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CMS DT Upgrade The Sector Collector Relocation

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Abstract

The Sector Collector relocation is the first stage of the upgrade program for the Drift Tubes subdetector of the CMS experiment. It was accomplished during Long Shutdown 2013-2014, and consisted in the relocation of the second-level trigger and readout electronics from the experimental to the service cavern, relieving the environmental constraints and improving accessibility for maintenance and upgrade. Extending the electrical links would degrade reliability, so the information is converted to optical with a custom system capable of dealing with the DC-unbalanced data. Initially, present electronics are used, so optical-to-copper conversion has also been installed.

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CMS DT Upgrade: The Sector Collector Relocation

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ABSTRACT: The Sector Collector relocation is the first stage of the upgrade program for the Drift Tubes subdetector of the CMS experiment. It was accomplished during Long Shutdown 2013-2014, and consisted in the relocation of the second-level trigger and readout electronics from the experimental to the service cavern, relieving the environmental constraints and improving accessibility for maintenance and upgrade. Extending the electrical links would degrade reliability, so the information is converted to optical with a custom system capable of dealing with the DC-unbalanced data. Initially, present electronics are used, so optical-to-copper conversion has also been installed.

KEYWORDS: Data acquisition circuits; Trigger concepts and systems (hardware); Radiation-hard electronics; Large detector-systems performance.

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1. Introduction

The Compact Muon Solenoid (CMS) experiment (Cessy, France) is one of the four detectors that record data from the high-energy collisions produced by the Large Hadron Collider (LHC). The outer layer of CMS comprises different types of muon detectors, one of them being the Drift Tubes (DT) [1], which is responsible for muon identification, and precise momentum measurement and triggering in the CMS barrel. The 172,000 drift tubes are organized into 250 chambers, which, in term, are grouped in 60 sectors, each covering a $\sim 30^\circ$ angle of one of the five wheels that make the CMS barrel.

A schematic of the different electronic systems carrying out the acquisition, processing and delivery of the information generated in the DTs as they were before the relocation is shown in figure 1. The signal generated when a charged particle traverses the drift tube cell is amplified and discriminated by the front-end electronics, and then digitized in the electronics contained in the so-called minicrates, in the detector wheels. The trigger and readout information generated in the minicrates is sent to the second level of the electronic chain, the Sector Collector (SC), which was located in the racks on the sides of the CMS detector, and, thus, inside the Underground Experimental Cavern (UXC). The SC is a complex system composed of 10 9U VME crates, hosting mainly the Trigger Sector Collector (TSC) boards and the Read-Out Server (ROS) boards, along with different boards for slow control and monitoring, TTC (trigger, timing and control) signal distribution, power distribution, etc. They carry out readout data merging and quality monitoring (ROS) [2] and trigger data multiplexing and sorting (TSC) [3], and deliver the result to the DT' Track Finder (DTTF) and the Device-Dependent Unit (DDU), which are both located in the Underground Service Cavern (USC).

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sector, and in this case 2 MTP connectors are used, as well as a single channel that is output and later merged into MTP cords.

The motherboard is in charge of configuration and monitoring of the laser driver. Monitoring is done by means of 12 ADCs (3 per mezzanine), and communication with the laser drivers is done over two wire Inter Integrated Circuit (I2C) protocol. Control of this process is done in two A3P600L ProASIC3L FPGAs from Microsemi, arranged in parallel for redundancy. Each FPGA is connected to an independent Controller Area Network (CAN) bus on the backplane.

Figure 3. Picture of the CUOF board.

In this system, it is very important to be able to fine tune the bias and modulation setting of the laser driver in order to be able to correctly transmit the trigger system signal, which is not DC-balanced.

2.1 Crate, power distribution and slow control

The crates that were used by the Sector Collector have been adapted and reused for the CUOF system. The top backplane, which served for VME communication, is no longer used, and a new backplane has been designed and installed in the middle slot for power distribution and slow control. The bottom backplane, previously devoted to TTC signal distribution, is no longer needed and has been removed in order to allow the connection of the fibre optic cables to the CUOF's output MTP connectors.

The A3100 CAEN DC-DC modules that were previously used for powering the Sector Collector have been transformed into A3050 modules which deliver 2 independent power supply channels. In each crate (2 per wheel), four different power partitions exist, so that the impact of a failure that affects a whole partition is minimized. The power consumption of the system has been cut in half with respect to the Sector Collector.

In order to increase robustness against failures and single-event upsets, the slow control chain has been made completely redundant. There are two different CAN buses that connect to each CUOF board in each wheel, and two Optical Control Boards (OCB) that interface this bus to optical in order to extend the bus to the Ethernet Control Boards (ECB) which are located in the service cavern. These boards bridge the CAN bus to CMS's TCP/IP network.

3. Optical fibres

For the optical communication, 850 nm transmission over OM3 50/125 μm fibres was chosen. The fibres are arranged in 60 trunk cables, 96 fibres each, grouped in 8 MTP cords for a total of 5760 fibres, which include the 3500 links needed plus spares. The MTP connectors at each end

of the trunk cable have been staggered in order to minimize the diameter of the bunch and ease installation through the tunnels that communicate UXC and USC.

One very important requirement for the fibres is that the propagation delays are closely matched, in order to preserve the phase relationship among trigger links, because there is no way to compensate for this in the TSC boards. The fibres were ordered to Draka by the CERN-TS-EL-OF group with this requirement, which was later verified by us by measuring the propagation delay of all of the fibres. In order to do this, a custom, low-cost, high-precision system was developed [6], based on the transit-time oscillation method. A self-sustained oscillation was started in a closed loop composed by the optical fibre cord to measure, and an optical receiver connected to an optical transmitter. The frequency of the resulting oscillation is directly related to the fibre's propagation delay, and was measured by an FPGA and displayed in computer, with an estimated accuracy in the picoseconds range. As a desirable side effect, this serves also as a continuity check for all the fibres.

The delay uniformity was found to be excellent, and fully compliant with requirements, with inter-cable differences below 2.5 ns, and same-MTP differences under 1 ns. A histogram of the maximum to minimum propagation time difference within each 12-fibres cord is represented in figure 4.

Figure 4. Histogram of same-MTP maximum delay differences.

4. OFCU system

The main goal of the new electronics developed for installation in the service cavern is to convert the optical links back to electrical (LVDS) in order to be able to use the Sector Collector electronics (TSC and ROS boards) in their new location. The TSC and ROS boards have been moved to USC, but they do not keep the same arrangement they had in UXC: before the TSC and ROS boards were interleaved in each crate, and now the trigger and readout crates are separated, due to space availability and to minimize latency of the trigger. Former backplane communication between the two of them is now impossible. In order to solve this, an optical link has been setup between both systems. Each TSC and ROS board communicate by means of pass-through backplane connectors with Rear Transition Module (RTM) boards plugged back-to-back. These RTM boards take care of this communication.

10 Wiener crates were purchased for this purpose, and each one hosts in its final configuration 12 9U boards (ROS or TSC depending on the crate), their respective RTMs, the TIM (TTC Interface Module), a Linco VME interface board, and a VMEpatch board. This VMEpatch board was developed to allow slow control communication to the RTM modules through the VME link, bridging it to a custom protocol in the middle backplane, because the

RTMs are 6U modules and do not connect to the VME backplane (which sits on top of the crate).

4.1 Trigger OFCU

The trigger optical to electrical conversion is done in a separate crate by the OFCU-TRG board, which is a 3U board that converts 24 links from optical signal from 2 MTP connectors on the back to LVDS signal on RJ45 connectors on the front.

The conversion is based on a commercial parallel optics receiver from AVAGO (HFBR-782BEPZ). The signal path in these boards is clean, parallel and free of skew between channels, which is important because of the phase uniformity requirement of the trigger. Rear-front configuration allows easy and tangle-free cable routing. The system features standalone operation (ready after power up), although boards do also have some monitoring capabilities. Power and monitoring are transmitted by means of a connection to a narrow backplane on the optical side.

Figure 5. OFCU-TRG board.

4.2 Readout OFCU and TSC-ROS link

The readout optical to electrical conversion is carried out by the OFCU-RO boards, which are located as RTM in the same crate as the ROS. It is based on the same receiver from AVAGO, and also features semi-autonomous operation. In this case, there are no skew requirements to be met. The LVDS signals are output to RJ45 on the back of the crate, and are carried to the ROS on the front by foiled twisted pair cables that run through openings in the crate.

As stated before, the OFCU-RO also carries out the reception of the TSC-ROS Link from a similar board plugged in the RTM of the TSC, the TSCrear. This link carries debug data information from the TSC for inclusion in the readout stream. The TSCrear receives this information carrying out the handshake that the TSC expects, and sends it over the 800 Mbps optical link. The OFCU-RO receives the data, makes some quality checks, and delivers it to the ROS when requested. This operation is completely transparent to the TSC and ROS boards.

Figure 6. OFCU-RO (left) and TSCrear (right) boards.

5. System validation

System validation is critical due to the high reliability needed. The most relevant challenge to address is the correct transmission of the TSC links over optical links, due to the severe unbalance of its 480 Mbps links, which have, during idle pattern, an 8 % duty cycle. In order to achieve this, it is important to fine-tune the bias and modulation current of the laser driver, to pair it with the receiver (several driver/laser/receiver combinations were evaluated). Eye diagrams of the output of the CUOF were taken with PRBS, trigger-like and readout-like patterns. As expected, the one corresponding to trigger patterns was the least open, but still sufficient for reliable transmission.

To aid in system validation, custom versatile Pattern Unit boards (both for transmitter and receiver) were developed. These boards are able to simulate the output of a minicrate and receive and verify the data at the other end, and can be used to validate a full sector of the system (up to 32 links simultaneously) without having the complete hardware chain.

A great effort was made to optimize and characterize the behaviour of the optical chain for the trigger links under all possible circumstances. A test stand was set-up that allowed the injection of custom patterns and the bit-by-bit verification of the output. Different bias/modulation working regimes were tested. An extensive test studying all possible link patterns, with their corresponding idle times, was done to verify that no systematic pattern-dependent errors arose. The following limits were set: single link bit error rate $< 1.4 \times 10^{-14}$, systematic error occurring when transmitting valid trigger data per chamber $< 0.2 \times 10^{-10}$, pattern dependent systematic error $< 1.2 \times 10^{-7}$. The electrical output was attenuated to account for the line equalizer at the input of the TSC.

In order to validate the CUOF's radiation tolerance, two irradiation tests were carried over the course of the project at CERN's H4IRRAD facility [7]. The first one, with 1.7 Gy TID, was focused on the optical chain, and showed no significant variation of optical power and a BER of less than 10^{-12} at 95% confidence level during the test. The second, up to 40 Gy TID, served to estimate the SEU rate at the FPGA around 10 /day during operation, which is fully sustainable providing the possibility to regularly refresh the setting. Additional tests involved full-chain tests with magnetic field, carried out at CMS, a power dissipation test, done with two crates full of mock-up boards and a real CUOF inside an LHC rack, and an accelerated aging test in climatic chamber (1000 hours at 70 °C, 70 % RH).

Figure 7. Scan test for readout-like pattern (left) and trigger -like pattern (right).

Several tests were done for quality control of the CUOF production, the most important being the “Scan Test” passed to each mezzanine and also to complete boards assembled with the optical fan-outs. This tests consisted in a BER measurement done while varying the bias and

modulation current throughout their respective ranges (2 – 3 mA for bias and 8 – 9 mA for modulation). An example of such test for trigger-like and readout-like patterns has been plotted in figure 7.

6. Installation and commissioning

The complete installation took place during LHC’s Long Shutdown 1 (LS1), between February 2013 and August 2014. It consisted in several sub-tasks: fibre laying, LVDS cables rearrangement, racks and crates refurbishment, new crates installation, etc. These tasks were highly inter-dependent, and they also had to be coordinated with the detector maintenance activities.

Commissioning was done after each wheel’s relocation, with cosmic rays and trespulse runs. Results were compared to off-line analysis results of cosmic global runs taken in similar conditions before (2012) and after (2014) the SC relocation. The latency had increased, as expected, by +3 BXs.

7. Conclusions

The Sector Collector relocation was completed in time for the 2015 data taking, and is performing satisfactorily. It significantly increases the reliability of the old Sector Collector electronics, by making the poorly-accessible electronics more simple, robust and redundant, and improving the accessibility of the data-processing electronic systems. It also allows carrying out further upgrade projects, placing it in an easily accessible area, with looser environmental constraints.

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