Prototype Pixel Optohybrid for the CMS phase 1 upgraded Pixel Detector

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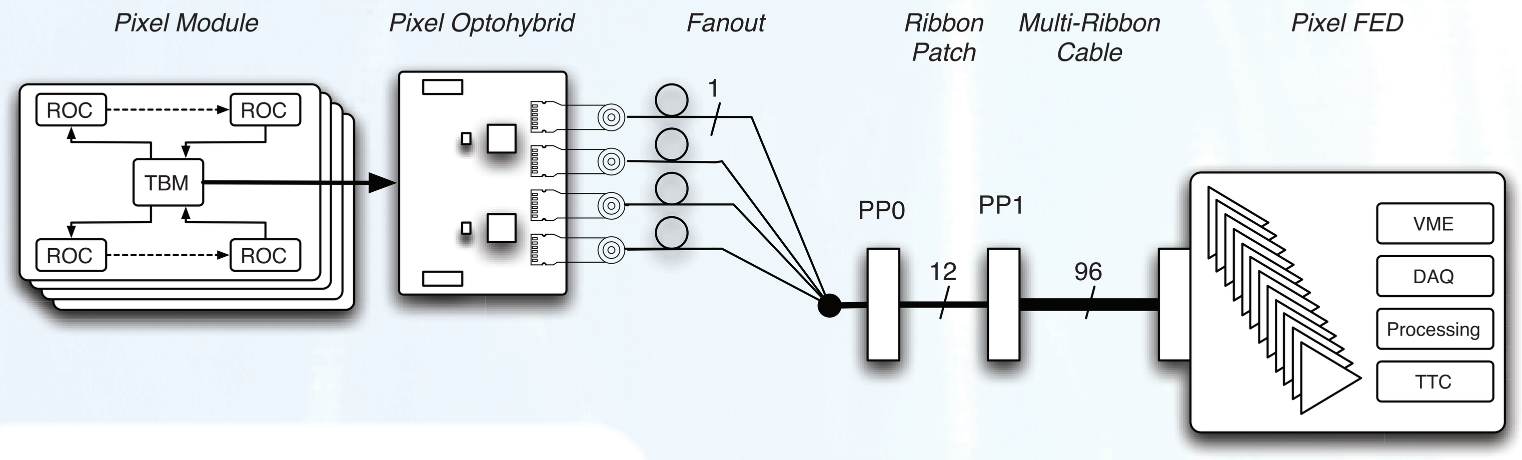
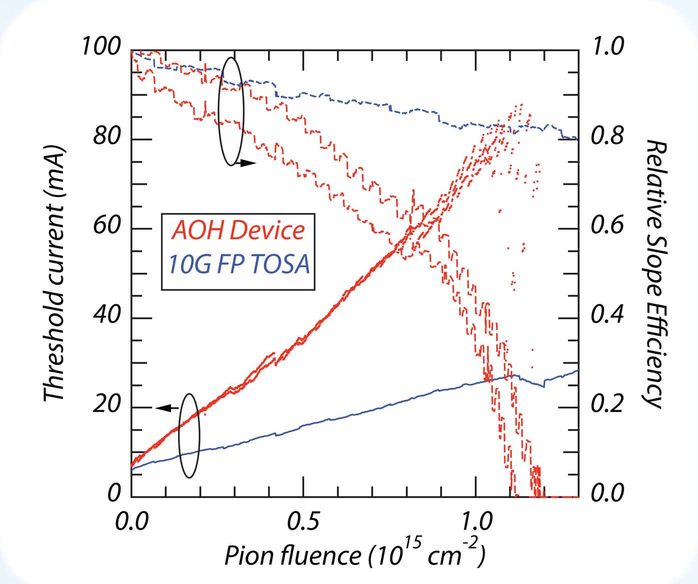
Abstract

The CMS Pixel detector phase 1 upgrade calls for an optical readout system operating digitally at or above 320 Mb/s. Since the re-use of the existing link components as installed is excluded, we have designed a new Pixel Optohybrid (POH) for use within this system. We report on the design and choice of components as well as their measured performance. In particular, we have studied the impact upon error-free link operation of the way the data are encoded before being transmitted over the link. We have thus demonstrated the feasibility of operating the new POH within the upgraded readout system.

Optical Link for CMS Pixel Phase 1 Upgrade

The CMS Pixel detector system is to be upgraded in the first phase of LHC upgrades. An upgrade is needed to maintain readout efficiencies when the LHC begins to exceed a luminosity of approximately 1034 cm-2s-1. Due to the changes to the front-end ReadOut Chip (ROC) that are necessary to improve the inefficiencies in the present readout scheme, it quickly became obvious that the upgraded system should operate using digital readout. The data-rate generated by the new system has been calculated to be 320 Mb/s per front-end module that houses 16 ROCs. Initially, it was thought that the Analogue Opto-Hybrid (AOH) used in the present Pixel system could simply be re-built as-is and used to transmit digital data at the increased rate. A key component of the AOH (its laser diode) is however no longer manufactured. It was thus decided to profit from the component selection studies being carried out in the framework of the Versatile Link project that have identified both functionally-suitable and sufficiently radiation-tolerant candidate components that would be suitable for use in the phase 1 Pixel optical link. Component selection is important as the single-mode optical fibres used in the present system must be re-used for the phase 1 upgrade.

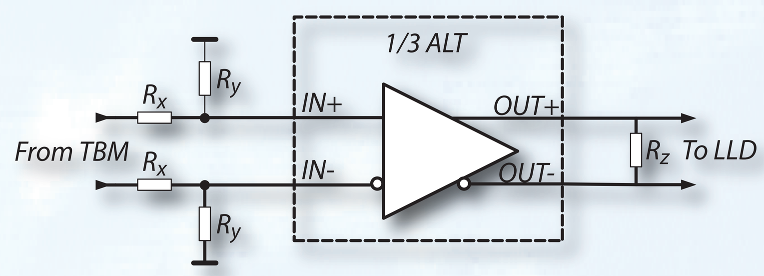


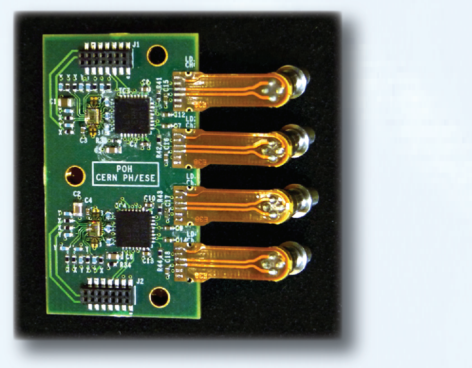


Irradiation testing of components for use in the Versatile Transceiver has shown that the newer high-speed laser diodes are significantly more radiation resistant than the devices used on the current AOHs. Radiation testing with 300 MeV pions (which represent the dominant particle species in the inner regions of CMS) has shown that the newer devices are approximately a factor of four more resistant to radiation damage in terms of threshold damage and can thus withstand higher total fluences. These newer devices are packaged as a Transmitter Optical Sub-Assembly (TOSA).

Pixel Optohybrid

The Pixel Optohybrid (POH) is a PCB designed to be mounted on the mechanical structure of the Pixel detector in the service tube. The POH receives input signals from the detector front-end that will be around 1m away. The final system will require approx. 400 POH, of which one quarter is for the forward pixel and the remainder for the barrel pixel detector. With a candidate Transmitter Optical Sub-Assembly (TOSA) component identified by the Versatile Link project, the design of a new Pixel Opto-Hybrid (POH) has been carried out. The TOSA contains a Fabry-Pérot edge-emitting laser diode operating at 1310 nm that is rather similar to the one currently installed in CMS. Strict dimensional constraints on the POH come from the layout of the service tube in which the POH will be mounted. These constraints have led to the POH PCB design measuring 40 mm by 22.5 mm. The POH houses the same chipset as the present AOH, consisting of an Analogue Level Translator (ALT) and a Linear Laser Driver (LLD). Each POH needs two ALTs and two LLDs, each driving two TOSAs for a total of four readout link transmitters per POH. The footprint of the two i/o connectors was kept compatible with the current AOH to ease in-system testing. This footprint and/or connector type may change in subsequent iterations of the design. A further iteration of the design to fully match new mechanical constraints may also be required.

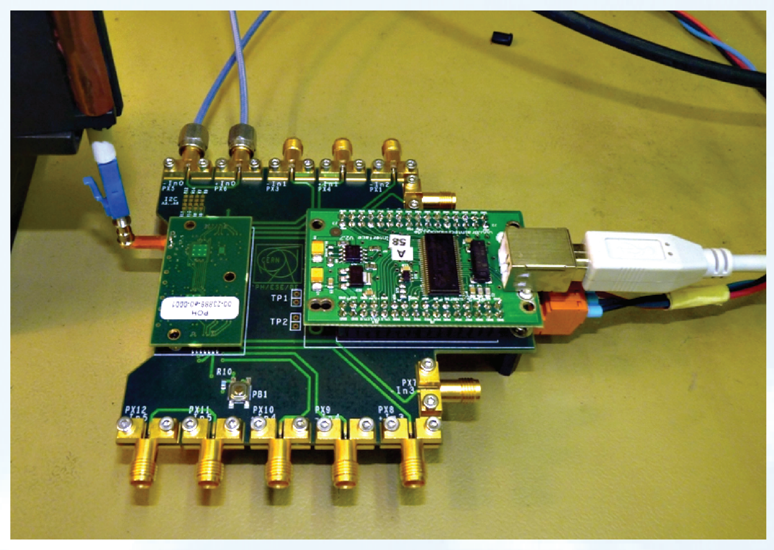




Test Board for POH Evaluation

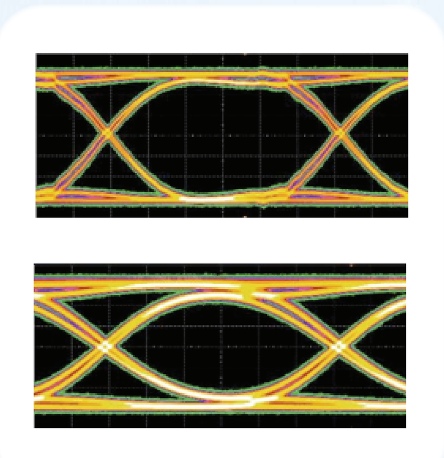
In addition to the POH itself, a test board was designed to be able to supply the necessary signals to the POH in order to be able to test it. Care was taken to equalize the trace lengths of the differential traces on both the POH and the test board. The test board provides power to the POH and hosts an I2C to USB converter board in order to allow the POH to be programmed.

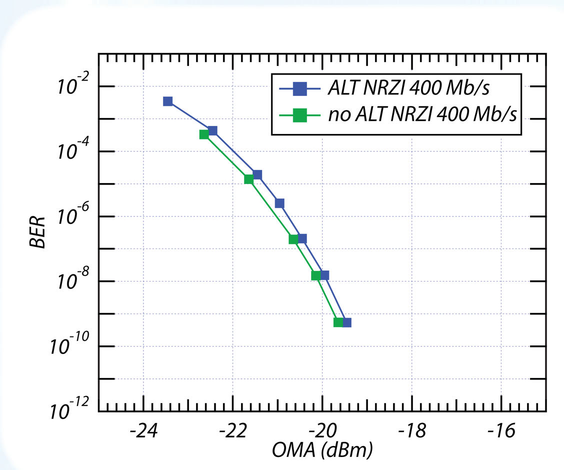
The data signals are brought onto the test board via SMA connectors. There are also jumpers that allow the I2C base address to be set.



Effect of ALT Bandwidth

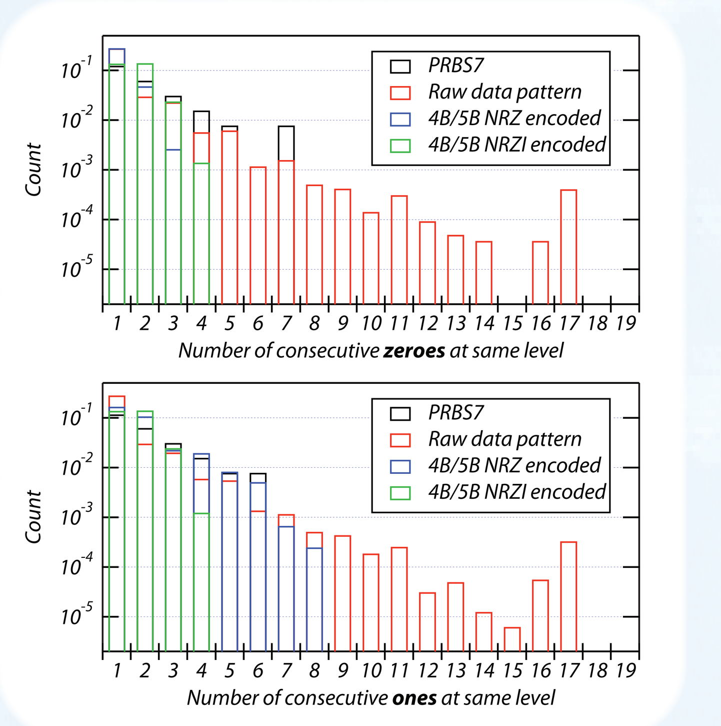
The ALT, which was designed to transmit an analogue signal at 40 MHz, has been measured to see if it is suitable for use as a level translator for a digital transmission at 400 Mb/s. The eye diagrams obtained at 320 Mb/s for two of the data patterns using POH prototypes with and without the ALT mounted show a reduction in bandwidth with use of the ALT that can be seen as an increased rise- and fall time in the eye, as well as a small amount of vertical eye closure. However, measuring the system BER for the two conditions shows that there is little link power budget penalty when using the ALT at 400 Mb/s.





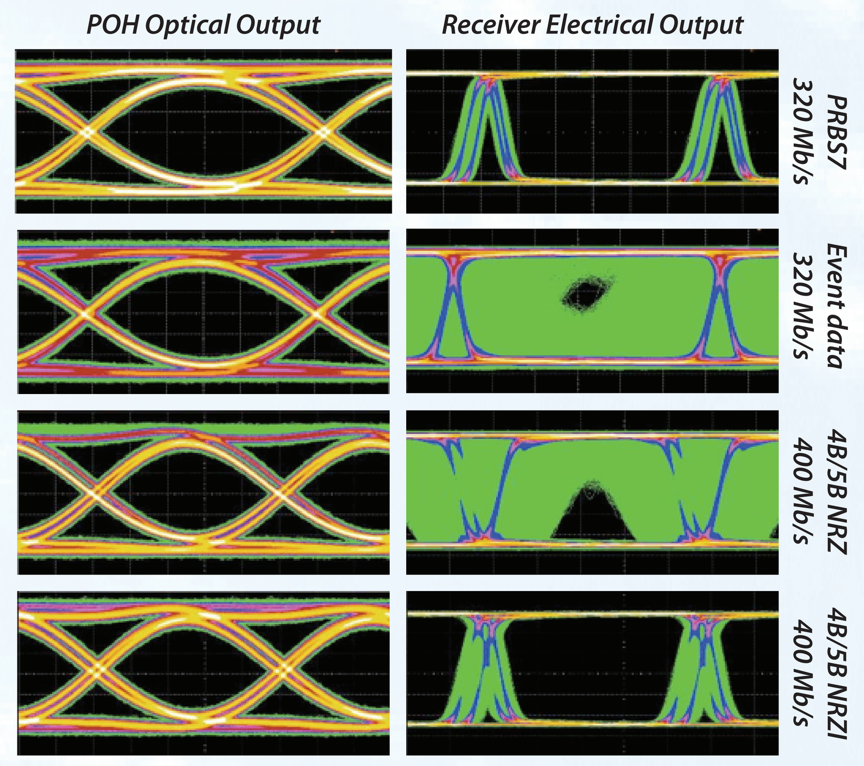
Data Encoding

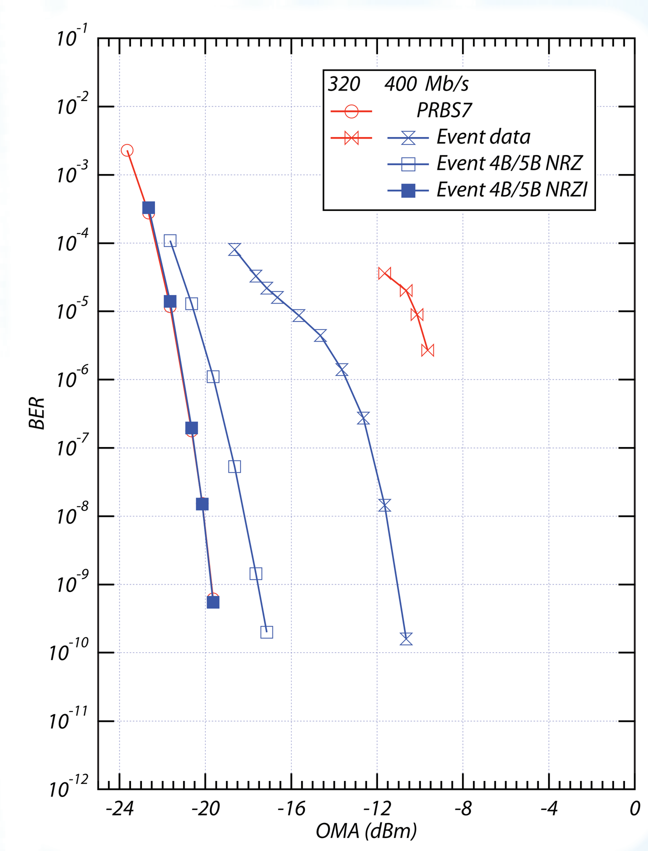
The initial system design calls for the data to be sent un-coded directly from the readout chips connected to each optical link. The raw data pattern is un-balanced (since it depends on the activity in the detector) and can contain many consecutive bits at the same level (one or zero). This is shown in the comparison of the number of consecutive bits at either the one or zero level. Thus we have measured the performance of the POH module & a candidate receiver when sending this raw data compared with standard PRBS7 and a 4B/5B encoded data pattern. Except for PRBS7, the patterns have been derived from particle interactions simulated inside the pixel detector and encoded by the readout electronics (ROC and TBM) that will be placed before the optical link. As such they are quite representative of the data that are to be transmitted over the link. For the 4B/5B coded pattern we have tested two line encoding methods: NRZ & NRZI. Non Return to Zero (NRZ) sends the logic level corresponding to the input data for the entire duration of one bit period. In contrast, a Non Return to Zero, Inverted (NRZI) signal has a transition at a clock boundary if the bit being transmitted is a logical 1 and does not have a transition if the bit being transmitted is a logical 0. As an example of a standardized system, the optical implementation of FDDI uses 4B/5B NRZI coding.



Full Link Results

Most digital optical receivers are sensitive to unbalanced codes as they typically operate AC-coupled and thus have an intrinsic low cut-off frequency. The raw data pattern from the TBM has a significant low-frequency content since it can contain a large number of consecutive bits at the same level. The eye diagram results obtained for the four data patterns clearly show a pattern dependence in the receiver output due to the relatively low data-rate of the pixel optical link. It is also clear that the use of a line-coding scheme that improves the DC-balance of the raw detector data will be mandatory. The eye diagrams already indicate that the 4B/5B NRZI coding scheme should allow correct operation of the link at 400 Mb/s.





The eye diagram result is confirmed by full link system BER measurements. Here we show that there is no additional penalty from operating the link at 400 Mb/s with detector data encoded with 4B/5B NRZI with respect to PRBS7 at 320 Mb/s. There would be an additional power penalty of 2.5-3 dB for using NRZ rather than NRZI on the 4B/5B encoded data, while for the raw data this penalty exceeds 10 dB.

The receiver sensitivity at 400 Mb/s using 4B/5B NRZI coding is measured to be -18 dBm. Based upon the TOSA specifications and some assumptions regarding the input signal amplitude the minimum transmitted OMA will be -10 dBm. Operating the link at 400 Mb/s with 4B/5B encoded data thus results in a link power budget of 8 dB, which is largely sufficient for a link of 60 m singlemode optical fibre with 2-3 optical connection breakpoints.

Conclusions

The prototype POH built using the existing radiation-tolerant ALT and LLD chips married to the candidate 1310 nm Fabry-Perot laser TOSA has been shown to operate correctly at both 320 Mb/s and 400 Mb/s independent of the data pattern used. The candidate digital optical receiver module operates correctly at 400 Mb/s when 4B/5B NRZI encoding is used, whereas it does not if the raw detector data are transmitted directly. There is ample margin (8 dB) in the link power budget to guarantee a bit-error rate of 10^{-12} if the raw detector data at 320 Mb/s are encoded with 4B/5B NRZI and transmitted from the TBM at 400 Mb/s. An optical link system based upon our POH prototype containing the current ALT and LLD chipset married to the receiver module will operate correctly for the Pixel upgrade optical links.

TWEPP-11 Topical workshop on Electronics for Particle Physics Vienna, Austria | 26-30 September 2011

Presented by:

Jan Troska obtained his BSc in 1995 and his PhD in 1999 from Imperial College, London. He has been working on the implementation of optical data transmission systems in particle physics experiments since 1996. Jan joined CERN in 2000 and is presently Project Leader for optical link developments.

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