Bandwidths of Micro Twisted-Pair Cables and Fusion Spliced SIMM-GRIN Fiber

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Abstract

The SLHC is designed to increase the luminosity of the LHC by a factor of ten. In the present ATLAS pixel detector, electrical signals between the pixel modules and the optical modules (opto-boards) are transmitted in ~ 1 m of micro twisted-pair cables. The optical signals between the opto-boards and the off-detector optical modules are transmitted in fiber ribbons. Each fiber link consists of 8 m of rad-hard/low bandwidth SIMM fiber fusion spliced to 70 m of rad-tolerant/medium bandwidth GRIN fiber. We currently transmit optical signals at 80 Mb/s and expect to transmit signals at 1 Gb/s in the SLHC. For the SLHC optical link, we would like to take advantage of some of the design features of the present pixel optical links and the many years of R&D effort and production experience. If the present architecture can transmit signals at the higher speed required by the SLHC, the constraint of requiring no extra service space is automatically satisfied. We have measured the bandwidths of the transmission lines and our preliminary results indicate that the micro twisted-pair cables can transmit signals up to ~ 1 Gb/s and the fusion spliced fiber ribbon can transmit signals up to ~ 2 Gb/s.

Keywords: SLHC; optical-link; bandwidth; micro twisted-pair cable; fiber

1. Introduction

The SLHC is designed to increase the luminosity of the LHC by a factor of ten to 10^{35} $cm^{-2}s^{-1}$. Accordingly, the radiation level at the detector is expected to increase by a similar factor. The increased data rate and radiation level will pose new challenges for a tracker situated close to the interaction region. The present optical link [1] of the ATLAS pixel detector [2] is mounted on a patch panel instead of directly on a pixel module. This separation greatly reduces the radiation level at the optical modules and simplifies the design and production of both the pixel modules and the optical modules (opto-boards). Data communication between the separated modules is achieved by transmitting electrical signals using ~ 1 m of micro twisted-pair cables. The optical signals between each optical module and the off-detector optical electronics are then transmitted via 8 m of rad-hard/low bandwidth SIMM fiber ribbon fusion spliced to 70 m of rad-tolerant/medium bandwidth GRIN fiber ribbon. We currently transmit optical signals at 80 Mb/s and expect to transmit signals at 1 Gb/s for the SLHC. If the present architecture can transmit signals at the higher speed, the constraint of requiring no extra service space is automatically satisfied.

We have started an R&D program to study the feasibility of an upgrade based on the optical link architecture of the current pixel detector while taking advantage of the several years of R&D effort and production experience. In this paper, we present preliminary results on the bandwidth measurement of micro twisted-pair cables and a fusion spliced SIMM/GRIN fiber ribbon.

2. Bandwidth of Micro Twisted-Pair Cables

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Commercial copper cables [3] can transmit several Gb/s over tens of meters. However, the diameters of these cables are too large for the pixel detector. The present pixel optical link uses a micro twisted-pair of wires for transmission of low voltage differential signals (LVDS) between a pixel module and the driver and receiver chips on an opto-board. Each pair of wires is twisted 5 turns per inch (TPI) which corresponds to 2 turns per cm. For barrel pixel detectors, each wire is aluminum with a diameter of 100 μm (38 AWG) plus 25 μm of insulation, for an outer diameter of 150 μm. The length of the twisted pairs varies from 81 to 142 cm. The wires for the end cap pixel detector are finer, 60 μm with 12 μm of insulation. The length of these copper twisted pairs is ~80 cm. The impedance of the twisted pairs is ~ 75 Ω.

We have measured the bandwidths of micro twisted-pairs of various lengths, diameters, and numbers of turns per inch. The cables tested include [4]:

- 38 AWG (100 μm core plus 25 μm of insulation): 5 TPI with 75 Ω termination.
- 36 AWG (127 μm core plus 9 μm of insulation): 5 TPI with 75 Ω termination and 10 TPI with 100 Ω termination.

For the bandwidth study, we transmitted LVDS pseudo-random data in the selected cable and measured the signal characteristics at the termination with a LeCroy WaveMASTER 8600A (6 GHz) oscilloscope and differential probe (7.5 GHz). The rise and fall times of the cables are shown in Figs. 1 and 2. The current barrel cable has the fastest rise and fall times.

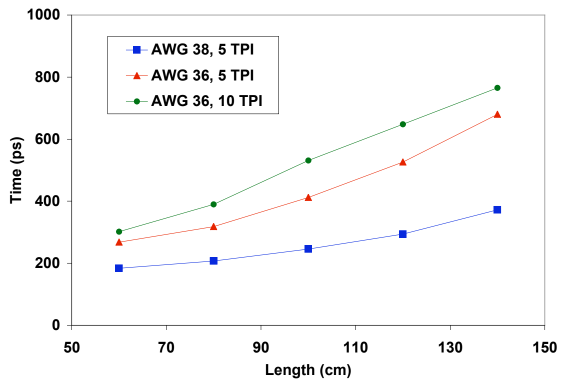

Figure 1. The rise times (20-80%) of the micro twisted-pairs vs. wire length for wires of various diameters and TPI.

The eye diagrams produced by transmitting pseudo-random data of 650 Mb/s and 1 Gb/s in the current barrel cable are shown in Fig. 3. The masks shown are adapted from Fig. 39-5 and Table 39-4 of the Gigabit Ethernet Specification (IEEE Standard 802.3) with the mask voltage levels modified to match the LVDS receiver chip used. From these figues, it is evident that the micro-twisted cable is adequate for transmitting signals at 640 Mb/s and that transmission at 1 Gb/s might be acceptable.

3. Bandwidth of Fusion Spliced SIMM/GRIN Fiber

There are three kinds of commercial fibers available with each having different bandwidths. Single mode fiber has a core diameter of less than 10 μm, no modal dispersion, and hence the highest bandwidth. The other two fibers, GRIN and SIMM, are multi-mode fibers with core diameters of 50 or 62.5 μm. The former has medium bandwidth and is radiation tolerant. The latter has lower bandwidth with a radiation-hard pure silica core. Each pixel optical link of the present pixel detector has 8 m of 50 μm SIMM fiber ribbon fusion spliced to 70 m of 62.5 μm GRIN fiber ribbon.

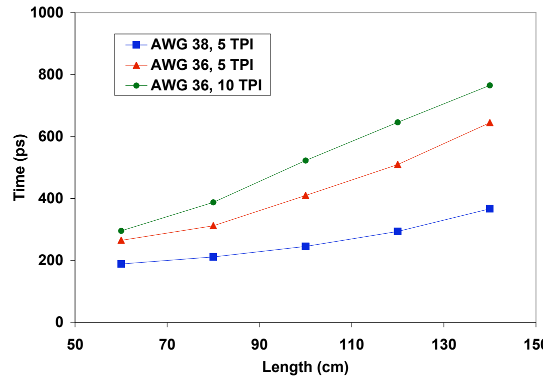

Figure 2. The fall times (20-80%) of the micro twisted-pairs vs. wire length for wires of various diameters and TPI.

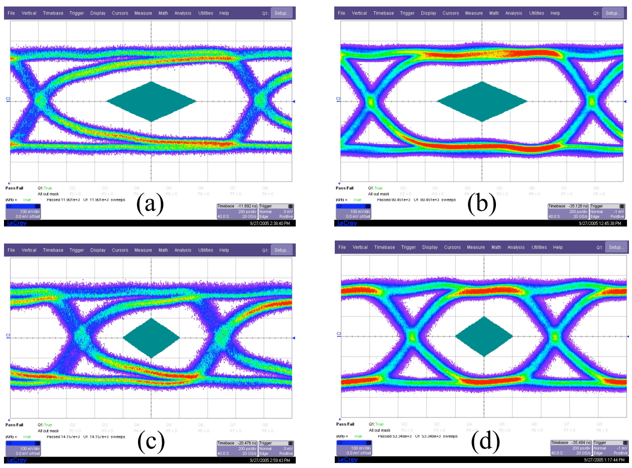

Figure 3. Eye diagrams for signals of (a) 650 Mb/s and (c) 1 Gb/s in a barrel cable of 1.4 m. (b,d) show the corresponding signals for a cable of 0.8 m.

We have measured the bandwidth of 13 m of 50 μm SIMM fiber fusion spliced to 16 m of 62.5 μm GRIN fiber. The optical signal was generated with an 850 nm VCSEL, contained within a Finisar FTRJ-8519-1-2.5 fiber optic transceiver, and measured using the above oscilloscope with a 4.5 GHz Optical to Electrical Converter. Resultant eye diagrams for pseudo-random signals of 650 Mb/s and 1 Gb/s are shown in Figure 4. The mask shown is adapted from Fig. 38-2 of the Gigabit Ethernet Specification (IEEE Standard 802.3) and in accordance with the specification, a fourth-order Bessel-Thomson software filter is used to view the signals. To represent the waveform more accurately we choose a higher bandwidth than recommended for the filter: 1.5 Gb/s instead of 487.5 (750) Mb/s for the 650 Mb/s (1 Gb/s) transmission. It is evident from these results that the fiber can adequately transmit signals up to at least 1 Gb/s and hence the transmission bandwidth of the wire link will be the limiting factor in the present pixel detector transmission lines. We plan to repeat the measurements with the length of the fusion spliced fiber ribbon as used in the current pixel detector. However, we expect this conclusion to be remain valid.

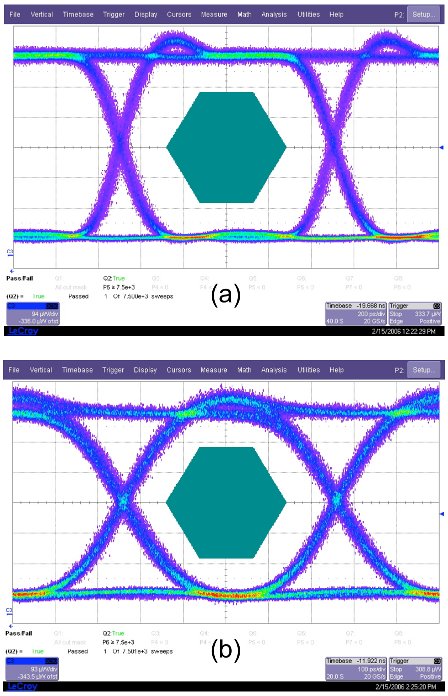

Figure 4. Eye diagrams for optical signals of (a) 1 and (b) 2 Gb/s in a fusion spliced SIMM/GRIN fiber.

4. Conclusions

We have studied the bandwidth of the electrical and optical transmission lines of the current optical link of the ATLAS pixel detector. Our preliminary results indicate that the micro twisted-pair cables can transmit signals up to 1 Gb/s and the fusion spliced fiber ribbon can transmit signals up to 2 Gb/s. The current infrastructure can therefore be used for the SLHC as a possible upgrade scenario.

5. Acknowledgement

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Reference:

[1] K.E. Arms et al., Nucl. Instr. Meth. **A554**, 458 (2005).
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[3] See, for example, J.H.R. Schrader et al, IEEE-J. Solid-State Circuits **41**, 990 (2006).
[4] MWS Wire Industries Twistite.