Results of Opto-Link R&D

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Outline

- SLHC opto-link channel count
- Radiation hardness of fibers
- Radiation hardness of PIN arrays
- Radiation hardness of VCSEL arrays
- Compact MT-style opto-pack
- Status of opto-chips
- Summary
SLHC Opto-Link Channel Count

<table>
<thead>
<tr>
<th>R (cm)</th>
<th>N. staves</th>
<th>Chip Area (cm²)</th>
<th>rate/module (Mb/s)</th>
<th>modules/stave</th>
<th>rate/half stave (Gb/s)</th>
<th>SMC/stave</th>
<th>Total Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.7</td>
<td>16</td>
<td>5.4</td>
<td>532</td>
<td>24</td>
<td>4.3</td>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>5.0</td>
<td>22</td>
<td>5.4</td>
<td>360</td>
<td>24</td>
<td>2.9</td>
<td>4</td>
<td>88</td>
</tr>
<tr>
<td>8.9</td>
<td>38</td>
<td>10.8</td>
<td>340</td>
<td>32</td>
<td>2.7</td>
<td>4</td>
<td>76</td>
</tr>
<tr>
<td>12.3</td>
<td>52</td>
<td>10.8</td>
<td>223</td>
<td>32</td>
<td>1.8</td>
<td>4</td>
<td>104</td>
</tr>
</tbody>
</table>

- Total number of SLHC barrel links: 333
- Current LHC barrel links: 1,458
  - number of links @ SLHC is manageable
  - no need to transmit at higher rate (> 3.2 Gb/s)
Bandwidth of Fiber

11 + 80 m spliced SIMM/GRIN fiber

- transmission at 3.2 Gb/s is adequate
- current SLHC architecture calls for raw rate of 3.2 Gb/s plus 20% overhead for 8b/10b encoding
  ⇒ more efficient encoding will improve margin of operation
Radiation-Hardness of Silicon PIN

- Irradiate PIN/VCSEL arrays with 24 GeV protons at CERN
- PIN responsivity decreases by 3x at 114 Mrad
  - SLHC: 69 Mrad or $1.5 \times 10^{15}$ 1-MeV $n_{eq}/cm^2$
- No degradation of rise/fall time
Eye Diagrams

- measured using coax terminated with 50 Ω
  - plan to reduce noise with TIA
- operating at 320 Mb/s is probably adequate
Radiation-Hardness of GaAs PIN

- All arrays are front side illuminated.
- PIN responsivities decrease by ~10x at 53 Mrad.
- Should repeat irradiation to SLHC dosage of 34 Mrad (8.2 x 10^{15} 1-MeV n_{eq}/cm^{2}).
VCSEL LIV Characteristics

- ULM requires higher voltage to operate
- all arrays have very good optical power

K.K. Gan
US ATLAS Pixel R&D Meeting
VCSEL LIV Characteristics

- both arrays have very good optical power

Pre-irrad
VCSEL Power vs Dosage

- Optowell & ULM (10 Gb/s) survive to SLHC dosage

2007:
Two arrays each
(2 x 7 channels)

1st irradiation period

2nd irradiation period
VCSEL Power vs Dosage

AOC (5 & 10 Gb/s) survive to SLHC dosage

2007:
Two arrays each (2 x 7 channels)

1st irradiation period

2nd irradiation period
Annealing of VCSEL Arrays

- recovery is slow
- **Optowell** has the highest annealed power
Annealing of VCSEL Arrays

- recovery is slow but adequate annealed power
More Annealing of VCSEL

- VCSEL might not fully recover after SLHC dosage
Irradiation Plan

- should repeat irradiation to dosage for 3,000 fb\(^{-1}\) instead of 5,000 fb\(^{-1}\)
  - PIN:
    - Si: TrueLight, Hamamatsu (new)
    - GaAs: AOC, ULM, Optowell, Hamamatsu (new)
  - VCSEL:
    - AOC, Optowell, ULM?
    - August 08 with 24 GeV/c protons (CERN) together with chips
Opto-Pack Development

- current pixel detector uses Taiwan optical packages
  - VCSEL mounted on PCB with poor heat conduction
  - micro soldering of 250 µm leads is difficult
- Ohio State develops new opto-pack for SLHC
  - uses BeO base with 3D traces for efficient heat removal
  - wire bond to driver/receiver chip
Results on Opto-Packs

- 35 VCSEL & 6 PIN opto-packs have been fabricated
  - all VCSEL opto-packs except one have good coupled power
  - principle of new opto-pack has been demonstrated

![Graph](image)

- MT ferrule
- VCSEL array
- Ceramic guide pin
Opto-Pack Development Plan

✓ Ceramic base successfully developed

😊 Current housing/connector difficult to connect/disconnect

หลายๆ  Modify MPO connector for ATLAS use

Need new non-magnetic spring

Need new housing: Cut housing into two and machine lower part as test of principle

.datasets

Need custom housing fabrication if test is successful
Opto-Chips

● 4 mm\(^2\) prototype chip was submitted on March 24
  ◆ PIN receiver/decoder operating at 40, 160 and 320 MHz
    ■ use bi-phase marked encoding due to the low speed
  ◆ VCSEL drivers operating at 640 Mb/s and 3.2 Gb/s
  ◆ both designs take advantage of LHC experience
  ◆ SMC block: 640 MHz serialization clocks
    ■ SEU tolerant multipliers (16 x 40 MHz or 4 x 160 MHz)
  ◆ extracted simulations show full functionality
Opto-Chips

640 Mb/s VCSEL Driver

3.2 Gb/s VCSEL Driver

640 MHz clock multipliers
   (4 x and 16 x)

2.6 mm

PIN receiver/decoder

1.5 mm
Clock Jitter Simulation

- Estimate jitter (pk-pk) of receiver/decoder in simulation:
  - 40 MHz: 460 ps
  - 160 MHz: 118 ps
  - 320 MHz: 73 ps
  \[ \text{jitter} \approx 2\% \]

- Jitter in clock multiplier:

<table>
<thead>
<tr>
<th></th>
<th>pk-pk jitter out with ideal source</th>
<th>pk-pk jitter in</th>
<th>pk-pk jitter out</th>
</tr>
</thead>
<tbody>
<tr>
<td>4X</td>
<td>1.3 ps / 0.08%</td>
<td>252 ps / 4%</td>
<td>210 ps / 13.4%</td>
</tr>
<tr>
<td>16X</td>
<td>15 ps / 0.96%</td>
<td>962 ps / 3.84%</td>
<td>365 ps / 23.4%</td>
</tr>
</tbody>
</table>

\[ \text{input jitter does not multiply} \]

- Eagerly await measurement with real chip and after irradiation
Opto-Chips Status/Plan

- Layout was reviewed at CERN on March 11, 08
- submitted to IBM via CERN to MOSIS on March 24, 08
- delivery date: July 08
- irradiation: August 08
  - use 24 GeV/c protons at CERN together with PIN/VCSEL arrays
  - study radiation-hardness and SEU
Summary

- fibers can be reused if necessary
- Si PIN probably can transmit at 320 MHz @ SLHC dosage
- GaAs PIN responsivity decreases by 10X @ SLHC dosage
- AOC and Optowell are potential candidates for SLHC
- should repeat irradiation to dosage for 3,000 fb\(^{-1}\) instead of 5,000 fb\(^{-1}\)
- compact MT-style opto-pack developed
- prototype chip submitted to test various upgrade scenario/radiation hardness