EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

ATLAS Experiment

Implementation of ATLAS Phase-I Upgrade Components for LAr Calorimetry & TDAQ Systems

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This report outlines the work done during the summer of 2019 to implement and commission Phase-I upgrades to the ATLAS Liquid Argon Calorimeter system. Included is an improved way to configure receiver monitoring boards at USA15, as well as the procedure and results of performing power measurements of the new ALTI Trigger, Timing, and Control boards.

KEYWORDS

ATLAS, Liquid Argon, ALTI, Configure Receiver Monitoring Board

1 | PHASE-I LIQUID ARGON UPGRADES

In order to gain a better understanding of the physics that governs rare events at high energies, experimental physicists at CERN are planning to vastly increase the luminosity of the Large Hadron Collider (LHC) over the next 20 years. The high luminosity LHC (HL-LHC) experiments are expected to reach instantaneous luminosities of $5-7.5\times10^{34}$ $m^{-2}s^{-1}$ and rates of up to 200 interactions per bunch crossing. This is equivalent to an order of magnitude increase in the amount of data produced before the HL-LHC. While this vast increase in data points is a great step forward for the future of physics, the high luminosity environment proposes challenges for many hardware and software components of the detector. During the Phase-I upgrade period from 2019-2020, the LAr Calorimeter is undergoing changes to

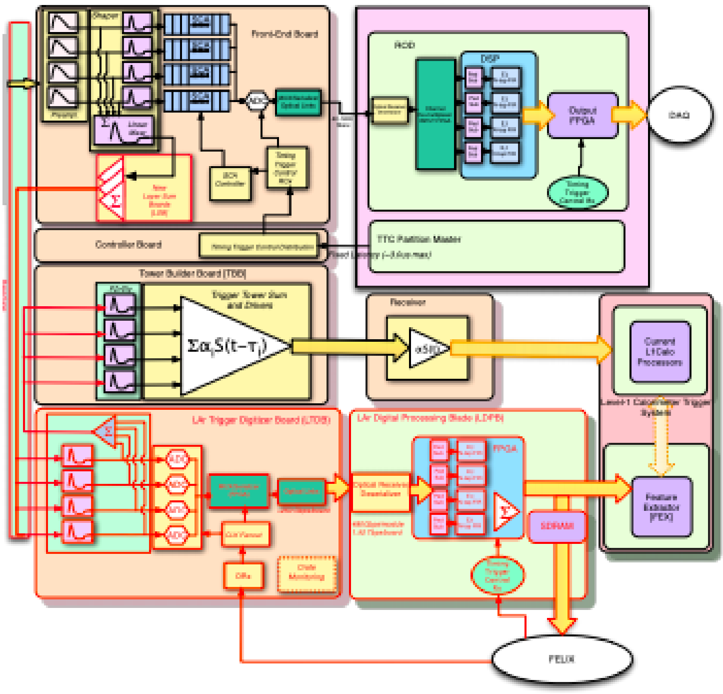


FIGURE 1 The proposed Phase-I updates for LAr front end readout electronics [1]

prepare for the Run 3 experimental conditions, when the LHC is expected to reach 2.5x its design luminosity. These upgrades will eventually be supplemented by Phase-II upgrades and accommodate full HL-LHC conditions.

The Liquid Argon Calorimeter was built to operate within the luminosities and interaction rates of the original ATLAS detector design specifications. Replacements need to be made to preserve the same level of accuracy and trigger acceptance rates while avoiding the pile up of data as it accumulates far faster than it ever has before. The strategy being implemented to combat pile up in the LAr Calorimeter data acquisition is increased granularity of signals to the trigger system. This will involve modification of on- and off-detector electronics, as well as software updates. Higher granularity will make the separating isolated events easier, allow for lower trigger thresholds, and adapt to the deployment of more advanced trigger algorithms which will produce data that is more easily understood. Additionally, front-end electronics need to be able to withstand the projected luminosities without succumbing to damage; in this case, that means installing new LAr Trigger Digitizer Boards (LTDB) that are designed for the radiation levels of the HL-LHC in the front end crates. The updated trigger readout electronics need to accommodate the new functionality of the LAr detector, including the increased granularity and the LDTB boards. A schematic diagram for the LAr trigger read-out electronics system upgrades is shown above.

2 | CONFIGURING ANALOGUE TRIGGER RECEIVER MONITORING BOARDS

A crucial aspect of the upgrade is the commissioning and validation of the new components, as well as the re-commissioning of the legacy elements which are remaining for Run 3, namely the main digital readout and the legacy analog trigger system. The LAr group has acquired some very nice oscilloscopes in order to be able to monitor the input signals for the main digital read-out in an independent way, without requiring the full data taking chain. This is extremely useful for determining what signals are being sent to new electronics hardware (in this case, the LTDBs). One project that I worked on was optimizing the process of configuring analogue trigger receiver monitoring boards so that these oscilloscopes can be used to effectively monitor important analogue signals without extensive infrastructure.

The connection between the trigger towers on the ATLAS LAr detector and the oscilloscope at USA15 is non-trivial; each trigger tower is connected to one of six monitoring boards, and the monitoring boards can be configured to transmit any of their connected trigger towers' signals through any of their 16 output channels. The eight oscilloscope channels can be connected to any of the 96 receiver monitoring board channels. In order to monitor the signal from a specific trigger tower on a specific oscilloscope channel, you need to know where the oscilloscope is connected at USA15 (both the monitoring board and the monitoring board channel) and then configure the monitoring board so that the trigger tower you want to see is connected to the same channel.

The LAr software development group had an existing bash command line script that configured the receiver monitoring boards, but it was obsolete; the program had several bugs and was only written for a single oscilloscope set up, which is no longer how the oscilloscope is connected at USA15. I cleaned up, debugged, and optimized the existing code, before generalizing it to adapt to any possible oscilloscope set up. Finally, I rewrote it in Python and converted it into a graphical user interface (GUI) for more convenient and straightforward use.

2.1 | Usage

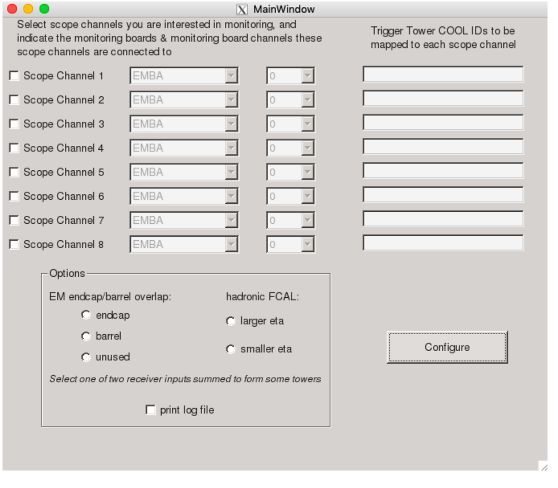


FIGURE 2 The graphical user interface used to configure receiver monitoring boards

Oscilloscope Channel Connections

pc-lar-scope-19a								
scope channel	1	2	3	4	5	6	7	8
monitoring board	EMECA	EMECA	EMECA	EMECA	EMECA	EMECA	EMECA	EMECA
monitoring board channel	0	1	2	3	4	5	6	7

FIGURE 3 The table showing where each oscilloscope channel is currently connected at P1. This table is accessible through the LAr Online Development Twiki and will be updated according to changes made to the oscilloscope set up

The graphical user interface for receiver monitoring board configuration is shown in Figure 2. After accessing the ATLAS gateway, connecting to a Point 1 computer, and running the command to launch the GUI, the user will be prompted to select the oscilloscope channels he or she intends to monitor. Once a channel is selected, the user will be able to choose the monitoring board that the scope channel is connected to, as well as the monitoring board channel. This information is available in a table (shown in Figure 3), on a Twiki page under LAr Online Development. The table will be kept updated with the current oscilloscope set up. The user can then enter the COOL ID of the trigger tower he or she wants to monitor on each scope channel, as well as select different options, if applicable. When the user clicks the configure button, the program starts running, configuring each of the relevant receiver monitoring boards.

3 | TRIGGER, TIMING, AND CONTROL

In order to test new hardware and software specific to Phase-I upgrades without interfering with the current set up, the LAr group has to put together a partition of components that will operate independently of the currently installed systems. One important component is the TTC system, which provides trigger, timing, and control functionalities; all parts of the detector and electronics should be synchronized with each other for accurate data taking. Currently at USA15, the TTC system for each sub-detector is composed of four boards: the LTPI, LTP, TTCvi, and TTCex (collectively referred to as the legacy TTC). The system as a whole transmits trigger timing signal from the central trigger processor (CTP) to the various sub-detector components. Unfortunately, these boards are no longer being manufactured. In order to perform the actions of the legacy TTC for new Phase-I partition testing, a single board called the ATLAS Local Trigger Interface (ALTI) was developed.

By performing all the functions of the LTPI, LTP, TTCvi, and TTCex boards on one single board, connections between different systems and opportunities for failure are minimized. In addition to the benefits of operating on a single board, the ALTI also has several features that do not exist in the legacy TTC system. The ALTI has an optical TTC analyzer and snapshot memory for input signals, meaning that it can read and interpret its own TTC signals as well as record the information to its own memory. There is also the possibility of a programmable phase shift for sub-detector timing and the implementation of a MiniCTP function so that the ALTI can “be its own master” and generate TTC signals as opposed to simply transmitting them. All of these factors make the ALTI very appealing, and it is largely expected to replace the legacy TTC system for the entirety of the LAr detector by the end of Phase-I, especially since the only alternative is to refurbish the old legacy TTC boards (which cannot be replaced since they are no longer being manufactured).

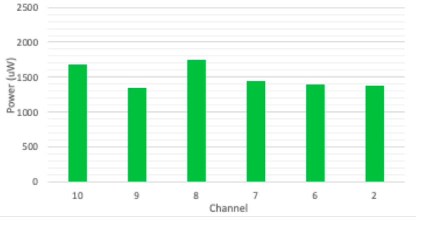
3.1 | Testing Procedure

In addition to the new features and decreased connections, the ALTI was designed to perform all of the same functions as the legacy system to an equal or better degree. One concern about the new system is that it will not be able to provide as much optical power for the TTCex signal transmission as the legacy TTCex board. In order to gain a better understanding of the power available to transmit the TTCex signal to the front end crates (FEC), the following power measurements were taken at 1310 nm (which is the wavelength of the TTCex signal).

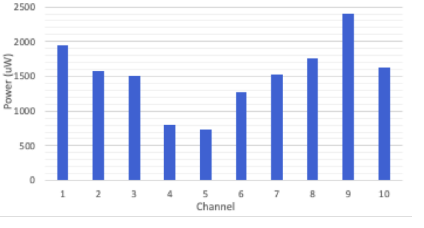
The optical power output from all accessible transmitter on the legacy TTCex boards was measured, both at the electronics maintenance facility (EMF) and at Point 1 (P1) to serve as a baseline. The optical power output from all 10 transmitters on the ALTI board was then measured, also at EMF and P1. On the ALTI board, measurements were taken using different configurations of the ALTI, specifically regarding the number of transmitter channels switched on. It is important to note that turning on all possible transmitter channels (1-10) did not have an effect on optical power output. To avoid redundancy, data taken when all channels are turned on are not included here.

Another set of measurements were taken, both on the legacy system and the ALTI, at an EMF set up that mimics the pathway the signal travels from the boards to the FEC. The signal traveled through a fiber of the same length as the fibers at P1, and an attenuator, and power was measured directly before the FEC to estimate how much optical power will actually be available to deliver the TTCex signal.

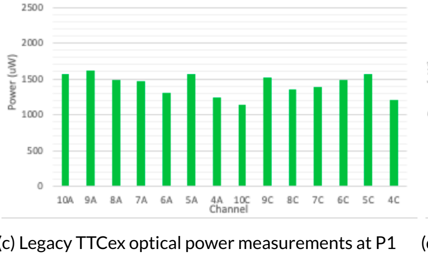
3.2 | Results



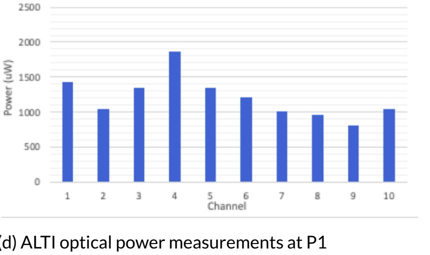
(a) Legacy TTCex optical power measurements at EMF



(b) ALTI optical power measurements at EMF



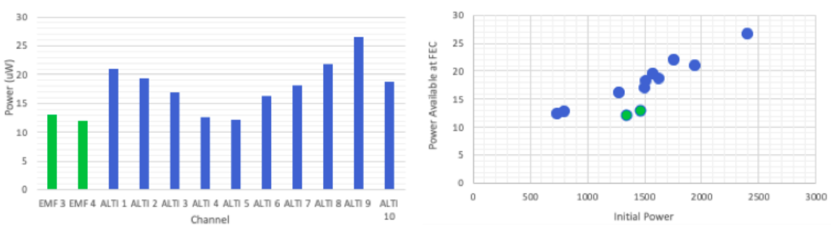
(c) Legacy TTCex optical power measurements at P1



(d) ALTI optical power measurements at P1

FIGURE 4 Optical power measurements at 1310 nm for different transmitter channels on Legacy TTCex and ALTI boards at EMF and P1. Legacy measurements are shown in green, while ALTI measurements are shown in blue.

Figures 4a, 4b, 4c, and 4d show the first set of measurements taken at EMF and at P1. One important feature to note is the high variation across ALTI board transmitters as compared to the variation across channels in the legacy system. Although the average power of the two systems is comparable, the range is around 400 μW for the legacy system at EMF and P1, while the power across ALTI transmitters ranges between 750 and 2500 μW at EMF and between 800 and 1850 μW at P1. Additionally, there is a distinctive pattern in the ALTI optical power at EMF that is inverted at P1. While the 4th and 5th transmitters produce the lowest power at EMF, these same transmitters produce the highest power at P1. This could be due to temperature dependence and differences in cooling techniques, or inherent differences between different boards.



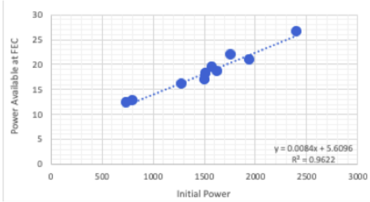
(a) Available power before FEC at EMF

(b) Available power as a function of initial power

FIGURE 5 Measurements taken directly before FEC at EMF, simulating available power after signal passes through the appropriate length of fiber and other electronics systems. Again, Legacy TTCex measurements are shown in green, while ALTI measurements are shown in blue

Figures 5a and 5b show the second set of measurements, which represent the actual available power to be delivered to the FEC at EMF, after the signal passes through the necessary fibers and attenuation. An interesting feature of these data is that, although the pattern of ALTI transmitter dependence is preserved through this transmission, the proportion of available power to initial power is significantly higher in the ALTI than in the legacy system. So much so, in fact, that even transmitters 4 and 5, which were measured to produce about 50% of the power of the legacy transmitters, produced power comparable to the legacy system directly before the FEC. This could be due to different frequency distributions of the TTCex signal between the ALTI and the legacy system, and it is a very encouraging result.

Since we did not have access to the front end crates at P1, we were unable to take the corresponding measurements at USA15. However, the relationship between initial power from ALTI transmitter channels and available power before the FEC is extremely linear. In order to estimate the power available to the FECs at P1, the linear regression formula was applied to power measurements from the ALTI transmitters at P1, and the results are shown in Figure 6 below.



(a) Available power as a function of initial power for ALTI measurements only. Linear regression and R^2 value shown on graph.

ALTI 1	17.60816
ALTI 2	14.4212
ALTI 3	16.97144
ALTI 4	21.29576
ALTI 5	16.90928
ALTI 6	15.7904
ALTI 7	14.07008
ALTI 8	13.724
ALTI 9	12.40856
ALTI 10	14.40272

(b) Predicted optical power available to FECs at P1, based on initial power measurements and linear dependence pf available power

FIGURE 6 Predicted values for available power at P1 FECs from different ALTI transmitter channels

3.3 | Conclusion

Although there is high variation over the ALTi transmitter channels, including some channels that produce significantly less power than the Legacy TTCex system, measurements of the power after the fiber and 20 db attenuator directly before the FEC at EMF indicate that there should be at least as much power delivered to FECs from the ALTI TTC signal as from the Legacy TTCex. Variation across transmitter channels need to be considered when implementing the new boards at USA15, and we should not assume that two ALTI boards will behave the same way.

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[2] The ATLAS Collaboration. "ATLAS Liquid Argon Calorimeter Phase-I Upgrade Technical Design Report," CERN, CERN-LHCC-2013-017, ATLAS-TDR-022-2013, 1 September 2013.