Optical Data Transmission for Semiconductor Trackers

K.K. Gan
The Ohio State University

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Outline

- Introduction
- Results from latest developments
- Summary
Use of VCSEL Arrays in HEP

- Large volume of data from semiconductor trackers at HL-LHC requires use of VCSEL array due to space constraint
  - 20,000 data links operating at 5 Gb/s for ATLAS pixel detector
  - 4 and 12-channel VCSEL arrays are compact solutions
    - 250 µm between two VCSELs (3 mm width for 12 channels)
- Arrays are widely used in off-detector (no radiation) data transmission
- First on-detector implementation is in pixel detector of ATLAS
- Optical links of a pixel detector must be located at a distance from the detector due to intense radiation
  - use of skinny cables for data transmission to reduce material limit the bandwidth of the data link
ATLAS ITK-Pixel Opto-Board Concept

- opto-board concept used in 1\textsuperscript{st} and 2\textsuperscript{nd} generation pixel opto-links
- candidate for deployment in the ATLAS ITK-Pixel
  - Keep opto-pack for mounting 12-channel VCSEL array
  - Keep copper backed PCB for heat removal
  - Keep MTP connector for easy mating
  - No lenses/mirrors used to turn the light
Opto-Pack for ATLAS ITK-Pixel

- Proposed opto-pack for ITK-Pixel has simpler design
  - continue to use BeO as substrate for heat management
- experience in building large quantity of opto-packs
  - fabricated 1,200 opto-packs for pixel opto-boards
  - fabricating 300 PIN opto-packs for off-detector opto-receivers
  - equivalent to 18,000 channels
ITK-Pixel Opto-Board

Connector secured to opto-board with screws instead of epoxy in current opto-board

Will be fabricated as one piece with mold injection to reduce the width

1.5 cm
Post Irradiation Results – 5 Gb/s

- All channels operational after irradiation with 24 GeV protons
- Optical amplitude reduced from 2.07 mW to 1.19 mW
  - consistent with power loss seen during irradiation
- Performance of the array driver/VCSEL combination at 5 Gb/s is acceptable
**Signal Equalization**

- ATLAS ITK-Pixel plans to transmit 5 Gb/s data via 5.5 m of skinny cables to optical modules
- signal will be badly distorted due to attenuation of high frequency components
- must apply signal equalization to restore high frequency response
- Ohio State/Siegen currently designing VCSEL array driver with equalization circuit
4-tap CTLE Equalizer

- Each successive stage increases gain for high-frequency components
  - Equalize the response across all frequencies

CTLE: continuous time linear equalization
Signal at 4 Taps (Preliminary)

End of cable  

Tap 1  

Tap 2  

Tap 3  

Tap 4
Versatile Link+

- Front-end to back-end link targeting inner detector use at HL-LHC
  - 1 MGy, $3 \times 10^{15}$ n/cm$^2$
  - -35 to +60 °C
  - 5 or 10 Gb/s upstream (out of detector)
  - 2.5 Gb/s downstream
- Collaboration: CERN, Oxford, Academia Sinica, SMU, FNAL
Versatile Link+ Results

- **Tx**: 10 Gb/s operation with good coupling efficiency
- **Rx**: operating with good margin and no interference with Tx

![Graph of BER vs. OMA (dBm)](Image)

50 μW
Versatile Link+

● Pro: reduce cost from large volume production

● Con: 4 Tx channels + 1 Rx channel in 12-channel fiber with attached pigtail is not a commercial standard

⇒ messy/costly signal rerouting to off-detector 12-channel COTS
- Two optical packages of general interest tested by Suen Hou (Academic Sinica)
- Challenge: convince the vendors to produce packages for trackers
Summary

- semiconductor trackers require low-mass optical links operating at high speed
  - multiple solutions currently being developed
- pixel detectors require data to be transmitted on skinny cables for up to 5.5 m before conversion to optical transmission
  ⇒ equalization circuit currently being designed