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Installation and Commissioning of the CMS Timing, Trigger and Control Distribution System

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The Timing, Trigger and Control (TTC) distribution system must ensure high-quality clocking of the CMS experiment to allow the physics potential of the LHC machine to be fully exploited. This key system provides the synchronization tools –bunch clock, first level Triggers and fast commands –that enable all sub-detector systems to take data for the same LHC collision. The challenges of its installation are described, along with the tools used to commission the system and verify that its design goals are met.

Summary

The Compact Muon Solenoid (CMS) detector is currently being assembled at the CERN Large Hadron Collider (LHC), due to start operation in 2007. The LHC will collide bunches of protons with a bunch crossing frequency of 40.0789MHz at an energy of 7TeV/beam. Given the high target luminosity of 10^34/cm2/s it is of paramount importance that data coming from all parts of the CMS detector be assigned to the correct (same) collision. The Timing, Trigger and Control (TTC) distribution system that provides all front-end and back-end components in CMS with the bunch clock is thus a key component in the overall system without which all others cannot take beam-synchronous data. There are over 10 million individual detector channels spread over 10 sub-detectors systems that rely on the TTC distribution system. The CMS TTC system is based upon a common LHC-wide development that has been adapted to the specific needs of the CMS experiment. The TTC system distributes the bunch clock, First-level Trigger (L1A) and fast control signals from a central location in the CMS underground counting room to the sub-detector electronics located in both the counting room and on the CMS detector itself. Fast control signals are used to synchronize the sub-detector systems with one another and with the LHC machine –an example signal is the "Orbit"pulse which marks the start of a turn in the machine every 3564 clocks and is a fundamental tool for synchronization to the LHC machine's bunch structure.

The installed TTC system must be able to transmit the bunch clock of the LHC that is expected to be 40.0789MHz with a tolerance of at least ±3kHz to allow for beam path variations. Requirements on the Jitter of the clock signal come from two major sources: the timing accuracy intrinsic to the various sub-detectors of CMS and the requirements of high-speed serial links that are widely used in the readout systems. For the detector types used in CMS, the former requirement is rather loose –of the order of 1ns. It is the requirement placed on the reference clocks for synchronous high-speed serial links that read-out data at speeds above 1Gb/s across many sub-detector systems in CMS which provides the most stringent constraint of maximum jitter of 350ps pk-pk. While care has been taken during the design and testing of the electronic ASICs and modules that make up the system to ensure that these requirements are met, the installation and commissioning of the TTC system provide the final in-situ verification.

The top of the CMS TTC distribution system is installed over two 52U-high racks in ten 6U VME crates. These racks are located approximately 100m below the surface in the CMS underground counting room in a central position to minimize the signal path for time-critical signals such as the L1A Trigger. Nine of the ten VME crates house the distribution electronics for the sub-detectors of CMS while electronics in the tenth receives the beam timing signals (Clock and Orbit) from the LHC RF systems and fans those signals out to the sub-detector TTC crates. Each sub-detector crate holds

one Local Trigger Controller (LTC) VME module, up to six TTC CMS Interface (TTCci) modules and up to six TTC Encoder and Transmitter (TTCex) modules. The LTC is used by sub-detectors to provide the sequences of Triggers and Fast Commands necessary for testing and commissioning in the absence of a Central (Global) Trigger system. These sequences are translated by the TTCci module into the commands specific to that sub-detector system and these commands are then encoded and sent to the sub-detector over single-mode optical fiber by the TTCex modules. Fibers are installed within the counting room to reach the racks used by the individual sub-detectors, from where the signals are split optically and further distributed to the on-detector electronics.
Once installed, the correct functioning of the system must be verified.
Commissioning of the TTC distribution in CMS will proceed in two phases: verification of signal integrity on installed lines that is carried out before hand-over to each sub-detector; followed by a period of signal verification and synchronization testing that is carried out with the sub-detectors. Software tools based on CMS-wide Data Acquisition framework XDAQ have been put in place to allow the installers to rapidly check the quality of the connections that are made. These are augmented by detailed measurements of the time stability of the central system in the first instance, followed by measurements of the signals received at the ends of the distribution system. Once the system is sufficiently stable the integration of sub-detector systems with the central systems is done one system at time. In this phase the synchronization of the entire system is built up step by step at the end of which the whole of CMS will be ready to sample the LHC beams when they turn on. The overall synchronization scheme will be described in detail for the individual systems and then the bringing together of all the systems to form a coherent whole. Once CMS is in this state a global phase shift of the master clock will be all that will be required to bring the detector sampling into phase with the actual particle crossings in the LHC.

Primary author: Dr TROSKA, Jan (CERN)

Co-authors: Dr HOLZNER, Andre (CERN); Dr CHRISTIANSEN, Tim (CERN)

Presenter: Dr TROSKA, Jan (CERN)

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