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Development of the ATLAS Liquid Argon Calorimeter Readout Electronics for the HL-LHC

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The ATLAS Liquid Argon (LAr) Calorimeter readout electronics will be upgraded to meet the new trigger and data-acquisition (TDAQ) buffering requirements and to withstand the high expected radiation doses at the high-luminosity LHC. The triangular calorimeter signals are amplified and shaped by analog electronics over a dynamic range of 16 bits, with low noise and excellent linearity. Development of low-power preamplifiers and shapers to meet these requirements in 130nm CMOS technology are ongoing. Development of a radiation-hard, low-power, 14-bit pipeline+SAR analog-to-digital converter (ADC) to digitize the analog signals in 65nm CMOS technology is ongoing. Characterization of the prototypes of the front-end components show good promise to fulfill all the requirements. The signals will be sent at 40 MHz to the off-detector electronics, where FPGAs connected through high-speed links will perform energy and time reconstruction through the application of corrections and digital filtering. Reduced data are sent with low latency to the first-level trigger, while the full data are buffered until the reception of trigger accept signals. The data-processing, control and timing functions will be realized by dedicated boards connected through ATCA crates. Results of tests of prototypes of front-end components will be presented, along with design studies on the performance of the off-detector readout system.

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1. Introduction

The ATLAS detector [1] is one of two general purpose detectors at the LHC, consisting of several sub-detectors including trackers, calorimeters, and muon spectrometers. The liquid argon calorimeter is a sampling calorimeter with 182,468 readout channels. The calorimeter consists of the electromagnetic barrel, the electromagnetic end caps, the hadronic end caps, and the forward calorimeter. The barrel and endcap regions have accordion-shaped structures with lead absorber plates to enable full azimuthal coverage. The hadronic endcap calorimeter employs a conventional parallel plate design using copper plates. The forward calorimeter has a paraxial electrode structure with copper and tungsten as absorber materials [2].

In the high-luminosity LHC (HL-LHC) period, we will collect data at 5–7.5x the nominal luminosity and the average number of collisions will be around 10x the current average [4]. Therefore, we will need to develop new readout electronics to record data with the desired resolution and withstand the higher radiation dosage. For the HL-LHC, we will replace the existing Front-End Board (FEB) board with newer FEB2 boards. Calorimeter signal from a readout channel will be sent to a preamplifier-shaper, which will shape the triangle pulse from the calorimeter into the liquid argon pulse. The liquid argon pulse will be digitized by analog-to-digital converters (ADCs) at a sampling frequency of 40 MHz, and the digitized signals will be sent to off-detector electronics via optical links.

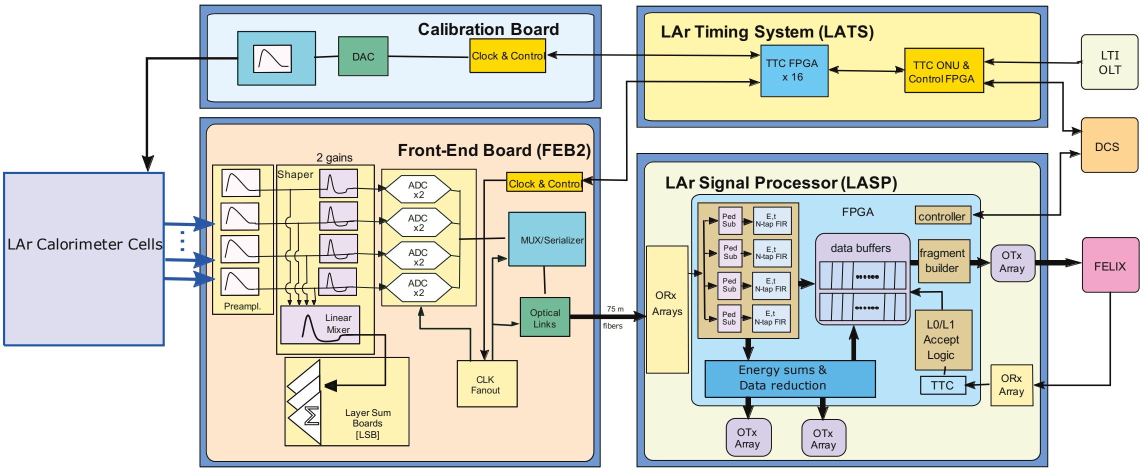

Figure 1: Schematic for the proposed upgrade of the LAr readout electronics. The calorimeter signal from a readout channel will be sent to a preamplifier-shaper, which will shape the triangle pulse into the liquid argon pulse. The liquid argon pulse will be digitized by the analog-to-digital converters and the digitized signals will be sent to off-detector electronics via optical links.

2. On-detector electronics

The front-end readout electronics will be implemented on a new Front-End Board, abbreviated as FEB2, that will replace the current FEB boards. As with the current FEBs, each FEB2 will handle 128 calorimeter channels, with a total of 1,524 FEB2 boards required to read out the entire LAr system [4].

2.1 Calibration

The calibration boards deliver a calorimeter pulse with precisely known amplitude and shape close to calorimeter ionization to calibrate the readout electronics. Each calibration board has 128 channels, referred to as calibration lines. Each calibration line injects charge onto a fixed number of channels. For the calibration board, the CLAROC ASIC, which is a 16-bit digital-to-analog (DAC) application specific integrated circuit (ASIC) with four high-frequency switches designed in 180nm XFAB is being studied.

2.2 Preamplifier-shaper

The preamplifier provides an active termination and amplifies the calorimeter signals. The shaper transforms the output of thepreamplifier circuit to a multi-gain differential output capable of directly driving the inputto the ADC, and adds a CR-RC^2 shaping to match the required signal processing requirements [4]. Both the preamplifier and shaper are implemented in one ASIC. The preamplifier-shaper ASIC will accomodate four calorimeter channels and shape the signal across two gains. Two proposed ASICs, LAUROC and ALFE, designed in 130 nm CMOS techology are being studied.

2.3 Analog-to-digital converter

The shaped-analog signal from each calorimeter channel will be digitized at 40 MHz and will cover the full 14-bit dynamic range, which is given by the smallest and largest signals that are expected to be measured at the HL-LHC in the LAr cells. The ADC will need to meet the radiation tolerance corresponding to 4000 fb^{-1} and consume less than 100 mW of power per detector channel [4]. The baseline solution is to use a 14-bit dynamic range ADC with two gain scales. Two options for the ADC are being considered, either the developmentof a full custom ADC design in 65nm CMOS technology, or the possible development of an ADC that integrates in its core a commercially available "Intellectual Property" (IP) block. The fully custom ADC, dubbed the COLUTA ADC, consists of a pipeline+SAR architecture is under study. The COLUTA ADC consists of a Dynamic Range Enhancer (DRE)/Multiplying DAC (MDAC) which selects the most significant two bits of the 14-bit digital code, followed by a 12-bit pipeline SAR block.

3. Off-detector electronics

The FEB2 boards will connect to the off-detector electronics via optical links. The off-detector electronics will provide the trigger, timing and control signals (TTC), receive the digitized waveforms, apply digital filtering, buffer and transmit data to the TDAQ systems. Therefore, the off-detector electronics are grouped into LAr Timing System (LATS), which will provide the TTC signals to the on-detector electronics, and the LAr Signal Processor (LASP), which will receive and process the digitized signals from the ADC, buffer and transmit the data to TDAQ systems. The LASP hardware implementation will be an evolution of the LAr DigitalProcessing System (LDPS) which will be installed during LS2 for the Super Cell readout [3].

References

[1] ATLAS Collaboration, *The ATLAS experiment at the Large Hadron Collider*, *JINST* **3** (2008) S08003.

[2] ATLAS Collaboration, *ATLAS Liquid Argon Calorimeter: Technical Design Report*, CERN-LHCC-96-41.

[3] ATLAS Collaboration, *Technical Design Report for the Phase-I Upgrade of the ATLAS TDAQ System*, CERN-LHCC-2013-018.

[4] ATLAS Collaboration, *Technical Design Report for the Phase-II Upgrade of the ATLAS LAr Calorimeter*, CERN-LHCC-2017-018.