ATLAS Level-1 Calorimeter Trigger: Subsystem Tests of a Jet/Energy sum Processor Module

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Abstract

The Level-1 Calorimeter Trigger consists of a Preprocessor, a Cluster Processor (CP), and a Jet/Energy-sum Processor (JEP). The CP and JEP receive digitised trigger-tower data from the Preprocessor and produce trigger multiplicities and total and missing energy for the final trigger decision. The trigger will also provide region-of-interest (RoI) information for the level-2 trigger and intermediate results of the data acquisition (DAQ) system for monitoring and diagnostics by using readout driver modules (ROD).
The Jet/Energy-sum Processor identifies and localises jets, and sums total and missing transverse energy information from the trigger data. The Jet/Energy Module (JEM) is the main module of the Jet/Energy-sum Processor. The JEM prototype is designed to be functionally identical to the final production module for ATLAS, and have the full number of channels. Three JEM prototypes have been built and successfully tested. Various test vector patterns were used to test the energy summation and the jet algorithms. Data communication between adjacent Jet/Energy-sum Modules and all other relevant modules of the Jet/Energy-sum Processor has been tested. Recent test results using the Jet/Energy Module prototypes are presented and discussed.

Summary

A highly selective, efficient and flexible first level trigger system is vital to achieve the physics goals of the ATLAS experiment. The ATLAS Level-1 Calorimeter Trigger provides information for the Level-1 trigger decision by identifying and counting clusters in the calorimeter data. They are considered candidates for jets, electrons/photons or hadronic taus. The total and missing transverse energy (SumET and ETmiss) is calculated, which is an important signature for many interesting physics processes. The algorithms are implemented in two processor systems: The Cluster Processor (CP) and the Jet/Energy-sum Processor (JEP). Those two processor systems send results for every bunch crossing to the Central Trigger Processor (CTP) which makes a Level-1 Accept (L1A) decision based on them, including additional data from the Muon Level-1 Trigger system. The latency of the Level-1 trigger is limited to 2 μsec. If the CTP accepts the event, the processors read out more detailed information on the types and locations of event features (Regions of Interest - RoI) and provides it to the Level-2 Trigger.

The Jet/Energy-sum Processor (JEP) covers the complete ATLAS calorimetry in the range of $-4.9 < \eta < 4.9$. The JEP must handle a large number of input signals and provide very fast logic. To minimise complexity of inter-module fanin-fanout caused by the use of sliding window algorithms, the system is subdivided into four quadrants, equivalent to the quadrants of the ATLAS calorimeters, which are each covered by a set of 8 Jet/Energy Modules (JEMs). For reasons of cost and flexibility, the JEM uses programmable logic devices (FPGAs). All algorithms are developed, simulated and implemented using the hardware description language VHDL. The JEMs are purely digital modules, controlled via VME interface.

Each JEM receives 88 data streams of 9-bit width via the serial links with each LHC bunch crossing (25 ns). These are the electromagnetic and hadronic components of jet elements 0.2×0.2 in $\eta - \phi$. The receiving link chips de-serialise the data back to 40 MHz parallel words. In the 11 Input Processor FPGAs, the input electromagnetic and hadronic data are summed to form the 10-bit Jet Elements, which are then sent to the JEMs central component, the MainProcessor FPGA. The jet finding algorithm requires not only data from one JEM, but it also needs to correctly analyse jets crossing the JEMs boundary. Therefore, the jet elements are also copied to the neighbouring JEMs via the backplane at 80 Mb/s. For the same reason, jet elements near the border of adjacent quadrants are duplicated in the PreProcessor and sent to JEMs in both quadrants. This results in a 11×7 area of jet elements available to the jet algorithms on one JEM. The energy sums are calculated from the 64 non-duplicated channels jet elements only.

The Main Processor calculates the local transverse energy (E_T) sum and the projections E_X and E_Y of E_T in X and Y direction for each $\Delta\phi$-bin.

These three energy values are coded to 8 bits each using a quad-linear compression scheme, and sent from each of the 16 JEMs located in one crate to a Common Merger Module running firmware that forms the crate energy sums and ultimately the trigger sums that are sent to the Central Trigger Processor (CTP).

The jet algorithm identifies clusters of energy deposition within overlapping windows

of adjustable size of 2×2, 3×3 or 4×4 jet elements. Jet locations are determined by looking for local maxima in regions of 2×2 jet elements. The total counts of jets above 8 different programmable transverse-energy thresholds and window sizes are sent to another Common Merger Module running firmware that forms crate jet multiplicities and ultimately the sums over the full trigger that are sent to the CTP.

In order to allow for standalone tests and diagnostics of the JEM, test patterns can be stored in "playback" memory blocks of 255 words depth located on the Input Processors. The data can be injected into the trigger data path to test transmission and processing further down the data chain. The results are sampled in local "spy" memories on the outputs of the Main Processor, also with a depth of 255 words.

In order to test the data reception of the JEM, 16 channels of LVDS serial data streams at 400 Mb/s were provided by LVDS Source modules simulating the data streams expected from the PreProcessor, covering two Input Processors. For long-term measurements of error rates, test patterns were injected into the real-time data path on the Input Processor. The spy-memory contents were analysed in the VME-PC and compared to the expected results obtained from software simulation of the module. Random numbers as well as simulated physics events were used as test data to show that the energy sum trigger algorithm works as expected. Random patterns were used for standalone tests of the JEM prototypes, filling all 64 channels used for the energy summation with 9-bit data (equivalent to 0-511 GeV). Overnight runs have been performed processing 6 million events, with all results for EX, EY and EY being as expected from the simulation. Furthermore, physics events from the ATLAS detector and trigger simulation of the channel tt $\rightarrow$ WW $\rightarrow$ 4 Jets have been processed. A set of 60 million events yielded the expected results for all events.

Three prototype modules were produced and tested. Currently the FPGAs carry near-final configurations allowing for full tests of the algorithms and the interfaces. The VME-crate contained a PC running on LINUX, and a multi-purpose data source/sink module and electronics for Timing and Trigger (TTC) distribution. The VME Interface of the JEM is used for control, and also allows *in situ* configuration of the FPGAs.

A total of 1.8 million events of random test patterns have been processed, where pairs of neighbouring Input Processors were fed. The results of the energy summation were shown to be correct. Signal lines from the Input Processors to the backplane and vice versa have been checked using loopback circuitry. The Readout-Interface implemented via HP G-Links at 800 Mb/s has been tested using a suitable data sink module. The JEM has been integrated into the ATLAS Online software environment.

Since all stand-alone tests of the electronics modules have been successful, two JEMs are being subjected to system tests in a setup simulating the final ATLAS environment. These measurements allow for thorough tests of all interfaces of the JEM to the outside world, encompassing both the physical interfaces as well as the software integration. A complete set of LVDS sources, the final backplane, Timing and Trigger distribution system and Readout System is available. Based on the positive results of this programme, the final Jet/Energy modules (Module 1) will be designed in 2003. Volume production of the 32 JEMs needed for ATLAS will start in 2004.