High-Speed Electrical Links on Low Mass Cables for CMS Inner Tracker Phase-2 Upgrade

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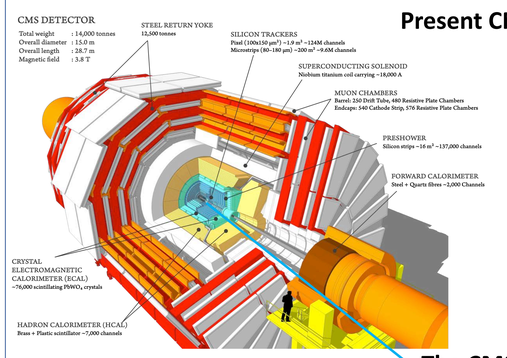
Abstract

For the High Luminosity-LHC, the CMS Inner Tracker with $2x10^9$ pixels is designed to deliver data from readout chips using 6680 electrical links at 1.28 Gbps. We present the design and performance of these low-mass, high bandwidth electrical links that will transfer the data from readout chips to low power gigabit transceivers. The transceivers will further send the serialized data at a rate of 10 Gbps through optical links to the Tracker backend electronics.

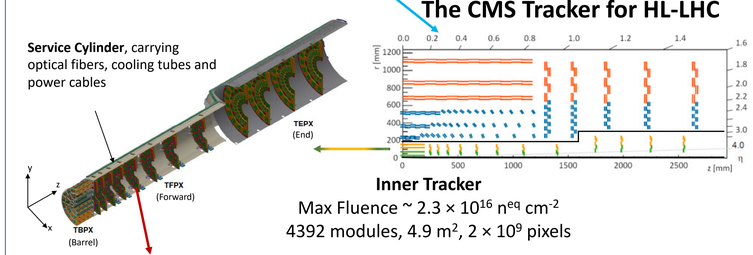
Introduction

The present **CMS Tracker** cannot sustain the implied radiation levels and data rates of the High Luminosity-LHC. Therefore, it has to be completely replaced by the end of Run-3 in 2023.

Present CMS Detector



The CMS Tracker for HL-LHC

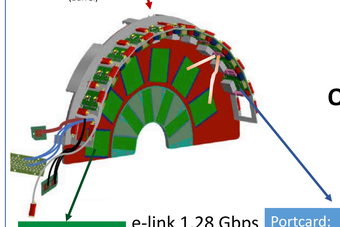


Inner Tracker

Max Fluence ~ 2.3×10^{16} n^{eq} cm^{-2}

4392 modules, 4.9 m^2, 2×10^9 pixels

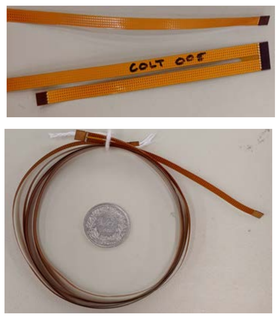
On Detector Readout Chain



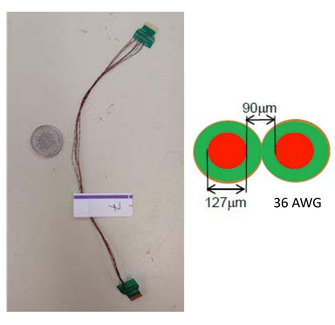
Prototypes & Design Goals

Prototypes: Cu cables

Flat Printed Circuit



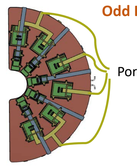
Twisted Pair



- Low Mass : 0.3 - 1.2 g/m
- Signal readout @1.28 Gbps for lengths up to 1.4 m
- Radiation hard : up to 1.5 GRad for 10 years of operation
- Total number : ~ 7K readout / 4K control links

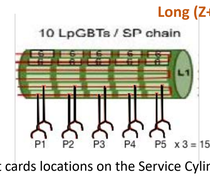
Physical & Mechanical Properties

- Visual inspection : Picture and video records before & after tests
- Radiation tolerance : Irradiate with gamma and proton sources
- Thermal cycling : -50 C to 25 C
- Layout and designs :



Odd Dee, TFPX

Port card location on the rim



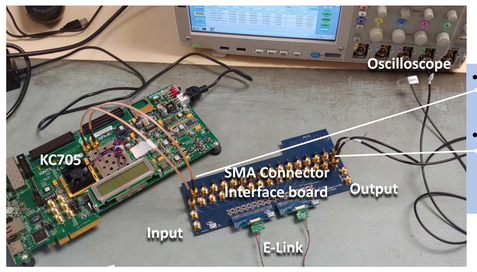
Long (Z+), Layer 1, TBPX

Port cards locations on the Service Cylinder

- Mechanical Stress : Bending, twisting, stacking

Electrical Properties

- DC resistance : 1.4 (4) Ω/m for TP (FPC) first prototype cables
- **Cross talk :** 5-10% for 1 and 1.4 m TP cables, 7% for 1 m FPC cables



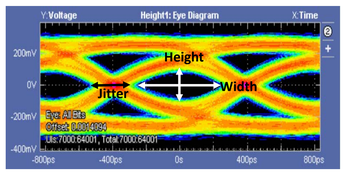
- Transmit differential signal with amplitude V_T
- Measure diff. amplitude V_{NX} on neighboring pair of wires to quantify the x-talk = V_{NX} / V_T

- Eye Diagrams *
- Vector Network Analysis *
- Bit Error Rate (BERT) *

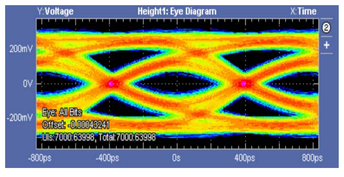
Eye Diagram

- How does the cable length impact signal at 1.28 Gbps rate?

PRBS7 signal generated with FPGA at 1.25 Gbps



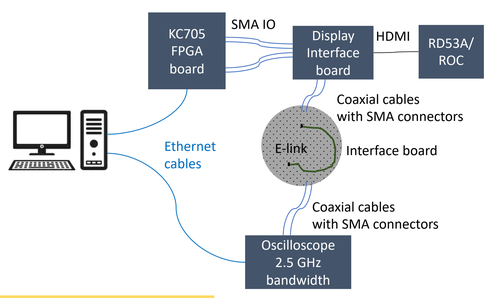
20 cm long TP



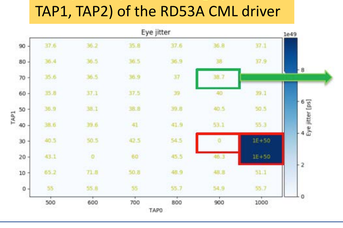
1.4 m long TP

- Are the ROC drivers tuned to provide adequate signal?

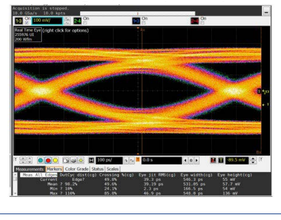
PRBS7 signal generated with RD53A at 1.28 Gbps



Tune pre-emphasis settings (TAP0, TAP1, TAP2) of the RD53A CML driver

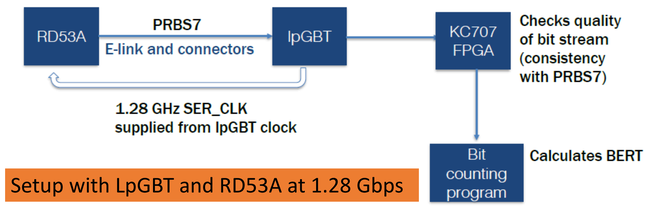


1.4 m long TP, after pre-emphasis

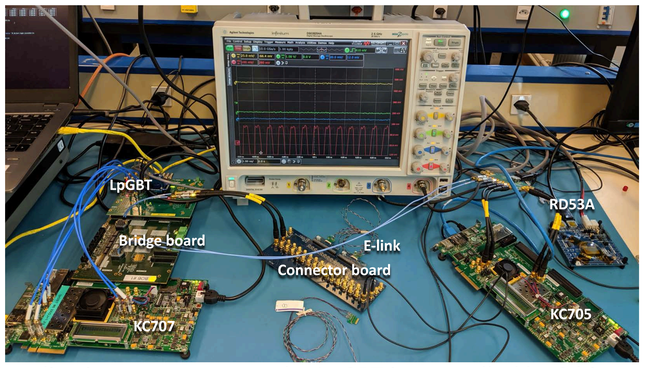


Bit Error Rate Test

- With PRBS7 differential signal from KC705 board, observed **0 errors/10^{13} bits @ 1.25 Gbps** for both FPC and TP cables
- Study the BERT with signal **transmit from RD53A @ 1.28 Gbps**, **received on LpGBT**



Setup with LpGBT and RD53A at 1.28 Gbps



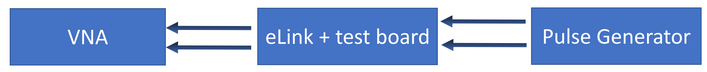
- Equalization parameter on the LpGBT is controlled by 2 bits
- Phase sampling over 1.5 × the clock cycle (1.28 GHz) at 15 points
- PRBS7 bit stream of length 10^8 bits from RD53A
- For several phase points the BERT is ~0

1.4 m long TP

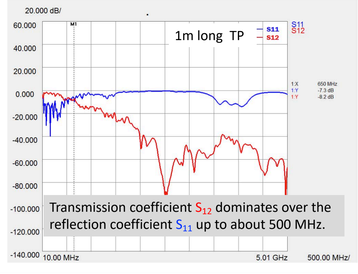
EQ	Ph00	Ph01	Ph02	Ph03	Ph04	Ph05	Ph06	Ph07	Ph08	Ph09	Ph10	Ph11	Ph12	Ph13	Ph14
0	0.00E+00	0.00E+00	0.00E+00	1.99E-08	8.26E-04	8.00E-02	1.19E-01	4.31E-03	0.00E+00	0.00E+00	3.97E-08	0.00E+00	4.42E-03	8.02E-02	9.49E-02
1	0.00E+00	1.99E-08	2.48E-08	2.48E-08	1.99E-08	8.38E-04	9.16E-02	8.31E-02	0.00E+00	0.00E+00	3.97E-08	0.00E+00	0.00E+00	7.25E-04	1.24E-01
2	5.61E-05	0.00E+00	0.00E+00	0.00E+00	1.99E-08	1.89E-04	7.77E-02	1.55E-01	1.87E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.30E-04	1.16E-01
3	1.56E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.43E-05	8.41E-02	1.66E-01	8.90E-03	0.00E+00	4.47E-08	0.00E+00	0.00E+00	2.32E-05	1.30E-01

Vector Network Analysis

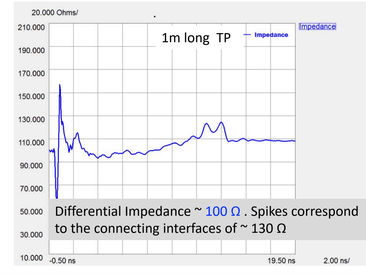
- S-parameters/Impedance
- Time Domain Reflectometry



PRBS7 signal from a pulse generator at 1.28 Gbps



Transmission coefficient S_{12} dominates over the reflection coefficient S_{11} up to about 500 MHz.



Differential Impedance ~ 100 Ω . Spikes correspond to the connecting interfaces of ~ 130 Ω

Acknowledgement

Testing was performed at the University of Kansas and CERN. Funding from the National Science Foundation supported this work.

Thanks to RD53A collaboration and the LpGBT development group at CERN for their conceptual and technical support.