The ATLAS Level-1 Central Trigger Processor (CTP)

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Abstract

The ATLAS Level-1 Central Trigger Processor (CTP) combines information from the Level-1 calorimeter and muon trigger processors, as well as from other sources such as calibration triggers, and makes the final Level-1 Accept decision. The CTP synchronises the trigger inputs from different sources to the internal clock and aligns them with respect to the same bunch crossing. The algorithm used by the CTP to combine the different inputs allows events to be selected on the basis of trigger menus. The CTP provides trigger summary information to the data acquisition and to the Level-2 trigger system, and allows one to monitor various counters of bunch-by-bunch as well as accumulated information on the trigger inputs. The design of the CTP with its six different module types and two dedicated back-planes will be presented.

I. The Level-1 Trigger System

The ATLAS Level-1 trigger [1] is based on multiplicity information from clusters found in the calorimeters and from tracks found in dedicated muon trigger detectors. An overview of the ATLAS Level-1 trigger is shown in Figure 1.

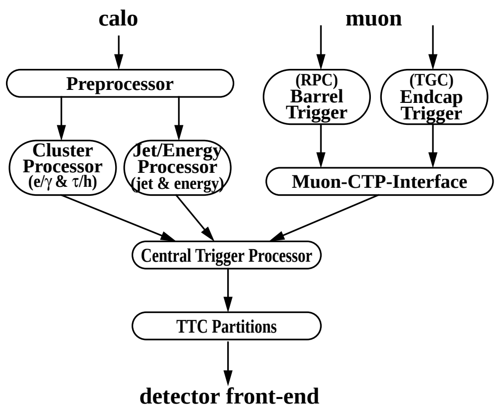

Figure 1: The Overview of the ATLAS Level-1 Trigger

The calorimeter [2] and muon [3] trigger processors provide trigger information to the CTP. The CTP forms the Level-1 Accept (L1A) and fans it out to the TTC partitions of the experiment. Each TTC partition contains one Local Trigger Processors (LTP), a TTC system proper [4], and a busy tree. The CTP provides trigger summary information to the Level-2 trigger system and to the data acquisition system [5]. It is configured, controlled and monitored by the Atlas Online system [6].

II. The Central Trigger Processor (CTP)

The CTP has many functions. They can be divided into three groups: the first group is the formation of the Level-1 trigger decision. The second group, actually fulfilled by the system CTP and LTP, is the broadcasting of the trigger information and the feeding back of sub-detectors signals to the CTP. The third group covers the CTP as a provider of data to, and a controlled system by the Data Acquisition system.

A. The Trigger Formation

The CTP receives trigger information from the calorimeter and muon trigger processors. The trigger information consists of multiplicities for electrons/photons, taus/hadrons, jets, and muons, and of flags for total transverse energy, total missing energy, and total jet transverse energy. The CTP also provides internal triggers from random generators, for bunch crossing groups, and pre-scaled clocks.

All triggers and their thresholds are programmable. Several thresholds are used concurrently for each type of trigger information. A total number of 160 input bits are taken into account by the CTP at any given time. The total number of input bits can be higher because of selection at the input to the CTP.

The CTP generates a L1A derived from the trigger inputs according to the Level-1 trigger menu. The Level-1 trigger menu consists of 160 trigger items each of which is a combination of one or more conditions on trigger inputs. E.g. if *"EM10 "* symbolizes the trigger input for electrons/photons with a transverse energy of at least 10 GeV, then *"1EM10"* symbolizes the condition of there being at least one electron/photon above that threshold. Several of these conditions can be combined to make a trigger item. Each trigger item also has a mask, a priority for the dead-time generated by the CTP, see Section III.C, and a pre-scaling factor. The L1A is the logical OR of all trigger items. An example of an excerpt of a Level-1 trigger menu is shown in Figure 2.

1 MU6	mask = ON, priority = LOW, pre-scaling = 1000
2MU6	mask = ON, priority = HIGH, pre-scaling = 1
1EM10 AND XE20	mask = ON, priority = LOW, pre-scaling = 1
...	

Figure 2: An Example of an Excerpt of a Level-1 Trigger Menu

The CTP not only generates the L1A but also provides with each L1A an 8-bit trigger type word which indicates the type of trigger and which can be used for event data processing in the detector front-end electronics. The CTP further provides mechanisms for generating a pre-pulse signal for the calibration of sub-detectors, and an event counter reset (ECR).

The formation of the trigger is required to be performed within four bunch crossings from input into the CTP until output of the L1A out of the CTP. This corresponds to a latency of 100 ns. The Level-1 trigger menu used for the trigger formation is likely to change frequently depending on the physics, beam and detector conditions. High flexibility has to be provided for the trigger formation.

B. The Trigger Broadcasting

The CTP sends all timing and trigger signals to the TTC partitions of the experiment. In the ATLAS experiment there are about 40 TTC partitions. Each TTC partition contains one LTP, a TTC system proper, and a busy tree. The TTC system proper has one TTCvi and a number of TTCex's, TTCtx's, TTCvx's, TTCoc's and TTCrx's. The busy tree is a fast feed-back tree for the detector front-end electronics to throttle the generation of L1As. It is based on the ATLAS ROD_BUSY module [7]. The trigger broadcasting is schematically shown in Figure 3.

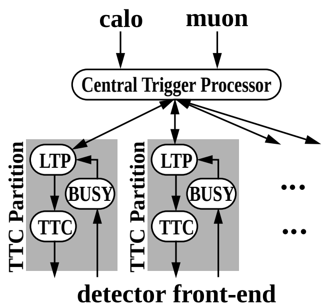

Figure 3: The Trigger Broadcasting

The LTP is a relatively new concept in ATLAS. The LTP provides input to the TTCvi, selecting from the signals coming from the CTP, signals generated internally in its own pattern generator, or signals from its local input. The last possibility allows several LTPs to be combined in a master-slave scheme. Several LTPs within the same sub-detector are daisy-chained.

C. The Data Acquisition

The CTP sends, at every L1A, Region-of-Interest (RoI) information to the Region-of-Interest Builder (RoIB) in the Level-2 trigger system for guidance of the Level-2 trigger algorithms.

The CTP further sends, at every L1A, trigger summary information to the Read-Out System (ROS) of the data acquisition system. This information is a superset of the RoI information and can contain several bunches before and after the triggering bunch for debugging and monitoring purposes.

The CTP also provides monitoring data: snapshots of incoming data, bunch-by-bunch monitoring of inputs, see Section III.D, and scalers of trigger inputs and trigger items before and after pre-scaling integrated over all bunches.

The CTP and the LTPs as well as the TTCvi and ROD_BUSY modules are configured, controlled and monitored by the ATLAS Online System [8].

III. THE DESIGN OF THE CTP

An overview of the design of the CTP is shown in Figure 4.

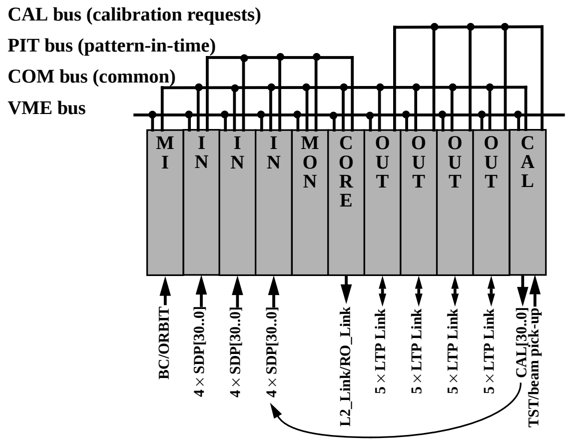

Figure 4: The CTP Design with its Modules, Backplanes, and Signals

The CTP consists of up to three input modules (CTP_IN), a core module for trigger formation and read-out (CTP_CORE), a bunch-by-bunch monitoring module (CTP_MON), up to four output modules connecting to the LTPs (CTP_OUT), a machine interface module for timing (CTP_MI), and a module for calibration requests from the sub-detectors (CTP_CAL).

The CTP modules are housed in a 9U VME64x crate. In addition to the standard VMEbus, the CTP modules also use dedicated buses for synchronized and aligned trigger inputs (PITbus, PIT = pattern in time), for the common timing and trigger signals (COMbus), and for the calibration requests from the sub-detectors (CALbus).

A. The CTP backplanes

The CTP uses two dedicated backplanes, which are shown in Figure 5

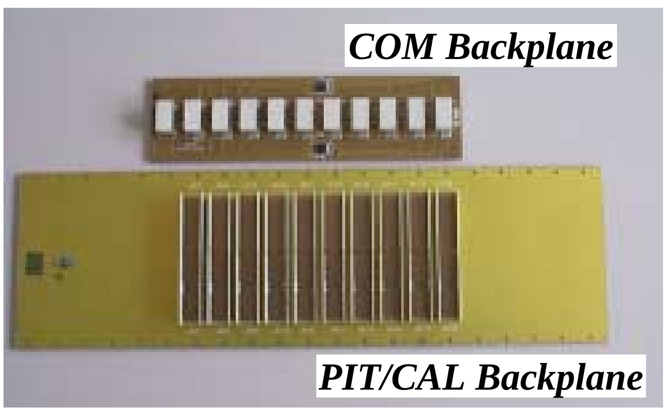

Figure 5: The CTP Backplanes

The first backplane contains both, the PITbus and the CALbus, since they do not overlap. The PITbus carries the synchronized and aligned trigger inputs from up to three CTP_IN modules to the CTP_MON and the CTP_CORE modules. The PITbus contains 160 signals, and extends over five VMEbus slots. The CALbus carries the calibration requests from up to four CTP_OUT modules to the CTP_CAL module. The CALbus contains 64 signals, extending over five VMEbus slots. The PIT/CAL backplane is mounted in the position of the J5/J6 connectors.

The second backplane contains the COMbus. The COMbus carries the timing signals, i.e. bunch crossing clock (BC) and LHC orbit (ORBIT), the trigger signals, i.e. L1A, the trigger type and the busy signal, and the control signals, i.e. event counter reset (ECR) and calibration pre-pulse. The COMbus extends over all eleven CTP modules, except for L1A, trigger type and pre-pulse which only go from the CTP_CORE module to all CTP_OUT modules and the CTP_CAL module. The busy signal is the wired-OR signal of the individual busy signals of all CTP modules. The COM backplane is mounted at the back of the J0 connector.

B. The CTP_IN Module

The block diagram of the CTP input module (CTP_IN) is shown in Figure 6.

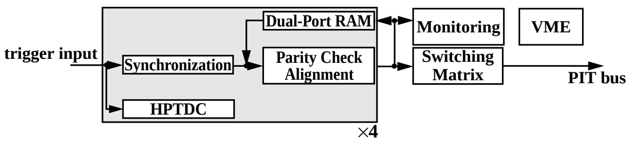

Figure 6: The Block Diagram of the CTP_IN Module

The CTP_IN module receives trigger inputs from the trigger processors, like the calorimeter or muon trigger processors or other sources. It synchronizes the trigger inputs with respect to the internal clock, checks their parity, and aligns them with respect to the bunch crossing identifier (BCID). The CTP_IN module selects and routes trigger inputs to be sent to the PITbus. It can store a snapshot of the trigger inputs into a test memory or provide trigger inputs from the test memory. The CTP_IN module also monitors the trigger inputs integrated over all bunches.

The CTP_IN module is based on FPGAs, dual-port memory for the test memory, switching matrices for the selection and routing of the trigger inputs, as well as on a CERN High-performance TDC (HPTDC) [9] for the phase measurement of the trigger inputs. The CTP_IN is currently under design.

C. The CTP_CORE Module

The CTP_CORE module receives and synchronizes the trigger inputs from the PITbus. It combines them with additional internal triggers to trigger items according to the Level-1 trigger menu and forms the L1A.

The CTP_CORE module also adds dead-time in order to prevent the detector front-end buffers from overrunning. Two leaky-bucket algorithms are used to count and limit the number of L1As generated over a given period of time. The two dead-times are associated to two different priorities of trigger items.

The CTP_CORE module sends the trigger results to the COMbus. It also sends RoI information to the RoIB of the Level-2 trigger system, and trigger summary to the ROS of the data acquisition system.

The basic idea for the CTP_CORE module is to use content-addressable memory for implementing the trigger items. Large FPGAs will be used for pre-scaling and for monitoring. The CTP_CORE module needs to be designed.

D. The CTP_MON Module

The block diagram of the CTP monitoring module (CTP_MON), see also Reference [10] is shown in Figure 7.

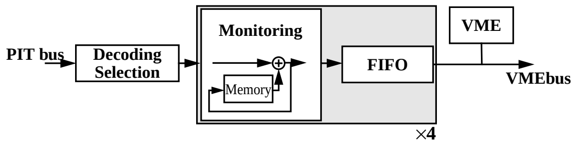

Figure 7: The Block Diagram of the CTP_MON Module

The CTP_MON module receives and synchronizes the trigger inputs from the PITbus. It decodes and selects the trigger inputs to be monitored. The CTP_MON module monitors trigger information on a bunch-by-bunch basis.

The CTP_MON module uses numerous segmented memories in four Altera Stratix FPGAs for the counters. A total of 2 MByte are required, i.e. 160 trigger inputs times 3564 bunch crossings times 30 bit. The CTP_MON which is shown in the photograph of Figure 8 is currently under test.

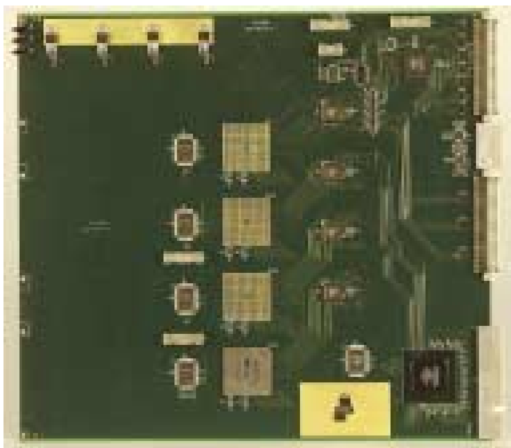

Figure 8: The Photograph of the CTP_MON Module

E. The CTP_OUT Module

The CTP_OUT module receives timing and trigger signals from the COMbus and fans them out to the LTPs of the sub-detectors. The CTP_OUT module also receives the busy signals and calibration requests from the LTPs. The CTP_OUT module masks and monitors the busy signal, and provides it the to the COMbus. It provides the calibration requests to the

CALbus.

The CTP_OUT module is a fan-out module which works between the CTP and the LTPs. It is planned to have only one link per sub-detector going to the first LTP, the other LTPs being daisy-chained. The link will carry thirteen bits from CTP_OUT to LTP and, four bits from LTP to CTP_OUT. The link will use low-skew cables. The CTP_OUT module needs to be designed.

F. The Local Trigger Processor (LTP)

The design of the LTP is based on an original idea of G. Perrot (LAPP Annecy, ATLAS LAr Calorimeter). It is a programmable input/output switch for timing, trigger and control signals. The input can be chosen among the signals from the CTP (from the CTP_OUT module) or from the LTP daisy-chain, from local input, or from the LTP's pattern generator. The output is available on the LTP daisy-chain, to the TTCvi and to local output. The functionality of the LTP is schematically shown in Figure 9

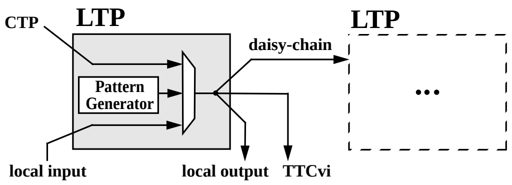

Figure 9: The Design of the LTP

The LTP allows each partition to run in one of the following modes:

- In *common* mode the CTP drives the TTC partition. This is the normal mode for physics running.
- In *stand-alone* mode the LTP drives the TTC partition from a local input or its pattern generator. This is the mode for calibration or debugging of a single partition.
- Two or more TTC partitions can be used in *combined mode* by programming one LTP as the master and by programming the other LTPs as slaves. This mode allows to run several TTC partitions together for calibration runs with more than one sub-detector, e.g. calorimeter detector and calorimeter trigger.

The design of the LTP has been discussed within ATLAS with all sub-detectors [11]. The LTP is currently under design and prototype modules are expected to become available in the Spring of 2004.

G. The CTP_MI Module

The block diagram of the CTP_MI module is shown in Figure 10.

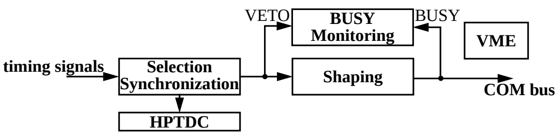

Figure 10: The Block Diagram of the CTP_MI Module

The CTP_MI module receives timing signals from the LHC via the TTCmi, or generates them locally. It controls and monitors the internal and external busy signals. The CTP_MI module sends the timing signals to the COMbus.

The CTP_MI module is based on FPGAs and the CERN high-performance TDC (HPTDC) [9] for phase measurement. The module is currently under design.

H. The CTP_CAL Module

The CTP_CAL module time-multiplexes the calibration requests on the CALbus per LHC ORBIT and sends them to the CTP_IN. The CTP_CAL module also contains other external inputs for beam pick-up monitors and test triggers which are provided to the CTP_IN module. The CTP_CAL module needs to be designed.

IV. CONCLUSION

The design of the CTP is well under way. The CTP has been defined to work on 160 external trigger inputs, selected from up to 300 signals, plus a number of internal triggers. It will generate 160 trigger items, of which the logical OR is the L1A. The CTP is based on six different modules and two different backplanes. One module and both backplanes have been manufactured and are being tested. Some other modules are currently under design and will be manufactured until the End of 2003. A full prototype of the CTP shall be available in the Summer of 2004. It is planned to participate with the CTP in a combined testbeam with other ATLAS sub-detectors and trigger processors in the Autumn of 2004.

A new module for the interface between the CTP and the sub-detectors' TTC partitions has been introduced, the LTP. The LTP allows one to run any TTC partition in common mode with timing and trigger signals from the CTP, or to run in stand-alone mode with timing and trigger signals from the LTP's pattern generator, from some other local input, or from another LTP. The LTP has been defined in consultation with all sub-detectors of ATLAS. The module is currently under design. Prototypes shall be available in the Spring of 2004.

The TTC partitions of the sub-detectors have been defined. The TTC system and its modules have been defined, as well as the ROD_BUSY module for the busy tree. The modules for the TTC system and the busy tree are being manufactured. Cabling and installation of the TTC partitions in the experimental area is being planned.

V. REFERENCES

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