The new radiation-hard optical links for the ATLAS pixel detector

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The ATLAS detector is currently being upgraded with a new layer of pixel based charged particle tracking and a new arrangement of the services for the pixel detector. These upgrades require the replacement of the opto-boards previously used by the pixel detector. In this report we give details on the design and production of the new opto-boards.

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1 Introduction

The ATLAS experiment is one of two large general purpose spectrometers at CERN’s Large Hadron Collider (LHC) whose goal is to measure the production and decay characteristics of the Higgs boson(s) and discover new particles that are not part of the standard model. An important sub-system of the ATLAS detector is its pixel detector. As originally built the pixel detector consists of three concentric tracking layers and three disks on each side of the interaction region. In all, there are 1744 pixel modules with a total of 80 M channels of electronics in the detector. Signals from the control room to a pixel module are sent at 40 Mb/s over 80 m of optical fiber to an opto-board and received by a PIN diode. An ASIC (DORIC) on the opto-board then decodes the bi-phase mark encoded signals and transmits the information to a pixel module using twisted pair copper cables. Transmission of data from a pixel module to the electronics located outside of the ATLAS detector is also routed through the opto-board. In this case an ASIC (VDC) on the opto-board converts the signals sent over a twisted pair of copper wires to optical signals using a VCSEL and transmits them at up to 160 Mb/s. The routing of signals to and from the opto-board is shown in Fig 1. Each opto-board provides 6-8 links, with each link consisting of a VCSEL/PIN pair that services a pixel module.

![Figure 1: The routing of signals to and from the opto-board. One link of an opto-board is shown.](image)

While the performance of the pixel detector was outstanding during the 7 TeV and 8 TeV data runs it was felt that its future performance and longevity could be enhanced by adding a 4th layer of pixel tracking immediately outside the beampipe. This new tracking layer is called the Insertable B-Layer (IBL). In addition, in order to make the pixel services more accessible for potential repairs, the location and organization of the services was re-worked. This project goes by the name of new Service Quarter Panels (nSQP). As a result of the IBL and nSQP upgrades, the opto-boards used for the 7 TeV and 8 TeV data runs have to be replaced. In the following

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*VCSEL = Vertical Cavity Surface Emitting Laser diode*
section we give the details of these re-designed opto-boards.

2 The new pixel opto-boards

There are several improvements in the design of the new opto-boards that take advantage of the experience gained from the production and operation of the first generation opto-boards. The new design eases their production and enhances their reliability. One major improvement is the re-design of the optical packaging of the VCSEL and PIN arrays. The original optical packages (opto-packs) were provided by Taiwan as an in-kind contribution to ATLAS. These opto-packs had several drawbacks. First, the VCSEL arrays were found to fail under moderate humidity and a suitable replacement had to be found. We measured the radiation hardness [3] and robustness (e.g. humidity resistance) of several commercial VCSEL arrays and chose an array manufactured by Finisar [4]. We also decided to switch to a more robust PIN array manufactured by ULM Photonics [5] after measuring the radiation hardness of several other candidates. In Fig. 2 we show pictures of the new opto-pack.

![Figure 2: (left) A 3D model of an opto-pack. (middle) A close up photograph of an opto-pack with a wire bonded VCSEL array. (right) Scale photograph of an opto-pack.](image)

Another drawback of the Taiwan opto-packs had to do with the soldering of the micro-leads on an opto-pack to an opto-board. Since the opto-board was fabricated out of BeO to take advantage of its excellent thermal conductivity it was very difficult to provide the appropriate amount of heat to solder a small lead to the BeO substrate. In fact, it has been determined from the extracted opto-board postmortem that the major failure mode was due to cold solder joints. To avoid this pitfall, the new opto-boards rely on wire bonds rather than solder [6]. Other improvements include the use of a polyimide PCB mounted to a copper plate instead of a thick film circuit on BeO. While BeO has excellent thermal properties it is an expensive material as well as one that requires special handling due to safety requirements. Our new PCB is a single sided board (the original opto-boards were double sided) and has a 1 mm thick layer of copper on the backside for thermal management. We also added redundant
control lines by taking advantage of unused pins on the opto-board’s connector as well as eliminating the daisy chaining of control signals on the opto-board. In Fig. 3 we show an example of a recently assembled opto-board.

Figure 3: A photograph of the re-designed opto-board showing the VCSEL driver chips (VDCs) that couple to the VCSEL opto-packs and the receiver chips (DORICs) that couple to the PIN opto-pack. Both ASICs were designed by OSU/Siegen for the first generation opto-boards.

These new opto-boards come in three varieties; IBL, B (originally used by the first layer of the pixel detector), and D (originally used in the disks and second and third layers of the pixel detector). All three varieties were extensively proto-typed both in system wide tests and irradiations. Twenty two proto-type boards were distributed to our collaborators and subjected to a further round of testing. The results of these tests gave us the confidence that we could move into the production phase.

The production of the opto-boards (60 IBL, 55 B, 275 D) began in the summer of 2013. This includes fabricating the opto-packs (1200), mounting of opto-packs and ASICs on the PCB, and wire bonding of opto-packs and opto-boards. Some of this work requires the components (e.g. VCSELs) to be placed with a precision better than 10 \( \mu \text{m} \) otherwise the optical coupling to the fiber will be poor. The two ASICs
(VDC, DORIC) on the opto-board are the same versions used for the previous opto-boards and were designed by OSU and Siegen [2]. Once an opto-board is fabricated it is subjected to an extensive array of tests including burn in at 50°C, thermal cycling, measurement of its optical power, rise/fall time, duty cycle, jitter, and bit error rate. Examples of the results of the quality assurance tests for a typical PIN and VCSEL are shown in Fig. 4. Opto-boards that pass all the quality assurance tests are then shipped to CERN where they are retested to insure that there was no damage due to shipping.

Figure 4: (left) Dark current vs. channel number and (middle) Responsivity vs. channel number for a typical PIN. (right) Optical power for a typical VCSEL vs. channel number at various production stages and test conditions.

3 Summary

In this report we have briefly described the assembly and testing of the new opto-boards being produced for the IBL and nSQP upgrades for the ATLAS detector. These opto-boards are expected to be more robust than the previous version of the opto-boards and be used until the LHC’s Long Shutdown 3 (LS3) in the early 2020’s.

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References

[1] G. Aad et al., “ATLAS Pixel Detector Electronics and Sensors,” JINST 3, P07007 (2008).

[2] K. E. Arms et al., “ATLAS Pixel Opto-Electronics,” Nucl. Instr. Meth. A 554, 458 (2005).

[3] K.K. Gan et al., “Study of the Radiation-Hardness of VCSEL/PIN,” in Proceedings of the 9th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors, Florence, Italy, 2009, PoS (RD09) 041 (2009); A. Nagarkar et al., “Study of the Radiation-Hardness of VCSEL & PIN Diodes,” in Proceedings of the 11th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors, Florence, Italy, 2011, PoS (RD11) 036 (2011).

[4] The VCSEL array used is V850-2093-001, fabricated by Finisar, Inc.

[5] The PIN array used is ULMPIN-04-TN-U0112U, fabricated by ULM Photonics.

[6] K.K. Gan, “An MT-Style Optical Package for VCSEL and PIN Arrays,” Nucl. Instr. and Meth. A 607, 527 (2009).