Project status of the CMS tracker optical links

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Abstract

The development phase of the optical data transfer system for the CMS tracker is now complete. This paper presents the project status and reviews the preparation for production. In particular, it focuses on the results of the market surveys for front-end components, and on the performance evaluation of a close-to-final readout chain.

I. INTRODUCTION

The ~40000 uni-directional analogue links used to read data out of the CMS tracker are based on edge-emitting laser transmitters and pin photodiode receivers operating at a wavelength of 1310nm. In every single-mode fibre, 256 electrical channels are time-multiplexed at a rate of 40MSamples/s. The individual fibres originating from the transmitters are fanned-in, first to a 12-way ribbon, and then to an 8-ribbon cable carrying 96 fibres away from the detector to the counting room, via two patch-panels. All system components situated inside the detector volume (lasers, fibres and connectors) have been shown to be radiation resistant [1] and are non-magnetic [2].

The ~1000 bi-directional digital links used for control and timing distribution are based on almost identical components as the analogue readout system, but with a different modularity. The transceiver modules placed inside the detector include radiation resistant photodiodes and discriminating amplifiers (which are not needed in the readout system), whereas the transceiver modules located in the counting room are based on standard commercial components.

A block diagram representing the CMS tracker readout and control systems is shown in Fig. 1. Apart from the custom designed electronics, all optical link components are based on Commercial-Off-The-Shelf products (COTS). Standard manufacturing processes will be used throughout, unless specific functionality requirements such as low back-reflection or environmental constraints such as high magnetic field require some degree of customisation. Section II describes in more detail the optical link architecture and the components intended to be used in the final system.

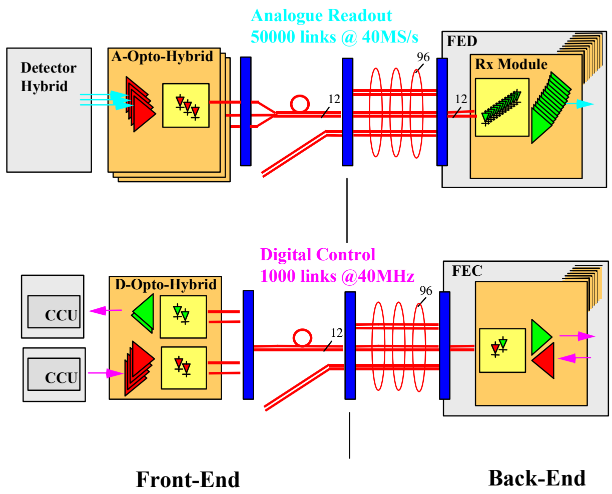

Figure 1: CMS-Tracker read-out and control system

Tests of readout and control chains are being performed with close-to-final components and architectures. The latest developments and experimental results are presented in section III, including for the first time an analogue opto-hybrid transmitter module and a 12-channel analogue receiver module.

Before orders can be placed to start production of optical links in large quantities, potential suppliers must be qualified in the framework of open market surveys. In the case of the CMS tracker, optical component suppliers have been grouped in four categories: manufacturers of lasers, connectors, fibre/cables and receiver modules. The status of the tendering process and the plans for production are detailed in sections IV and V.

II. ARCHITECTURE

By its very nature, an optical link is a distributed system. Its elements must adapt to different constraints (size, modularity, environment) depending on their positions in- or outside the detector. A careful specification and selection of components is therefore required to reach an optimal compromise between CMS-tracker requirements and commercial availability.

A few baseline choices such as fibre type, transmitter type or wavelength of operation were made early on [3] to allow the development work to proceed. However, now that industrial suppliers must be qualified and tenders issued, the link elements must be specified in every detail with as few open options as possible.

Table 1 relates the basic components that must be selected, and the assembled devices that will need to be purchased from industry.

Table 1: Optical link components and assemblies

Components ⇒	Laser diode chip	SM fibre	1-way con-nector	12-way SM ribbon	12-way con-nector	Pin diode chip	Rx ASIC
Assemblies ⇓							
Laser Transmitter	♦	♦	♦				
Pin diode receiver		♦	♦			♦	
'Terminated fibre ribbon			**12x♦**	**1x♦**	**1x♦**		
Terminated multi-ribbon cable				**8x♦**	**16x♦**		
ARx-Module					♦	**12x♦ array**	♦

Pigtailed laser diodes and pin diodes consist of individual semiconductor chips assembled on ceramic or Si-submounts, coupled to single mode optical fibres and terminated with small form factor connectors of type MU (1.25mm ferrule). These assemblies are radiation resistant, low mass and non-magnetic; they will be delivered pre-tested to the opto-hybrid assembly centres.

The ruggedized ribbon cable consists of a 12-fibre ribbon protected by aramide yarn and sheathed with a polyethilene layer. It is terminated at one end with a 12-fibre connector based on a MT ferrule; at its other end (laser transmitter pigtail side), it is fanned-out to 12 individual fibres and terminated with a compact and simplified version of the MU connector.

The multi-ribbon cable is a rugged, halogen-free flame-retardant assembly running outside the detector to the counting room. Its high density (less than 1cm diameter for 96 fibres) and flexibility (8cm bending radius) are compatible with the CMS routing constraints. It is terminated at both ends with eight, 12-fibre connectors. Both ruggedized ribbon and multi-ribbon cables will be delivered pre-terminated and pre-tested by industry.

In the new tracker layout adopted in the spring of 2000, the use of front-end detector hybrids with either 4 or 6 APVs is foreseen. This corresponds to either 2 or 3 lasers to read-out these hybrids. Accordingly, opto-hybrids with a base-modularity of 3 lasers will be designed. They will be populated with only 2 lasers in cases where 4 APVs need to be read-out.

Whereas the laser transmitters and cables will be used both for the analogue and digital links, the 12-channel Rx module is specific to the read-out system and adapted to the size requirements of the Front End Driver boards (FED). It consists of a 12-channel pin-photodiode array coupled to a 12-fibre connector. A custom designed 12-channel current amplifier array directly converts the photocurrents into levels compatible with the 10-bit ADCs. The receiver modules will be delivered to the FED assembly centres pre-tested by industry, ready to be surface mounted.

The architecture of the readout system based on the assemblies described above is schematically shown in Fig. 2.

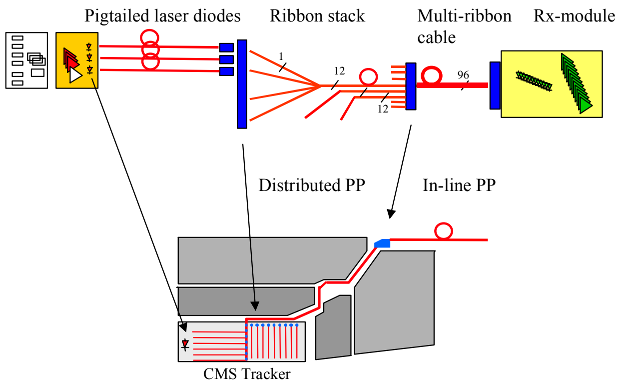

Figure 2: Optical link architecture.

The three optical patch-panels are clearly visible. The distributed patch-panel is based on single-fibre MU connectors. It is positioned at the edge of the mechanical structures carrying the detector modules (rods for the barrel, petals for the forward) and allows easy testing and maintenance of the optical front-end components at the rod/petal level. Also, the use of single-fibre connectors allows to optimise the 12-fibre ribbon usage with full flexibility, since fibres originating from different hybrids can be conveniently connected to a common ribbon. Replacement or re-routing of individual channels is also possible at this point.

The in-line patch panel is located between the CMS magnet cryostat and the H-Cal end-cap. It is partitioned in cassettes housing 480 optical connections each, based on forty 12-channel MT ferrules. A small amount of ribbon slack (~20cm) can be compensated for in the cassette, and limited space is available if a faulty connector needs to be repaired or a ribbon needs to be fusion spliced. No repair or re-routing at the individual channel level is possible however.

The digital control link architecture is expected to be very similar to the one described above. The final details of its implementation remain to be defined.

III. FEASIBILITY

The feasibility of analogue and digital optical links meeting the performance levels required from the CMS tracker experiment has been demonstrated on several occasions [4, 5]. Over 50 prototype links have been distributed to CMS users in the past two years and/or installed in test-beams.

Compared to these early prototypes, recent developments include: a) the design of analogue laser driver and digital pin diode receiver chips in deep submicron technology, b) the realisation and testing of opto-hybrid prototypes, and c) the demonstration of 12-channel receiver modules with integrated electronics. More details are given below.

a) ASICs. Both laser driver and pin-receiver chips have been designed and produced in 0.25µm technology. Only minor modifications were made to previous designs [6,7], with one noteworthy exception in the laser driver case, where multiple gains were introduced. This improvement relaxes the tolerance constraints on optical link components to acceptable levels. Also, it maintains the freedom to optimise the system dynamic range at a late stage. A first attempt to simulate the effect of gain switching on system performance is discussed in [8].

b) Optohybrids. Thick film ceramic and FR4 optohybrids have been designed, produced, and populated with lasers and driver ASICs. Functionality has been verified. New versions matching the TIB, TOB and TEC detector layout requirements have been designed and are currently being evaluated.

c) Receiver modules. The integration of the receiver electronics with a pin-photodiode array into a 12-channel module simplifies the interface between optical link and FED: the receiver module can be tested and screened independently, before being surface mounted onto the FED boards. The receiver module is currently in the tendering stage and no final component has been designed or selected. However, a prototype ASIC has been designed in 0.8µm BiCMOS technology and successfully integrated into a commercial parallel optical link module, thus demonstrating feasibility. The test of 13 prototypes supplied in the market survey framework gave confidence that several suppliers are in a position to manufacture modules compatible with the CMS-Tracker requirements.

The following three plots show the performance obtained with a chain closely resembling the final system sketched in Fig. 2. Two optohybrids, populated with 3 channels each, feed via three breakpoints a 12-channel receiver module with integrated electronics. Figure 3 shows the transfer characteristic of the 6 links under study. The mean link gain is 0.83V/V. The typical operating range matches well the 600mV output range of the APV chip.

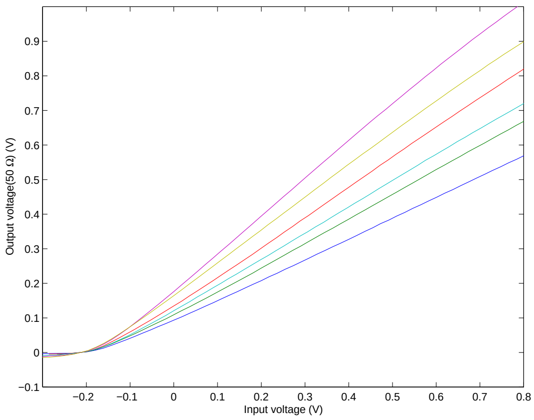

Figure 3: Static transfer function of 6 channel link

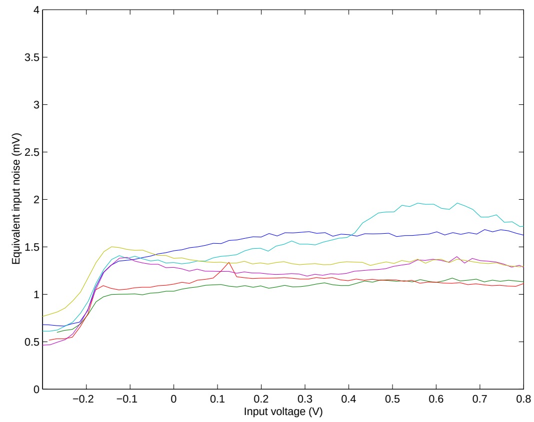

Figure 4: Equivalent input noise characteristic of 6 channel link

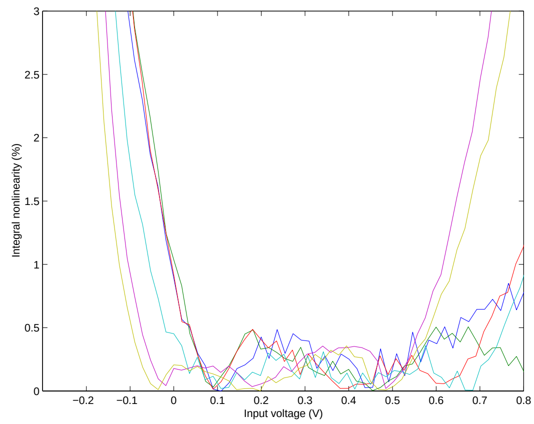

Figure 5: Integral non-linearity of 6 channel optical link

The equivalent input noise (EIN) of the full chain is shown in Fig. 4. Over a 0V to 0.6V input voltage range, the average EIN value is 1.35mVrms. This noise contribution translates to 350 electrons rms, given a front-end chip output gain of 0.1V/MIP. Typically, a noise contribution of less than 600 electrons rms is expected from the final system.

The integral non-linearity of all 6 channels is illustrated in Fig. 5 (normalised to 600mV full-scale input). The exact shape of the curves depends strongly on the chosen operating range and fitting algorithm. In any case a deviation of less than 2% can be expected from the final system.

IV. TENDERING

Apart from the electronics (driver and receiving amplifier ASICs) which is custom designed, all opto-electronic components will be procured from industry, following standard CERN purchasing procedures.

Market surveys for semiconductor lasers and optical connectors were issued in 1999 and are now closed. They were answered by 11 and 19 companies respectively. Market surveys for optical fibre, ribbon and cable as well as for receiver modules were issued in the first half of 2000 and were answered by 14 and 13 companies respectively. In all cases, evaluation samples were requested from the companies interested in tendering, and subjected to the standard test sequence shown in Fig. 6. In the laser case, the irradiations consisted of both gamma and neutron tests, while in the connector and fibre/cable cases they consisted only of gamma tests. No CERN-specific environmental tests were performed on the Rx modules, which will be operated in the control room, away from radiation and magnetic field.

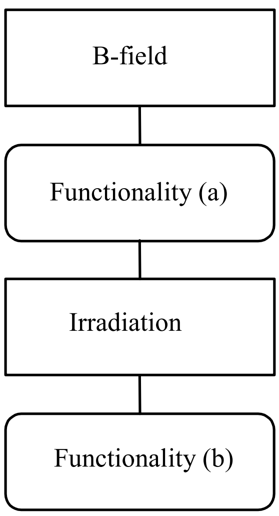

Figure 6: Validation programme work-flow

In order to be technically qualified, companies must meet a well-defined set of criteria encompassing production capacity, quality control, compliance to the specifications and of course positive validation tests.

As was shown in Table 1, the assemblies, which will need to be purchased from industry, are composed of several surveyed components. The strategy adopted for the invitation to tender phase is as follows: first, suppliers of fibre, ribbon and cables will be invited to tender. In a second step, connector manufacturers will be asked to submit offers to assemble their connectors on a fibre/cable delivered by the CERN appointed supplier. Finally, laser and photo-diode suppliers will be invited to mount their components with a pigtail manufactured by the CERN appointed supplier. The first call for tender (fibre, ribbon and cables) was sent out in Nov. 2000. The others are following in a sequence estimated to last until approximately mid 2001.

V. TOWARDS PRODUCTION

The CMS tracker will require ~40000 optical links to operate its analogue readout and digital control systems. The tens of prototypes evaluated during the feasibility phase and market survey tests give confidence that specifications will be met by the final system. This quantity is however clearly insufficient to assure quality during production, and a full qualification phase must be envisaged. However, as industrial products evolve on a much shorter time-scale than the LHC project, a meaningful qualification can only start once specifications are frozen and orders have been placed.

The first step towards production is thus to agree on the interfaces with the front-end electronics and the DAQ system, and to freeze specifications at the components level. Interfaces for the CMS-tracker optical link were agreed in May 2000.

Once orders will have been placed, pre-production will immediately follow. These pre-series will form the basis for the qualification of the manufacturing process. The front-end components will need to be built from wafers and fibre-preforms validated for radiation hardness. These advanced validation tests are required since the optical link components are based on commercial off the shelf products (COTS) sold with no radiation hardness guarantee whatsoever. Ideally, validated wafers and fibre pre-forms will be stored and subsequently used throughout the production period.

Once the production processes of pigtailed lasers and pin-diodes, terminated ribbons and cables, as well as receiver modules have been qualified, full scale production will start in industry, and products will be delivered pre-tested by the manufacturers. Only a fraction (typ. 1-2%) of these deliveries will be re-tested at CERN on a lot by lot basis, to monitor the stability of the process. The definition of this test procedure is currently under way, and more details can be found in [9, 10].

The pre-production of front-end assemblies will start in late 2001, while the back-end modules will lag approximately one year behind.

VI. CONCLUSIONS

The CMS-tracker optical link project is entering its production phase. Feasibility has been demonstrated with close to final components, and specifications are being finalised. Market surveys covering all elements in the chain have been issued, and qualified manufacturers have been short-listed.

Four calls for tender will be launched between October 00 and June 01. Only then will we know the exact composition and cost of the system.

VII. ACKNOWLEDGEMENTS

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