*Pres. VII Int'l. Conf. on Calorimetry
in High Energy Physics, Tucson, AZ,
9-14 November 1997.*

BNL -65097

CONF-971100--

OVERVIEW OF THE FRONT END ELECTRONICS FOR THE ATLAS LAR CALORIMETER*

S. Rescia

Brookhaven National Laboratory
Upton, NY 11973-5000

&

The ATLAS LARG Collaboration

November, 1997

*This work was supported in part by the U. S. Department of Energy: Contract No. DE-AC02-76CH00016.

OVERVIEW OF THE FRONT END ELECTRONICS FOR THE ATLAS LAR CALORIMETER

S. RESCIA[1] AND
THE ATLAS LARG COLLABORATION,
Brookhaven National Laboratory, Upton, NY 11973-5000, USA

Proposed experiments for the Large Hadron Collider (LHC) set new demands on calorimeter readout electronics. The very high energy and large luminosity of the collider call for a large number of high speed, large dynamic range readout channels which have to be carefully synchronized. The ATLAS liquid argon collaboration, after more than 5 years of R&D developments has now finalized the architecture of its front-end and read-out electronics, which have been written down in its Technical Design Report (TDR) [1]. An overview is presented below. More details, schematics and measurement results are shown in Ref. [1].

1 Requirements

As is detailed in [1], the electronics system has to read out several sub-detectors (presampler, e.m. calorimeters, hadronic end-cap and forward calorimeters) for a total of ~180,000 channels. These detectors deliver on their electrodes a triangular shaped current signal with a fast rise time (a few nanoseconds), decreasing to zero at the end of the drift time of ionization electrons in liquid argon (~450ns). The amplitude of the current varies from one sub-detector to another, but a value of 2.8 μA/GeV is typical for the e.m. accordion calorimeters. This signal is delivered on the detector impedance which, to a very good approximation, is a pure capacitance from as low as 20pF to as high as 3nF.

The main requirements for the readout electronics can be summarized as:

- The energy to be measured in a single read-out cell can be as large as ~3TeV. On the low end, energy from multiple interactions in a single crossing produces a distribution in deposited energy whose mean and width is ~50MeV. This distribution can be described statistically and is given the name "pile-up noise". The dynamic range to be covered is around 16 bits.
- The LArG e.m. calorimeters measure energy with a relative resolution of ~10%/√E, reaching a lower limit at high energy set by various imperfections of ~0.5%. The read-out electronics should not degrade this performance apart from unavoidable electronics noise which contributes significantly only at low energy. In particular, to maintain a small constant term in the energy

[1] This research was supported by the U.S. department of Energy: Contract No. DE-AC02-76CH00016

resolution, the readout system should be calibrated to better than 0.25% over the whole energy range.

- The energy of an electromagnetic cluster or of a jet is the sum of the energy measured in many cells (~100 to ~1000). Noise coherent over many cells should be kept to a minimum. More specifically the amount of coherent noise per cell should be less than 5% of the level of incoherent noise.

- The readout system should sample the signals at 40MHz and introduce no additional dead time. Since there is a 2.5 μs latency of the Level 1 trigger, a pipeline with a depth of at least 2.5 μs should be provided; in addition a large enough derandomizing buffer and a fast enough readout should allow for a maximum Level 1 trigger rate of up to 75kHz.

- Cells should be summed in trigger towers of 0.1×0.1 and the result sent out to the Level 1 processor. The required precision for the analog trigger sums is limited to no worse than 5%.

- A fair fraction of this electronics will be located in an area with limited access. High reliability is thus a concern. In addition, although radiation levels at that location are not very large (10^{12} n/cm^2/yr.; 20Gy/yr.; 10^{10} ionizing particles/cm^2/yr., this electronics does have to be radiation tolerant.

- The large number of channels (~180,000) involved requires a solution with low power consumption and at low cost.

2 Readout Architecture

Signals from the detectors are processed in various stages before being delivered to the DAQ system. Figure 1 shows the logical flow of information as well as the basic elements of the system: preamplifiers, shapers, pipeline memory, digitization, digital filtering. The data is then sent out to Level 2 buffers.

The harsh environment in the neighborhood of the detector (a limited space with poor accessibility in a non negligible radiation field) suggests a solution with remote electronics. On the other hand, the large signal dynamic range and the requirement of a very low level of coherent noise favors a solution with at least the preamplifiers on the detector. In addition, practical considerations concerning the size of the cable plant needed to extract the information indicate the need for multiplexing the data in any "off detector" solution. Detailed consideration of all of these points has led to the readout architecture sketched in Figure 1, which is common to all the LArG calorimeters.

Much of the digital electronics: control, digital filtering, Level 2 buffer, is located off the detector, in the control room. This limits digital activity close to sensitive analog electronics to the absolute minimum. The off-detector electronics will use standard non rad-hard techniques. It will be easily accessible, and can be delivered relatively late, i.e., it can use the latest available technology. It would also be more easily upgradable.

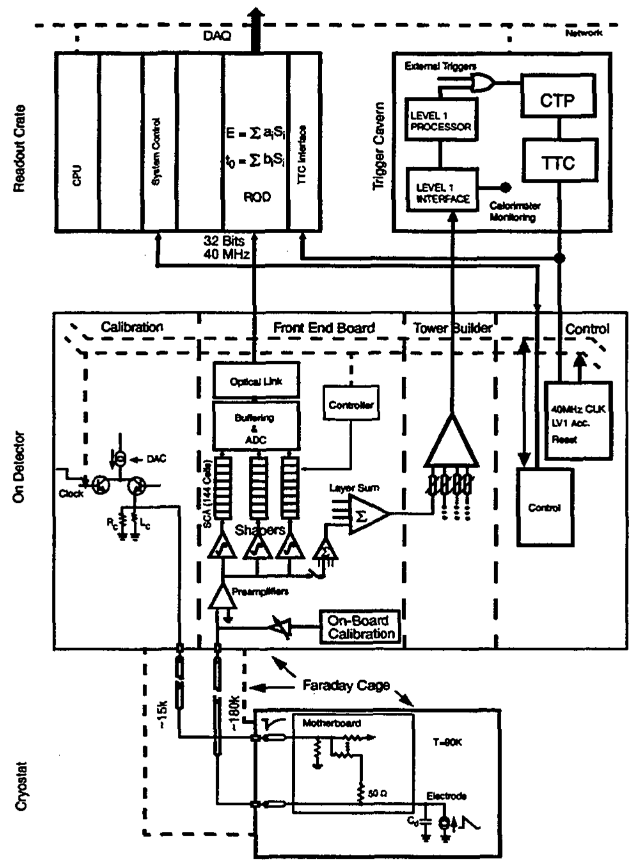

Figure 1: Block diagram of the readout electronics for all of the LARG calorimeters.

The sensitive analog electronics is housed on the detector, in front-end crates attached to the cold to warm feedthroughs, in the crack between barrel and end-cap calorimeters and at the rear of the end-caps. This crate is positioned on top of the warm feedthrough flange to provide for an extension of the cryostat Faraday cage.

This should efficiently shield the readout electronics against external electromagnetic radiation and minimize pick-up noise which might be coherent over many channels. In addition, this location keeps the warm part of signal and calibration cables to a minimum length and therefore minimizes the associated attenuation and noise. The very limited space puts constraints on the packaging of the electronics and on the power dissipation and cooling.

The front-end crate contains the following type of boards:

- Calibration Boards with precision pulsers;
- Front-End Boards (FEB) which
  - amplify and shape the analog signals,
  - sum by layer calorimeter cells to prepare the input signals for the tower builder board,
  - store the signals in an analog memory waiting for the decision by the first level of triggering,
  - digitize the selected pulses, and transmit on optical fibers the multiplexed digital results.
- Tower Builder Boards to perform the final level of analog summation to form trigger tower signals and to transmit the analog signals to the trigger room for digitization and processing by the Level 1 trigger processor.
- Control Boards to receive and distribute the 40MHz clock, the Level 1 accept signal, as well as other fast synchronous signals, and to receive and distribute control information to configure and control the various boards in the crate.
- Monitoring Boards to read out various monitors (temperature, strain gauges, argon purity).

3 The Front End System

Figure 1 shows schematically the Front-End crate with the various boards and links to the rest of the electronics.

3.1 Calibration Pulsers

The aim is to calibrate the readout electronics of the e.m. calorimeters to a precision better than 0.25 % to keep the constant term in the energy resolution small. Precisely known current pulses are injected as close as possible to the readout electrodes through high precision resistors located inside LAr, to simulate energy deposited in the calorimeters.

The pulser system covers the whole dynamic range and allows measurement of cross-talk between channels. Experience in the test beam with the RD3 2m prototype [2] revealed several systematic effects at the percent level. They are being carefully studied and there is good hope to meet the ATLAS goal.

The timing of the calibration pulses is set as to also reproduce the timing of physics signals, taking into account the variation of time of flight.

3.2 Preamplifiers

Preamplifiers must amplify the detector signal to be above the noise level of downstream stages and thus should be the only contributor to the electronics noise. They have to accept the whole signal dynamic range (16 bits) and have a high speed, requiring them to have a low input impedance. The high radiation levels in the e.m. endcap calorimeters led to the development of remote preamplifiers coupled to the detector through transmission lines [3]. This permits the preamplifiers to be located remotely, in the front-end crate, at room temperature and where there is a reduced radiation field. This technique was successfully tested in the beam by the RD3 collaboration. To minimize any coherent noise pick-up at the preamplifier input, these circuits are carefully enclosed in a double shielded Faraday cage. Precision energy measurement requires also to minimize the amount of dead material in front of the calorimeter. Transmission line coupled preamplifiers are ideal in this respect as there are no electronic circuits in the cold and in addition there is no need for hardware to cool them. Therefore this technique was also selected for the presampler and the strip section of the barrel calorimeter.

Depending on the cell capacitance, the cable impedance is either 50Ω (presampler and strip layers) or 25Ω (middle and back sections). The high speed silicon bipolar transistors used in these preamplifiers should provide adequate radiation hardness.

The mechanical structure of the Hadronic Endcap (parallel absorber plates with electrodes forming an electrostatic transformer structure) is very different from that of the electromagnetic part, and the ganging in depth of the cells is not as natural as in an accordion structure. In each gap, 50Ω transmission lines running radially bring signals to cold preamplifiers located at the periphery of the detector at a radius of ~2 meter. The radiation field in this area is manageable. There is no need to read out individual gaps and signals are therefore summed locally in groups of four or eight, and only the sum is sent outside of the cryostat. A GaAs chip containing 8 preamplifiers and two summing amplifiers/drivers has been developed for this purpose. These circuits are described in the J. Fent contribution elsewhere in these proceedings.

No presently available electronics can survive the intense radiation flux received by the Forward Calorimeter, so transmission line coupled preamplifiers are mandatory. Four 1.5 nF cells are ganged together to form a tower by means of a wide bandwidth transmission line transformer and are coupled via a 25 Ω transmission line to a remote preamplifier identical to the one used in the e.m. section. This solution allows also a fourfold reduction in the number of feed-through connections.

3.3 Shaping Amplifiers

Shapers are the input to the sampling stage, and one of their functions is to limit the system bandwidth to match the 40MHz sampling frequency. In addition, to minimize baseline shift, a bipolar $CR\text{-}RC^2$ prefilter is adopted. The shaping time constant is not critical, as downstream digital processing can effectively modify it (within limits), which is an advantage since the optimum shaping time is luminosity dependent. In order to maximize the range of luminosities over which the digital filtering functions optimally, a value of the hardware shaping time which minimizes the total noise (electronics⊕pile-up) at nominal luminosity is selected.

Precision calorimetry requires very good calibration of the electronics response. Experience has shown that this is best achieved in linear systems. However, it is not possible to handle without degradation the 16 bit dynamic range of the input signal on a single gain scale. Multiple ranges, each with a linear response can be used to extend the dynamic range. As explained below, a 12 bit pipeline and digitizing system is used. Two such systems could be used to span the entire range, but there is essentially no margin for unanticipated coherent noise. To be on the safe side, a system with three ranges has been chosen. Thus for each input, the shaper produces three output signals with gains approximately in the ratio 1/10/100; each gain has a dynamic range better than 12 bits. The resulting quantization error is negligible and this provides some immunity against coherent noise which would enter the system downstream of the shaper output.

The shaping amplifiers are built as integrated circuits using a bipolar technology, which should provide adequate radiation hardness. There are four shaper circuits (three gains each) in one IC. In addition the IC contains a linear mixer, which provides a first level of analog sum for the trigger. A set of capacitors and switches programmed during final testing allows to trim the peaking time to the desired value, to compensate for the large process variations.

3.4 Analog Pipeline/ADC

Signals from the shaper outputs are sampled at 40MHz and the results stored in an analog memory chip during the latency of the first level trigger (2.5 μs maximum). The phase of the sampling clock is adjusted so that one sample is near the peak of the pulse. To minimize digital noise pickup, the number of clock phases on the front-end board is kept to a minimum. The cabling has been carefully arranged to insure that each front-end board treats only cells from the same layer, as there the pulse shape is more or less constant but can vary considerably between layers, due to large differences in cell capacitances and in cable lengths.

Upon receipt of a trigger accept signal (75kHz maximum average) typically 5 samples around the peak of the pulse originating at the triggered crossing are extracted and multiplexed to a 12 bit ADC for digitization. One ADC digitizes the signals from eight calorimeter cells. The same gain is used for all samples in order to minimize systematic effects due to small differences in pulse shapes of the various gains. Results are sent off detector through digital optical links. The analog pipeline is 144 cells deep, giving, in addition to the 100 cells needed to cover the trigger latency, enough memory to store 8 events with 5 samples each. The dead time due to the finite size of this derandomizing buffer is very small, less than 0.5 %.

Results obtained in test beams with this kind of electronics, convincingly demonstrate that the required performance is achievable. A first attempt at producing a radiation hard chip has been done using the DMILL technology and the results are very encouraging. Evidence that commercial bipolar ADCs can resist the expected level of radiation has also been reported at the 2nd LEB conference [4].

3.5 Level 1 Sums

The trigger towers in the ATLAS calorimeters are everywhere divided in electromagnetic and hadronic sections, with a transverse size of 0.1×0.1. Inside of a trigger tower, all samplings in depth are summed together. There are typically 60 cells in a trigger tower.

Transverse energy is the important quantity for the first level trigger and the signal delivered should be proportional to E_T with saturation at or above 250GeV. The precision is limited to ~5 %. The noise level is another important parameter as it impacts both the capability to tag the bunch crossing for low energy cells in triggered events and the threshold that can be set on towers which should contain zero energy. The summation tree should degrade as little as possible the limit set by the preamplifier electronics noise.

An analog summation scheme has been adopted. The four channels in a shaper chip are first summed together and the signal shaped and amplified to minimize the effect of downstream noise. Cells from the same layer in depth are cabled to the same Front-end board; the summed signals from the shapers are summed again in a plug-in "layer sum board" which adapts to the varying number of channels per trigger tower and drives the layer sum signal to the Tower Builder board located in the same crate. Up to that point, inside of a trigger tower, signal shapes and gains are uniform enough (3 %)to be summed together without any adjustment. Summing in depth is done in the Tower builder, where provision is made for gain, shape, and timing adjustment between the various layers in depth. This board also drives the output signals to the first level trigger cavern on individually shielded twisted pair cables. If state-of-the-art analog optical links reach the required performance with respect to dynamic range, linearity, stability, and cost, they will also be considered. The signal is received in the trigger cavern, where an η-dependent gain factor is applied to bring all signals to a common transverse energy scale, to within 10%. They are then fed into the trigger processor (where a last calibration in E_T is applied) and also made available to a waveform monitoring station. This will be useful as a diagnostic tool for problem channels, for detecting possible pickup, and for measuring system parameters such as the noise autocorrelation function.

3.6 Read-Out Driver (ROD)

The read-out driver (ROD) performs the energy and time calculations for all channels of the LAr barrel and forward calorimeters by means of a linear combination of the 5 samples with pre-computed optimal filtering coefficients which are channel and luminosity dependent. This is a very computing intensive operation (~1TFlop), which is best performed by exploiting the natural parallelism of the problem.

3.7 Low Voltage Power, Cooling, Grounding

Quite a substantial amount of power (~250kW) is needed to supply the large number of electronics channels in the front-end system. No heat should be transferred to the surrounding detectors and water cooling is mandatory. The baseline is to use the "leakless water cooling" system as developed at CERN for the L3 experiment.

The distribution of this large amount of power has to be done carefully. Each front-end crate will have its own low voltage power supplies. These supplies will be "isolated". Strict control of ground loops will be observed, and there will be only one location where connection to ground is made. The cryostats with all their cryogenic lines and services will be electrically isolated.

4 Organization of the Work and Status

An intense R&D activity with many tests in the beam have led to the definition of the readout chain described in the TDR [1]. The activity is now moving to a construction phase, starting in 98 with ~5,000 channels for "module 0". Given the size and complexity of the project, rather strict rules have been set:

– For each part, detailed specifications have to be written up. The TDR [1] is a first step in that direction and provides the general guidelines. These documents will be approved by the people in charge of the construction of the corresponding parts and the electronics conveners.

– For each important item, design review meetings check the design and compare results obtained on prototypes against specifications. They will help in setting up milestones before undergoing on mass production. Such meetings have already been held on preamplifiers and shapers.

– Coherent noise can be very detrimental to the detector performance. In order to keep this kind of noise at an acceptable level, rather strict rules concerning decoupling of wire entering cryostat, links to the outside world, and cabling of power supplies will be defined.

– A policy of systematic tests will be enforced. This includes: test of radiation resistance, cold testing of every part which goes in the cold with a particular attention to cold preamplifiers, burn in of components and of full boards. Time has been reserved in the schedule for these important activities. An essential element in this testing policy is the "module 0" exercise.

Most of the elements described above (preamplifiers, shapers, pipelines, calibration boards) have now been produced as prototypes and tested to meet the specified requirements. The production for "module 0" has started at end of `97 and will constitute a major milestone before starting the full production.

5 Acknowledgment

This contribution is based on the introduction to the electronics section of the TDR, originally written by J. Colas and re-edited by C. de La Taille. Many useful discussions with M. Citterio, W. Cleland, A. Gara, J. Parsons, V. Radeka, W. Sippach as well as other members of the ATLAS collaboration are also gratefully acknowledged.

6 References

1. ATLAS Liquid Argon Technical Design Report CERN/LHCC/96-41, 15 Dec. '96 and references therein.
2. O.M. Gingrich et al. (RD3 collaboration) *NIM* **A364** (1995) 290-306.
3. R.L. Chase, C. de La Taille, S. Rescia and N. Sequin, Transmission Line Connection between Detector and Front End Electronics in Liquid Argon Calorimetry, *NIM* **A330** (1993) 228-242.
4. P.Denes, CMS Electromagnetic Calorimeter Readout, *Proceedings of the 2ndWorkshop on Electronics for LHC Experiments*, Balatonfured, Hungary, Sept. 23-27, 1996, 48-52.

Report Number (14) BNL--65097
CONF-971100--

Publ. Date (11) 199711
Sponsor Code (18) DOE/ER, XF
UC Category (19) UC-400, DOE/ER

DOE