Electronic Link Testing for the Inner Tracker Pixel Detector Upgrade at the Compact Muon Solenoid Experiment

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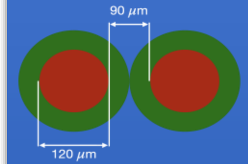
Abstract

The electrical signal transmission characteristics of electronic links (E-links) are measured for the Compact Muon Solenoid's (CMS) Inner Tracker Detector upgrade. In the KU CMS Electronics Lab, E-links are produced and tested. Data derived from the collisions inside CMS, recorded by a custom readout chip, must be transmitted to low power gigabit optical transceivers which will send the data outside CMS to be analyzed and stored. This requires a wired connection which can transmit data at speeds of 1.28 gbps over lengths of up to two meters. Electrical transmission characteristics including DC resistance, impedance, and bit error rate must be measured. The results illustrate how E-link quality varies from cable to cable. Statistical analysis is used to construct a grading system which makes it easier to determine whether future E-links need to be repaired or if they are ready to be installed at the CMS detector. The results document how the performance of cables varies as a function of length.

Introduction

The CMS particle physics collaboration is upgrading the innermost tracking pixel detector to be installed in 2026. The upgraded detector will have 2 billion channels with custom electronics readout chips (RD53A) capable of reading 145,000 channels attached to silicon sensors inside the larger CMS detector. Electronic links (E-links) take the signals from the readout chips to optical converter boards to be sent off the detector. At KU, 58 E-links with lengths from 0.35 meters to 2.00 meters were studied and a grading scheme was developed from these tests. These are low mass (<3 grams), 36 AWG copper, differential twisted pair cables capable of sending signals at a speed of 1.28 gbps with 5 differential channels. There are different types of cables which connect via a paddleboard to the readout electronics. E-links are hand-produced and checked for continuity, impedance, and signal transmission quality.

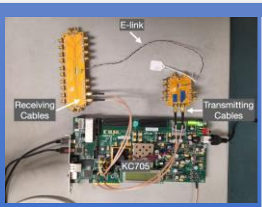


Cross section differential pair for 36 AWG E-link: copper (red) and polyamide insulation (green)

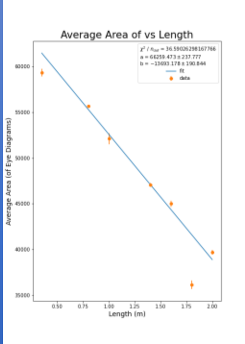
Connection paddle for our type 1 E-links. Notice the 5 separate differential pair channels

EYEBERT

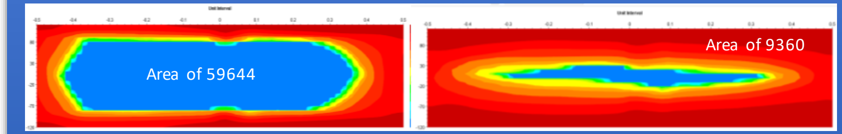
A Bit Error Rate Test (BERT) measures the error in received signals from a known transmission of a pseudorandom bit stream (PRBS). We developed tests using a field programmable gate array (FPGA) board (KC705). The KC705 transmits a PRBS through the E-link and measures the number of errors received in the signal. We want an error rate of < 1 error received per 10^{13} bits sent. Since it takes too long to send 10^{13} bits, other methods of measuring the bit error rate are used. An Eye Diagram is created by superimposing alternating current waveforms over each other and viewing the diagram in a certain time domain and we measure the area with less than 10^{-6} BER.

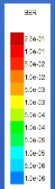


EyeBERT Setup



The plot above shows the linear regression of area of EyeBERT scans versus the length of cable.

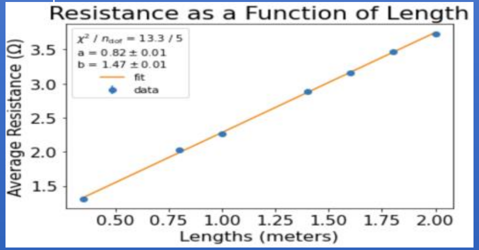




Example Eye BERT scans: (LEFT) Scan for E-link TP_0p35_137 (0.35 m) is shown. (RIGHT) Scan for E-link TP_1p0_146 (1.0 m) is shown. E-links with an area less than 25000 are graded as a fail, hence E-link TP_1p0_146 would be labeled as a fail.

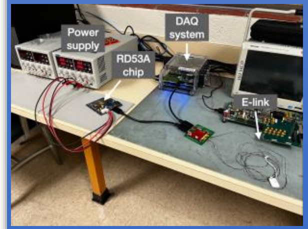
DC Resistance

The 4-point direct current resistance is measured which is the first indicator of a broken cable. In the figure, the resistance is plotted as a function of the length of the wire and there is a clear linear relationship between the points. The resistance values measured are acceptable.

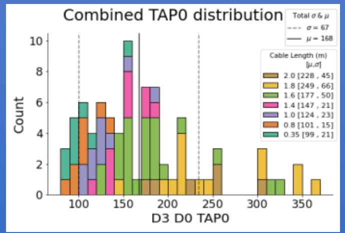


RD53A Chip Driver Test

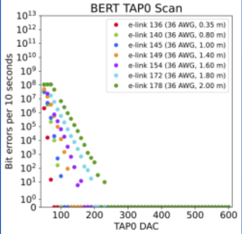
The RD53A chip driver test measures how many errors accumulate in a signal as it is transmitted through the E-link. The RD53A chip sends a PRBS through the E-link to the data acquisition (DAQ) system where it is checked for the number of errors. We send 10^{11} bits over 10 seconds and vary the amplitude (TAP0). The amplitude where the error rate is < 1 per 10^{11} bits is recorded. Notice in the histogram that TAP0 is a function of length.



Hardware Setup



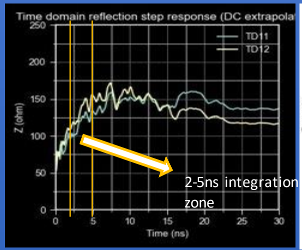
minimum TAP0 needed for zero errors for every cable



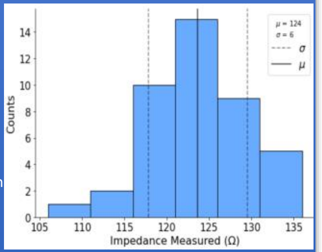
Plot of data collected over a single test for multiple cables

Impedance

The RD53A chip sends out signals with an impedance of 100 Ω and one wants the E-Links to approximately match that value. The Vector Network Analyzer (VNA) plots the signal's impedance as a function of time (left plot). The impedance of the E-link is found by integrating over a portion of the graph determined by the length of E-link or from 2-5ns. A 2 to 5 ns integration allows us to compare the different lengths of cables. The figure on the right shows the average to be around 124 Ω and not vary by more than 6 Ω. Although this average is above 100 Ω, acceptable transmission occurs.



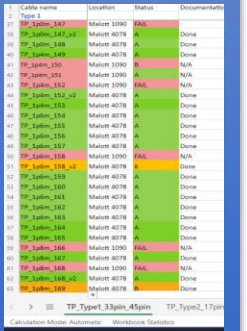
Impedance vs Time for 2 meter E-link



VNA Count Distribution

Results

Each cable's test results must be analyzed to see whether they are acceptable for use in CMS. Results of all tests are used to construct a way to grade cables as A, B, or Fail.



Of the 58 cables tested, 37 were graded as A, 6 were graded as B, and 15 failed. These results have helped us to improve the cable production and testing procedures.

The mean and standard deviation are used to determine a range for our grading scale. For example, for the impedance, E-links graded as A were within 3 σ of our mean value. Impedance measurements outside of that range or low EYE BERT areas contributed to most of the E-links graded B. Failed E-links were mainly had continuity issues. Once the E-Links are tested and graded, they are stored for future use.

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