The Compact Muon Solenoid Experiment

Conference Report

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The CMS Timing Control and Distribution System

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Abstract

The Compact Muon Solenoid (CMS) experiment operating at the CERN (European Laboratory for Nuclear Physics) Large Hadron Collider (LHC) is in the process of upgrading several of its detector systems. Adding more individual detector components brings the need to test and commission those components separately from existing ones so as not to compromise physics data-taking. The CMS Trigger, Timing and Control (TTC) system had reached its limits in terms of the number of separate elements (partitions) that could be supported. A new Timing and Control Distribution System (TCDS) has been designed, built and commissioned in order to overcome this limit. It also brings additional functionality to facilitate parallel commissioning of new detector elements. We describe the new TCDS system and its components and show results from the first operational experience with the TCDS system in CMS.

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Index Terms—timing, trigger, FPGA, MicroTCA.

I. INTRODUCTION

CMS (the Compact Muon Solenoid) [1] has been operating at the world's most powerful particle accelerator – the Large Hadron Collider (LHC) [2] – since 2009. The LHC, when it reaches its design performance, will collide protons with centre of mass energy of 14 TeV and a peak luminosity of $10^{34} \text{ cm}^{-2}\text{s}^{-1}$. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. Extensive forward calorimetry complements the coverage provided by the barrel and endcap detectors. It is of paramount importance that all parts of the detector are synchronized to each other and to the passage of particles from the LHC. The original CMS Timing, Trigger, and Control (TTC) system [3] made this possible during the first period of data-taking at the LHC from 2009 to 2012. Detector upgrades foreseen to

be completed in the coming years require a greater number of individual detector partitions to be available than were available in the TTC system. This along with the upcoming upgrade of the CMS Global Trigger (GT) [4] allowed us to re-define the boundary between the previous TTC and GT systems and to separate the pure trigger functionality from that of controlling and synchronizing the data-taking of CMS. The new CMS Timing and Control Distribution System (TCDS) has been designed, built and installed in CMS during the first Long Shutdown (LS1) of the LHC and is now routinely used to control CMS data-taking.

II. CMS TCDS OVERVIEW

The CMS TCDS distributes timing and control (synchronization) data flowing to the detector front-ends and receives back status information related to the readiness of the detector systems to handle more triggers. In the downstream (towards the detector) direction, the clock reference that is distributed along with the fast control information is synchronous with the particles in the LHC accelerator, which is required to keep the data-taking in step across the various detector systems that make up CMS. The detector systems are able to provide basic status information (TTS) regarding their readiness for accepting more triggers by sending data back to the TCDS in the upstream direction.

Figure 1 shows an overview of the different parts that make up the TCDS. Physics triggers are received from the GT (existing and upgraded) system by the Central Partition Manager (CPM) module that is the controller responsible for orchestrating global data-taking in CMS that involves multiple sub-detectors. The system clock (received from the LHC RF systems) is also received by the CPM for further distribution. Residing in the same crate are a number of Local Partition Managers (LPMs) that are able to orchestrate local data-taking for a particular sub-detector in CMS. Each LPM contains eight identical firmware blocks that translate the generic synchronization commands emitted by the Partition Manager (Central or Local) into the sub-detector specific commands that are understood by the detector front-ends. The final module in the chain (of which there is one per detector partition) is the Partition Interface (PI). The PI serves as a fan-out for downstream clock and data (TTC), and an intelligent OR-based fan-in for the status information (TTS) coming back upstream.

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Fig. 1. Overview of the CMS TCDS system.

An important new feature of the TCDS system is that it enables existing systems that interfaced to the pre-LS1 TTC system to be connected along with upgrading systems that are based on the new common CMS readout module (AMC13 [5]). The latter provides a bi-directional optical interface in contrast to the legacy systems where the TTC data are optical while the TTS are electrical signals.

III. TCDS HARDWARE OVERVIEW

The TCDS is based on the MicroTCA family of standards, using full size, double width AMC (Advanced Mezzanine Card) modules in a 12-slot MicroTCA shelf with a telecom backplane and redundant power modules. In the partition manager crate, the backplane is used to distribute clock and fast timing commands from the CPM to the LPMs as well. These data are relatively low speed, being a 40 MHz clock and 160 Mb/s data. The backplane is also used to transmit control data downstream for the synchronization of the new CMS luminosity data acquisition system (LumiDAQ), this time using high-speed serial links running at 5 Gb/s. High speed serial links operating at 5 Gb/s are also used to aggregate the TTS information and send it from the LPMs to the CPM. This is where the use of the MicroTCA architecture is a major benefit to the TCDS project.

The CPM module reuses the same hardware as the AMC13 together with custom firmware. The LPM and PI modules are based upon the same AMC, the FC7 [6], and are differentiated by the choice of FMCs (FPGA Mezzanine Cards: I/O modules providing the connectivity to the FPGA on the AMC) mounted on the FC7. A photograph of the PI is shown in Figure 2.

The system as currently installed at CMS consists of one partition manager crate and five partition interface crates, distributed over two adjacent racks. Each rack is equipped with a separate AC-DC converter, providing 48 V to a redundant pair of power modules in each crate. The AC-DC converters in turn are also equipped with four parallel power modules to provide 'three-out-of-four' redundancy.

IV. TCDS INSTALLATION IN CMS

The TCDS was installed in CMS in two phases: in the first phase a demonstrator was installed in parallel with the existing TTC system to allow sub-detectors to become familiar with

Fig. 2. Photo of a PI module showing FC7 carrier and FMCs.

the TCDS hardware and software functionality; and in the second phase the TTC system was removed and replaced with the full TCDS at which point CMS fully switched over to TCDS. This was the first time a major system in CMS installed MicroTCA infrastructure and thus provided a model to be copied in subsequent installations, notably for the upgrades of the CMS Trigger systems.

V. OPERATIONAL EXPERIENCE

The TCDS system was installed in CMS six months before the LHC restart in 2015. This time was used to commission the various systems and finalize the functionality required for data-taking with particle collisions in CMS. A particularly important part of the validation of the installation was the verification of the latency added to the existing system. This has been verified to be two bunch crossings (i.e., 25 ns) more than expected from initial assessment. The main reason for this has been found to be the additional interfaces necessary for the transmission of the Physics Trigger between the TCDS and the existing GT.

VI. SUMMARY AND CONCLUSION

The CMS TCDS system has successfully applied the MicroTCA system architecture to the design, production, installation and operation of a timing distribution system for a major particle physics experiment. The TCDS system represents the first major installation of MicroTCA hardware in CMS and as such provides a reference for future applications of this technology in particle physics applications.

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REFERENCES

- [1] S. Chatrchyan *et al.*, "The CMS experiment at the CERN LHC," *JINST*, vol. 3, p. S08004, 2008.
- [2] CERN. The Large Hadron Collider. [Online]. Available: <http://cern.ch/lhc>

- [3] J. Troska, E. Corrin, T. Rohlev, J. Varela, and Y. Kojevnikov, "Implementation of the timing, trigger and control system of the CMS experiment," in *Real Time Conference, 2005. 14th IEEE-NPSS*, June 2005, pp. 4 pp.–.
- [4] A. Tapper and D. Acosta, "CMS Technical Design Report for the Level-1 Trigger Upgrade," CERN, Geneva, Tech. Rep. CERN-LHCC-2013-011. CMS-TDR-12, Jun 2013, additional contacts: Jeffrey Spalding, Fermilab, Jeffrey.Spalding@cern.ch Didier Contardo, Universite Claude Bernard-Lyon I, didier.claude.contardo@cern.ch. [Online]. Available: <http://cds.cern.ch/record/1556311>
- [5] E. Hazen, A. Heister, C. Hill, J. Rohlf, S. X. Wu, and D. Zou, "The AMC13XG: a new generation clock/timing/DAQ module for CMS MicroTCA," *Journal of Instrumentation*, vol. 8, no. 12, p. C12036, 2013. [Online]. Available: <http://stacks.iop.org/1748-0221/8/i=12/a=C12036>
- [6] M. Pesaresi, M. B. Marin, G. Hall, M. Hansen, G. Iles, A. Rose, F. Vasey, and P. Vichoudis, "The FC7 AMC for generic DAQ and control applications in CMS," *Journal of Instrumentation*, vol. 10, no. 03, p. C03036, 2015. [Online]. Available: <http://stacks.iop.org/1748-0221/10/i=03/a=C03036>