Electrical Transmission On Cables At Gbit/s Rates

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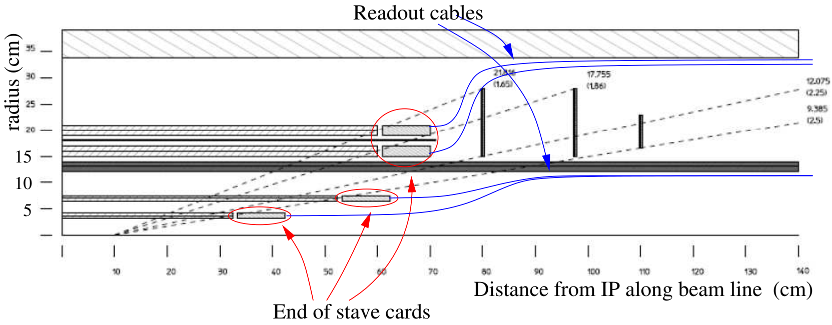
Introduction

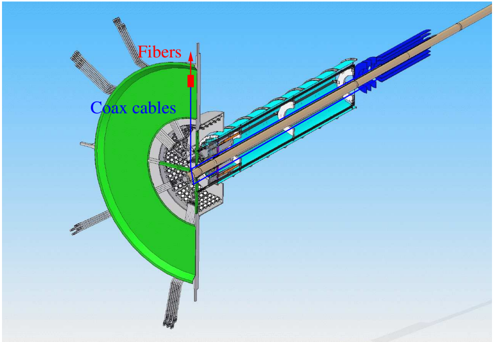
The ATLAS pixel detector at sLHC

- At sLHC the B layer is likely to be at a radius of about 3.5 cm.
- 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 and transmitters would not survive at this dose.
- Can coaxial cable be used to transmit the data electrically over 4 m to a place outside the high radiation area to interface with optical fibers?

Cable Routing



Additional Benefits

- Optical boards are accessible.
- Optical transmitters don't have to be operated at -30°C.
- No routing of delicate fibers inside the tracker.
- No bulky fiber transmitters on the end-of-stave cards.

Data Transmission Elements

Coaxial Cable

- Pair of coax cables.
- "Twinax" (2 center wires with a common shield).

Transmission ASIC

- Serialization of the data of multiple FE chips into one high rate stream.
- Encoding for DC balance and clock recovery.
- Pre-emphasis for improved signal transmission.
- Perhaps framing, forward error correction, ...

Integration

- Connectors.
- Interface with the front ends.
- Interface with the optical links.

Coaxial Cable Properties

- **Electrical Transmission Properties**
  - Dielectric material makes a big difference at Gbit/s rates.
  - Diameter of the center conductor is an important parameter.
  - Choice of metal matters (copper is best).
  - Geometry (coax vs. twinax).
- **Material Budget**
  - Bigger cables are better for transmission, but add material inside the tracking volume and are bulky to install.
  - Aluminum is preferable to copper.
- **Radiation Hardness**
  - The dielectric material must be extremely radiation hard.
- **Temperature**
  - The cable must work at -30°C.
- **Toxicity**
  - No fluorocarbons allowed inside ATLAS.

Coaxial Cable Losses

Metal Loss

- Caused by skin effect.
- Proportional to $\sqrt{\text{frequency}}$.
- Depends on the bulk resistivity of the metals.
- Good materials are copper and silver.
- Depends on geometry, mainly on inner conductor diameter.

Dielectric Loss

- Proportional to frequency.
- Proportional to $\sqrt{\epsilon_r}$ and to a material constant called “loss tangent” or “dissipation factor.”
- Low-loss dielectric materials are for example Teflon and polyethylene.
- Does **not** depend on the cable diameter or geometry.

Coax Cable Examples

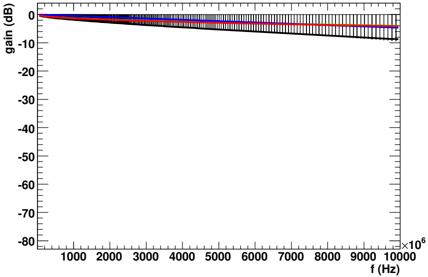
Compare cables of different sizes and dielectrics:

1. RG223
   - 5 mm OD.
   - Polyethylene dielectric.
2. Hitachi
   - 1.2 mm OD.
   - Teflon dielectric.
3. "Liquid Argon"
   - Used in the ATLAS LAr calorimeter.
   - 1.2 mm OD.
   - Kapton dielectric.
   - Very rad hard.

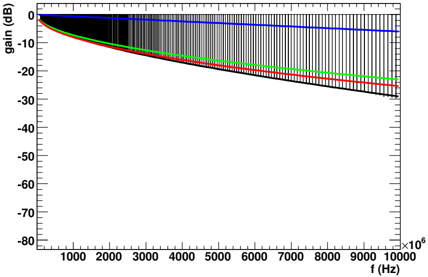
Loss Comparison

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

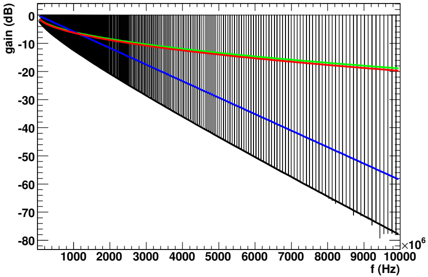
RG223 cable



Hitachi cable

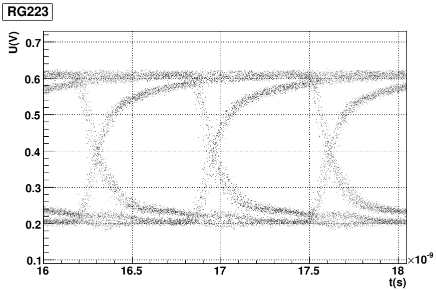


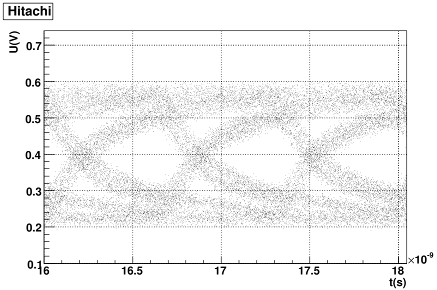
Liquid Argon cable

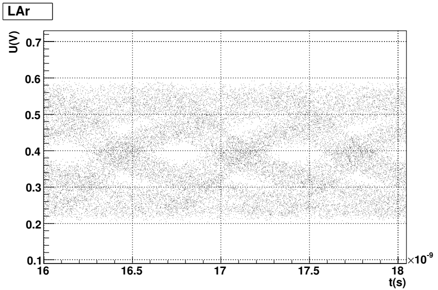


Eye Diagrams

- Look at signal on the scope.
- Bit rate is 1555 Mbit/second.
- Right plot: RG223
- Lower left plot: Hitachi
- Lower right plot: LAr



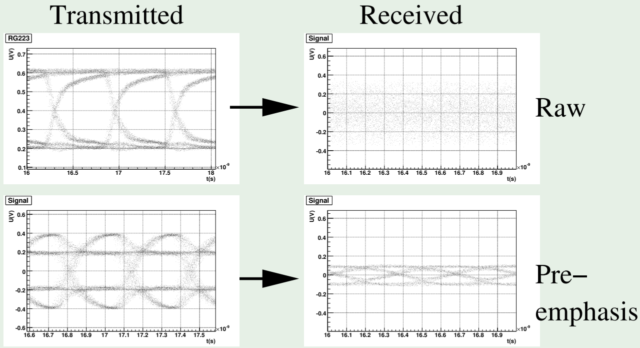




Signal Enhancements

Pre-emphasis

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



8B/10B encoding

- 8 bits mapped onto 10 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

- Used Xilinx V4 as a bit error rate tester.
- Table shows highest rate with no errors after 10^{11} or more bits.
- Test frequencies are quantized by clock multiplication/division.

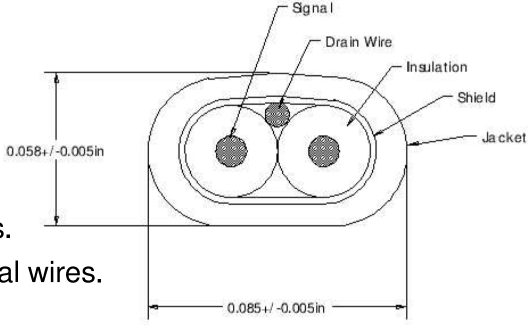
Cable	Raw	Enhanced
4 m RG223 d=5 mm	3110	9952
4 m Hitachi d=1.2 mm	1555	6220
4.3 m LAr d=1.2 mm	?	4095*
4 m Twinax d=1.2 mm		5100

* Tested to 10^{14} bits without error.

Comments

- "Enhanced" means with pre-emphasis and bit encoding.
- d is the outer diameter of the cable.
- “?” means less than 1555 MBits/sec.
- The target rate is around 5 Gbit/s.
- Twinax is a cable with 2 inner conductors OD ca. 175 μm. Shield looks like Al foil. Dielectric unknown. 4 m cable was made of 2 spliced pieces. This cable does extremely well for its size.

Custom Cable

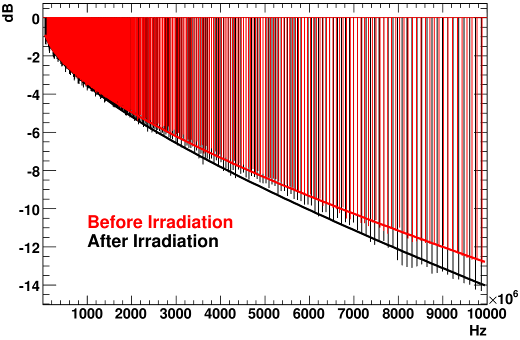


- Copper clad Aluminum wires.
- AWG 30 (0.25 mm) OD signal wires.
- Polyethylene dielectric.
- Aluminum foil shield and drain wire.
- Polyurethane jacket.
- Total size 1.25 mm x 1.95 mm.
- Adds ca. 0.05 % of X_0 (one cable smeared over stave width).

A prototype of the cable has been ordered.

Irradiation

- An irradiation test was done at Los Alamos.
- The total dose was $8 \cdot 10^{15}$ protons.
- The damage after irradiation was very minor.



Cable specs

- Twinax.
- 0.3 mm center conductors.
- Polyethylene dielectric.
- Copper wires/shield.

Transmission ASIC

- SLAC had started working on its own ASIC but we may switch to the CERN GBT chip as it has been converging with our needs:
  - Up to 10 input lines at 320 MBits/s.
  - Forward error correction.
  - DC balancing.
  - Radiation hard design.
- Chip size might be an issue since the GBT chip has 320 pins and we will have to place up to 4 chips on one end-of-stave card.
- The GBT chip has to be configured so it would have to be included in the frontend control scheme.
- We are reviewing the GBT specification document at the moment.

Transmission ASIC - driver

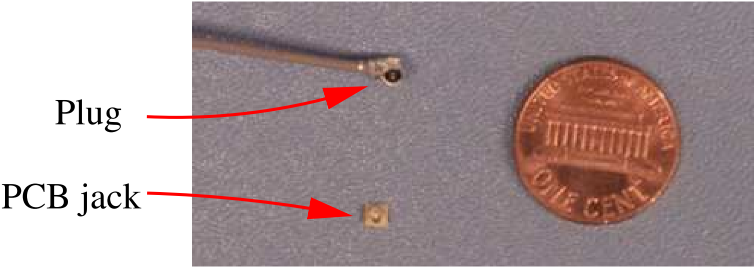
- The GBT driver (GBLD) is on a separate chip.
- It is supposed to drive the laser for the versatile link.
- We want to test this driver for driving coaxial cable.
- The chip has pre-emphasis.
- If the driver turns out to be unsuitable we could combine our own driver with the GBT main chip.

Summary

- The ATLAS pixel detector at sLHC needs electrical data transmission at Gbit/s rates over 4 m.
- Could also be a good solution for the strip dectector.
- R&D on transmission over coax cable has been done at SLAC.
- Data transmission over 4 m of micro coaxial cable at 5 Gbits/s is possible.
- A prototype cable has been ordered.
- The GBT ASIC looks like a good solution for serialization and encoding.
- The GBLD chip will be tested as a driver for coax cable.

Backup - Connectors

U.FL aka AMC aka MHF aka IPEX aka IPAX connectors



- Advantages:
  - Very small and lightweight: Plug plus receptacle is 75 mg.
  - Good up to 6 GHz.
  - Good to -40°C.
  - Connection seems fairly robust.
  - Cheap.
- 2 plugs & 2 jacks smeared over a 3 mm wide ring across stave: 2.9 % X0.