Optical Readout and Control Systems for the CMS Tracker

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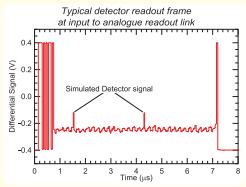
Analogue Readout

The ~10 million microstrip channels of the CMS Silicon Tracker will be time-multiplexed with a ratio of 256:1 and read-out over ~40000 analogue optical links.



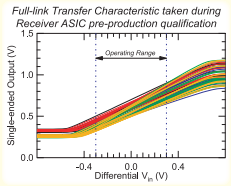
The readout link must transmit detector data over 50-100m to the remote counting room with the following characteristics:

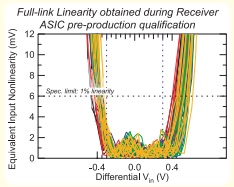
- Settling time: 20ns (40MS/s)
- Dynamic Range: 7-8bits
- Linearity: 1-2%
- Gain: 0.8V/V (target)

The system operates over single-mode optical fibre using Fabry-Perot edge-emitting diodes lasing at 1310nm.

All components have been chosen and contracts are in place with the relevant manufacturers for the volume production to begin in Q4 2002. Production will last until Q3 2004. The first ("pre-production") batches are being delivered to CERN where qualification is taking place.

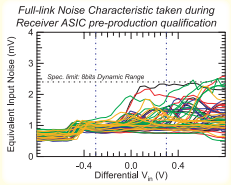
As a result of the extensive prototype testing that has been carried at CERN since the start of the project, it has been possible to put in place a well-documented test sequence that allows both pre-production qualification and lot acceptance to be carried out. These test procedures have been accepted by the component manufacturers to form the basis of the production process monitoring once the initial qualification has been performed. As such they have already been used on the prototypes tested to date and are now being used to qualify the first pre-production batches as they are received from the various manufacturers.

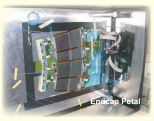




Pre-production qualification of all active components will be complete by April 2003. Since the overall production schedule of link components reflects the installation timescale of the CMS Tracker, the final component to be qualified (in December 2003) will be the rugged multi-ribbon cable which carries data through the shielding wall between detector cavern and counting room. Once the full-scale production is cleared by the qualification step, a sub-set of the qualification testing is carried out as Lot Acceptance approximately once per month - in line with the delivery of batches of components.

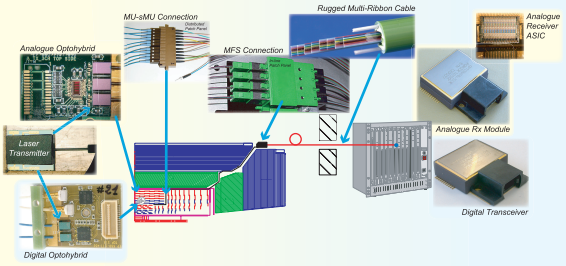
Data are shown from such testing carried out on the analogue receiver ASICs from the pre-production batch. Data from 5 measured devices (60 channels) are shown. Both noise and linearity performance comfortably meet the specifications for the analogue readout system. Linearity and Noise measurements are shown referred to the link input. This allows better comparison of overall link operating parameters for both front- and back-end components as well as components from different production batches.



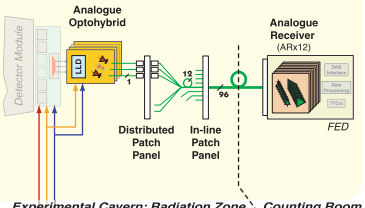


Full-system testing has also been carried out in parallel to the component-level testing. Both front- and back-end optical link components have been integrated into larger mechanical structures together with silicon detector modules that have then been successfully read-out.

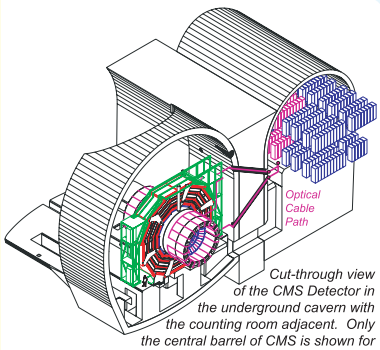
Implementation



Analogue System Overview



Digital System Overview



Cut-through view of the CMS Detector in the underground cavern with the counting room adjacent. Only the central barrel of CMS is shown for clarity. The optical cable path for both readout and control is highlighted.

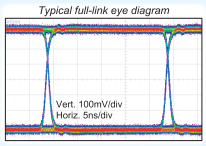
Digital Control

The CMS Tracker control system will consist of 320 control rings. Each control ring requires two digital optohybrids for redundancy, which yields a total of ~2500 digital optical control channels.

The control link must transmit control information as well as the multiplexed 40MHz bunch-crossing clock and Level-1 trigger over 50-100m between the remote counting room and the front-end with the following characteristics:

- Speed (Data): 40Mb/s
- Speed (Clock): 80Mb/s (40MHz)
- Bit Error Rate: $<10^{-12}$
- I/O levels: LVDS

Due to the significantly smaller number of digital compared to analogue links required, the control system links re-use the components of the readout links wherever possible. Only the photodiodes at the front-end and the transceivers at the back-end are different.



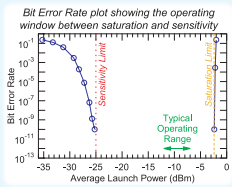
One control link 'unit' consists of two channels that transmit information from the counting room to the detector front-end and two channels which return that information from the front-end back to the counting room. Of the two channels carrying information in either direction, one carries clock and trigger information while the other carries the NRZI control data that passes around each control ring. A trigger is encoded onto the clock as a missing pulse. The sampling clock is recovered at the front-end detector modules by a PLL ASIC which also extracts the trigger pulse for the front-end amplifiers.

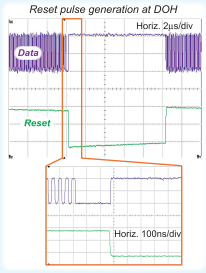
Two basic digital system measurements are used to characterise the control link:

- The 'eye' diagram
- Bit Error Rate (BER) testing

Typical examples of these two measurements are shown (above and right). The eye diagram shows the digital datastream exiting the digital optohybrid (DOH) to be very clean with low jitter for a 40Mb/s system.

Plotting the BER as a function of incident light level it is possible to measure both the upper (saturation) and lower (sensitivity) limits on the optical power that a receiver channel can operate with.





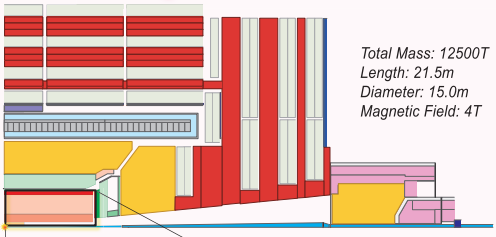
Measurement of these two limits for different components allows assessment of the interoperability of the fully commercial back-end components with the semi-custom front-end ones. It is clear from the plot shown that the margins from the typical operating range to the limits are quite wide in this system.

In order to implement a 'hard-reset' signal without increasing the number of optical links this signal is coded onto the data channel by the Front-End Controller (FEC) as an absence of light. Missing Data of this kind lasting for ~10 clock cycles or more is interpreted by the digital receiver ASIC (Rx40) of the control link as a reset. The generation by the DOH of this signal is shown to the left.

Components that are unique to the control link are currently undergoing final specification and the commercial actions required for them to go into production will take place by Q2 2003.

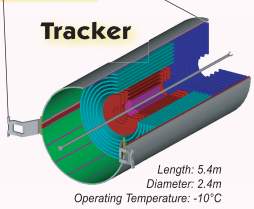
The final validation of the control link embedded in a full control system is currently being carried out. Preliminary results from the system-level testing confirm the detailed link testing already carried out.

Compact Muon Solenoid



Total Mass: 12500T
Length: 21.5m
Diameter: 15.0m
Magnetic Field: 4T

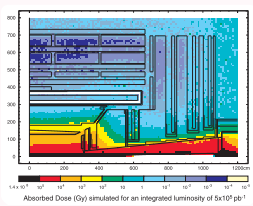
Tracker



Length: 5.4m
Diameter: 2.4m
Operating Temperature: -10°C

*The **High Radiation levels** expected within the central parts of CMS place one of the most stringent requirements on the electronic systems that are deployed in the front-end readout systems. Components for the Tracker readout system must be qualified to the following levels:*

Displacement damage: 3×10^{14}n/cm^2 (1MeV equiv.)
Ionisation damage: 150kGy



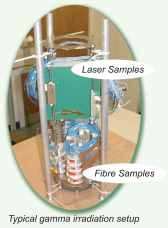
*The **CMS Tracker** is composed of:*

Pixel Detector
containing ~40 Million pixels
Silicon Strip Tracker
containing ~10 Million strips

The total area of silicon deployed in the CMS Tracker is ~250m^2

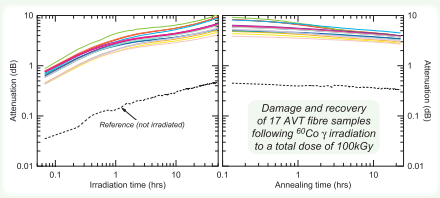
Radiation Hardness Assurance

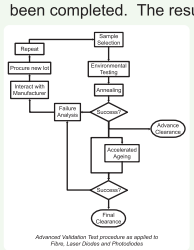
The high levels of radiation that will be present within the CMS Tracker, together with our strategy of using COTS components which are not guaranteed radiation tolerant, require us to qualify the components that will be used inside CMS.



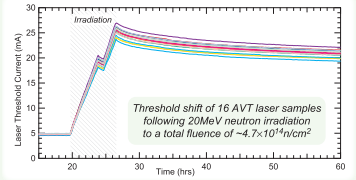
Typical gamma irradiation setup

We have confidence, based upon the extensive radiation testing carried out on candidate components to date, that the chosen components are and will remain sufficiently radiation tolerant throughout the 2002-2004 production period. A programme of Advanced Validation Testing (AVT) has been put in place to monitor the radiation tolerance of the fibre preforms and laser diode wafers that will be used in the production batches of fibre, fibre ribbon/cable and laser transmitters. The procedure illustrated below is carried out periodically, each AVT qualifying sufficient raw fibre or laser die to cover several months' production. The first AVTs involving fibre and laser samples has been completed. The results are shown in the adjacent plots for gamma (fibres) and 20 MeV neutron (lasers) irradiation.





Positive results were obtained for the irradiation and subsequent annealing steps, with the tested samples showing very similar results to those obtained in earlier irradiation tests. These results confirm the stability of the manufacturing processes. They have allowed us to issue advance clearance for production of laser transmitters, buffered fibre and fibre ribbon.



http://cern.ch/cms-opto