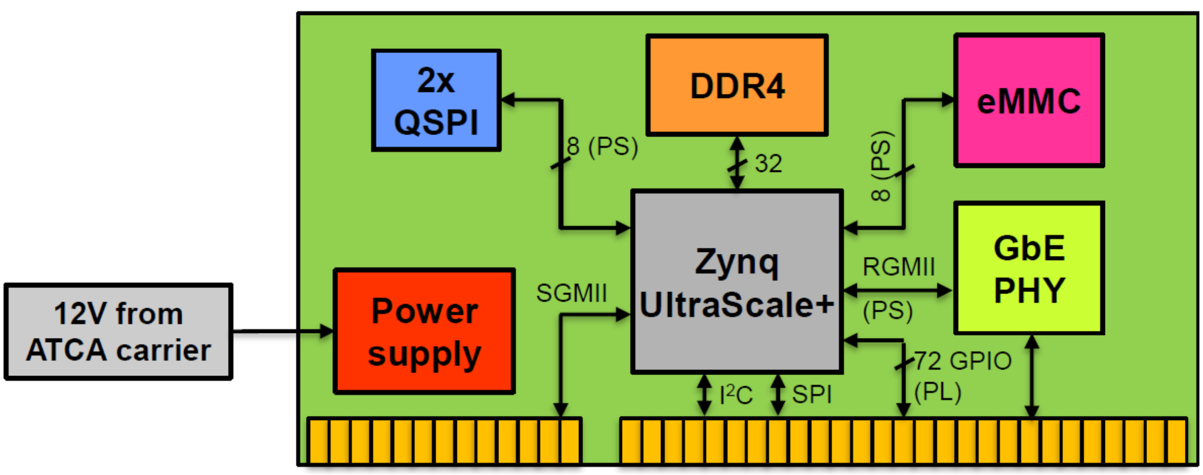

Figure 4. The TileCal Computer On Module (TileCoM).

Figure 4 shows the TileCoM architecture with connection interfaces to the ATCA carrier. The TileCoM main components are the Zynq UltraScale + ZU2CG and 2GB DDR4. All the interface components are used for the main functionalities of the TileCoM. The TileCoM will receive 12V power supply from the ATCA carrier to power all the components. The DC/DC regulators are used to step-down the voltage to supply other components that are on the board.

ISBN: 978-0-620-97693-0

The Transmission Control Protocol (TCP) and the Internet Protocol (IP) are used to remotely connect to the TileCoM and implement the main functionalities. The Inter-Integrated Circuit (I^2C) protocol is used to interface with the ATCA temperature and voltage sensors for monitoring purposes. The TileCoM reads these temperatures and voltages, and send them to DCS through a GbE port.

3.2. Software implementation for TileCoM functionalities
The three main functionalities of the TileCoM involves remote programming, interface with TDAQ[8] and integration with the Detector Control System (DCS)[9]. The remote programing aplication is used to remotely program all the FPGAs on the ATLAS TileCal Phase II upgrades electronic readout chain. The interface with TDAQ is used to monitor and control the data acquisition on the TilePPr. Lastly, the integration with DCS functionality is used to remotely control and monitor the health status of the readout modules. All these functionalities are implemented in the software application level of the embedded linux running on TileCoM. TileCoM drivers are developed to integrate with the TileCoM hardware and the rest of the ATLAS TileCal Phase II upgrades electronic readout chain. The Extensible Markup Language (XML) is used as a lightweight data-interchange format to read data from the electronic readout chain.

The Open Platform Communications United Architecture (OPC-UA) projects are part of the DCS TileCoM functionality that is used to control and monitor the readout electronic chain. This DCS TileCoM functionality is divided into two projects. The first OPC-UA project focuses on only reading the Xilinx Analog to Digital Values from the TileCoM. This project was successfully integrated and tested with the SCADA system of the DCS to remotely acquire sensor data. The second OPC-UA project is currently in process of implementation and involves software integration with the CPM on the ATCA carrier board.

3.3. Progress status of the South African contribution
Figure 5 shows a Gant Chart with the projects for the South African contribution towards the TilePPr for 2021. All the projects are on schedule in terms of production and developments of software applications. The final design of the TileCoM involves integration tests with the TilePPr and TDAQ FPGAs. This project will commence on the last quarter of 2021 together with the production of TileCoM boards by South African companies.

The plan for the year 2022 on-wards is to perform electrical and communication tests on the TileCoM boards produced in South Africa. This will commence early 2022 and will involve testing the TileCoM as well as integration tests with the other ATLAS TileCal Phase II upgrade electronic readout chain boards.

4. Conclusion
Current work at CERN involves progressing towards Phase II upgrades to accommodate an increase in the instantaneous luminosity by a factor 5 compared to the current operation of the LHC. The University of the Witwatersrand and iThemba labs are contributing towards the off-detector electronics. This contribution involves software developments and production of boards by South African companies. The University of the Witwatersrand has produced six fully functional TileCal GbE Switch boards.

The first OPC-UA software developmenet project has been completed and integrated successfully with the SCADA systems of the DCS. The ATLAS TileCal note is a document that contains all the details about the TileCoM and it is currently under review. The production of TileCoM boards as well as the development of the second project for the OPC-UA will commence on the last quarter of 2021. All the projects of the South African contribution are on schedule.

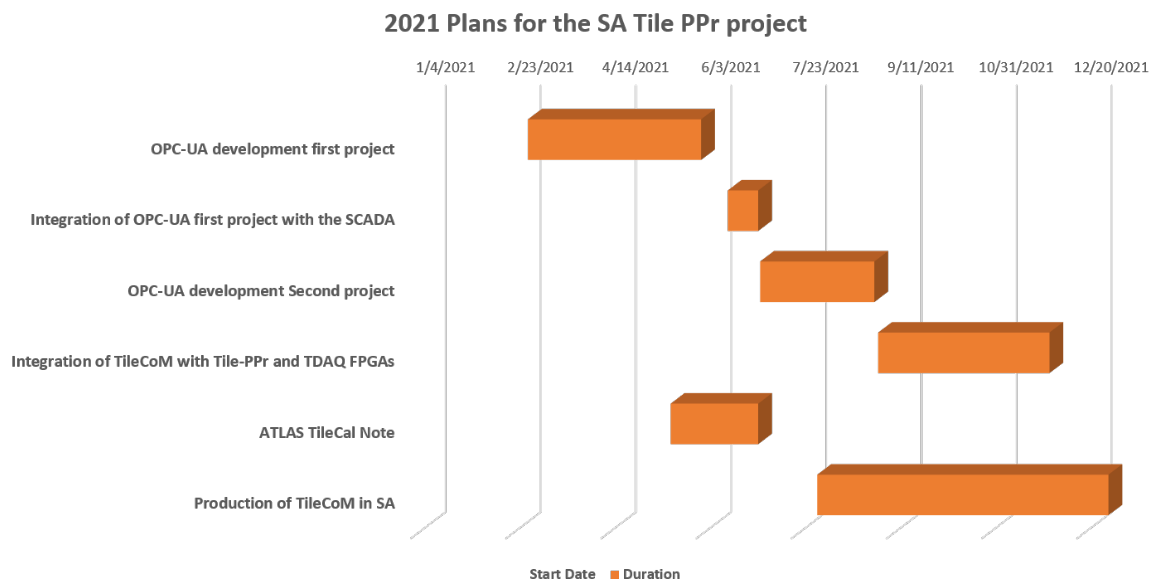

Figure 5. Progress status of the South African contribution towards TilePPr.

References

[1] Benedikt 2004 *LHC Design Report* (Geneva: CERN)
[2] Collaboration 2012 *Letter of Intent for the Phase-II Upgrade of the ATLAS Experiment* (Geneva: CERN)
[3] Ressegotti M 2019 *Overview of the CMS Detector Performance at LHC Run 2* 9
[4] Vyvre P V 2014 *Performance of the ALICE Experiment at the CERN LHC* 108
[5] Collaboration 2014 *LHCb Detector Performance* 83
[6] Santurio E V 2020 *Performance of the ATLAS Hadronic Tile Calorimeter Demonstrator system for the Phase-II upgrade facing the High-Luminosity LHC era.* 4
[7] Argos F C and Valero A 2019 *The PreProcessor Module for the ATLAS Tile Calorimeter at the HL-LHC* 4
[8] Xiaoguang Y 2019 *TileCal TDAQ interface module for the Phase-II Upgrade of the ATLAS Tile Calorimeter* 4
[9] Martins F 2016 *The ATLAS Tile Calorimeter DCS for Run 2*