ATLAS Tracker
Upgrade Projects

Martin Kocian
DOE Review
SLAC, 8 July 2008

- Pixel data transmission
- SCT test stand
- Pixel test stand

SLAC
Why upgrade the pixel detector?
The SLHC luminosity target is $10^{35} \text{ cm}^{-2}\text{s}^{-1}$, 10 times that of LHC. To handle the increased event rates, background levels, and radiation dose the pixel detector will need:

- Smaller pixels size for better granularity.
- Higher data bandwidth.
- Better radiation hardness for pixels and readout.
- Lower power consumption and better cooling.
The pixel sensors are bonded directly to the readout chips.

The chips are arranged on modules, 4 per module for the outer layers, 2 for the inner layers.

In the barrel all modules of equal $\phi$ are attached to a support stave.

The data for the chips of each half of a stave is read out by a super module controller at the end of the stave.

The supercontroller serializes the data and sends it off the detector.

The data rates for the innermost layers can be up to 9 GBits/second.
In some of the layouts for SLHC the innermost layer is only 3.5 cm from the beam.

At this radius the yearly dose will be hundreds of Mrads.

Because of assembly constraints the readout cables have to be routed at low radius.

Optical fibers (used in ATLAS now) would not survive at this dose.

Can coaxial cable be used to transmit the data over 4 - 6 m to a place outside the high radiation area to interface with optical fibers?
SLAC (Dave Nelson, Su Dong, M. K.) is working on R&D on Gigabit rate transmission between the stave and the optical fiber link. This includes:

- **Coaxial cable:**
  - What rates can be achieved?
  - Which type of cable works the best?
  - How much material does the cable add to the pixel detector?
  - Is there coaxial cable that is sufficiently rad hard?

- **Transmission technology:**
  - Which electrical standard works best (single ended, differential, one or two coax cables per line)?
  - Do we need transmission enhancements like bit encoding and pre-emphasis?

- **Integration:**
  - How can the tranceiver be implemented in a rad hard ASIC?
  - Design a serializer to interface with the tranceiver in the ASIC.
  - How does the cable get attached to the board?
Coax Cable R&D

- Test cables of different sizes and materials.
- Use a random bit generator to look at the signal on the scope.
- Use a network analyzer to understand cable losses.
- Use a bit error rate tester to measure actual data transmission rates.
- We use the Xilinx 405 test board with RocketIO transceivers and a bit error rate test design:
Eye Patterns

- Bit rate is 1555 Mbit/second.
- Right plot: RG223 (5 mm, polyethylene dielectric).
- Lower left plot: Hitachi (1.2 mm, Teflon dielectric)
- Lower right plot: ATLAS Liquid Argon Calorimeter cable (1.2 mm, Kapton dielectric).
Understanding coax losses

- Measured with a network analyzer.
- Histogram: Data
- Black: Fit to $a_0 + a_1 \sqrt{f} + a_2 f$
- Green: Metal loss $\propto \sqrt{f}$
- Red: Predicted metal loss
- Blue: Dielectric loss $\propto f$

Hitachi cable

Liquid Argon cable
Signal enhancements

Pre-emphasis:

- Pre-emphasis creates an overshoot at each signal edge.
- This widens the “eye” of the signal.

Bit encoding:

- 8B/10B or 64B/66B encoding can be used.
- 8 (64) bits are mapped on 10 (66) bits for transmission.
- This avoids long sequences of only 0’s and only 1’s.
- Reduces bandwidth requirements.
- Better DC balance.
- Easier clock recovery.
Rate Measurements

- The table shows the highest rate with no errors after $10^{11}$ or more transmitted bits. (MBits/sec).

- Test frequencies are quantized by clock multiplication/division.

<table>
<thead>
<tr>
<th>Cable</th>
<th>Raw</th>
<th>Emph/Eq only</th>
<th>8B/10B &amp; Emph/Eq</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 m RG223 d=5 mm</td>
<td>3110</td>
<td>6220</td>
<td>9952</td>
</tr>
<tr>
<td>4 m Hitachi d=1.2 mm</td>
<td>1555</td>
<td>3110</td>
<td>6220</td>
</tr>
<tr>
<td>4.3 m LAr d=1.2 mm</td>
<td>?</td>
<td>3110</td>
<td>4095</td>
</tr>
</tbody>
</table>

- Test was done on coax pairs in the CML standard.
- d is the outer diameter of the cable.
- “?” means less than 1555 MBits/sec.
- The max rate for 6 m LAr cable is 3.1 GBit/s.
Next Steps

- Design a custom cable with good transmission and a low amount of material.
- Calculation predicts about 0.1% of a radiation length per coax cable pair and stave (Up to 3 pairs may be needed).
- Test different transmission types (differential signal on one cable, single-ended signal).
- Do a radiation test on dielectric (planned for July at LANL).
- Investigate connectors.
- Design an ASIC to implement our own transceiver in rad-hard technology.
SLAC (D. Nelson) is designing a test stand for the silicon strip detector.

The present SCT test stand is not fully adequate:

- Too slow.
- Not flexible enough to accommodate future readout development.
- Proprietary hardware/software (National Instruments/Lab Windows).

Features of the new test stand:

- Fast histogramming implemented in FPGA.
- USB based instead of VME.
- Linux-compatible.
- Electrically robust.

The design of the new test board is complete.

FPGA design and test software to be done.
What is the need for a new pixel test stand?

- The current test stand can only test the present generation of chips.
- It can only test one module at a time.
- It has a complicated setup (VME crate, National Instruments controller, Lab Windows, Microsoft Windows).

We (D. Nelson, Su Dong, M. K.) plan to design a new test stand at SLAC with the following features:

- Compatible with the present and with the new generation of readout chips.
- Can test a single module or a full stave.
- Can test several modules in parallel.
- USB based instead of VME.
- Linux-compatible.
- Fast histogramming implemented in FPGA.
Next Steps

- As a first step we have set up an existing “TurboDAQ” pixel test stand at SLAC.
- The TurboDAQ test stand will serve as a reference and for comparison of the results and the performance.
- We plan to use a similar Xilinx based technology for the new test stand as in our new SCT test stand.
- In a first phase we will reproduce the calibration results for the present generation chips.
- Next we will make the test stand work with the new generation of chips which is expected to come out next year.
- Finally the test stand will be made compatible with the to-be-designed stave supercontroller.
Summary and Outlook

Data Transmission:

- High rate transmission of pixel data is a crucial part of the pixel detector upgrade.
- This project is under active development at SLAC.
- From the initial R&D this looks like Gigabit rate transmission through coaxial cable is feasible.
- Our plan for the data transmission includes the design for coaxial cables, connections, and a serializer-transceiver ASIC.

Test stands:

- An FPGA based test stand for the SCT is under development.
- Work on a pixel test stand for the next generation of readout chips is starting.