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CMS Tracker Optical Readout Link Specification

Part 2.2.1.1: Buffered Fibre

Version 3.5, 26 April, 2001

CERN EP/CME

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1. Introduction

1.1. General system description

This specification defines the design requirements for the analogue optical link to be used in the readout system of the tracker sub-detector of the CMS detector [1.1] at the CERN [1.2] Large Hadron Collider (LHC). The tracker sensing elements are silicon microstrip detectors. The approximate total number of detector channels is 12 millions, to be multiplexed and read-out by approximately 50000 optical links. A thorough description of the CMS tracker is found in [1.3].

The CMS tracker optical readout link is embedded into the data acquisition chain shown in Fig. 1.1. It starts at the electro-optic opto-hybrid interface and ends at the opto-electric receiver module interface. Specifications for the Front End Driver board (FED), MUX and APV front-end chips can be found in: [1.4] and [1.5]

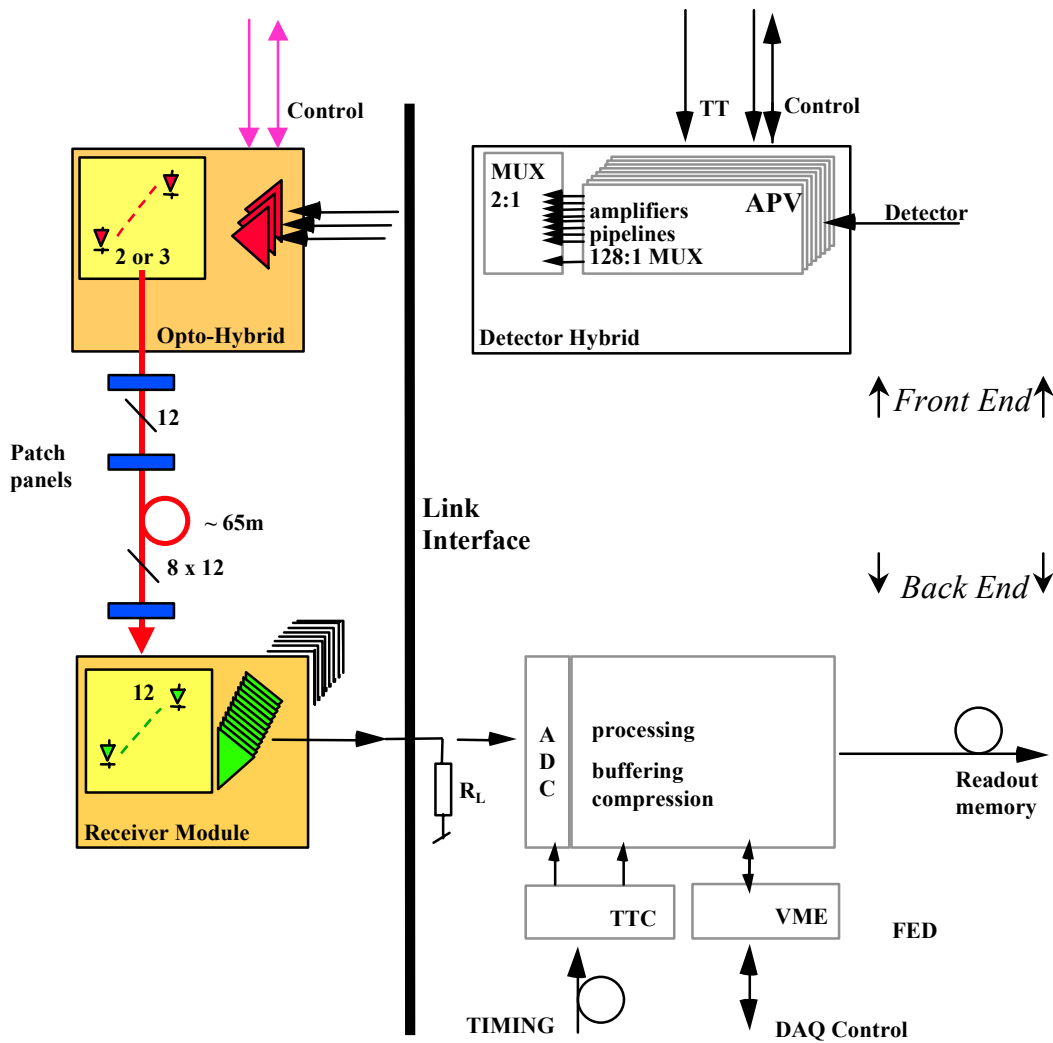


Fig. 1.1. Tracker readout chain with optical link highlighted on the left.

To ease the understanding and use of this document, a brief explanation of the CMS tracker sub-detector data flow is given below. A more detailed description of the CMS tracker readout chain can be found for instance in [1.6]. Signals from all sensor channels are sampled and stored every 25ns in the APV front-end chip analogue memory. In the event of a Level 1 trigger occurrence (TT), the analogue samples corresponding to the time slice of interest in the memory are processed, time multiplexed and transferred in packet form from the detector hybrids to the opto-transmitter hybrids via short lengths of flexible cable tape (0 to 30 cm typ.). They are then sent via optical fibres to the receivers situated at the link back-end, where they are converted back to electrical. A to D conversion, processing and buffering take place on the Front End Driver (FED) boards before the data packets are sent out to the readout memory and computer farms.

1.2. Document structure and convention

The optical link specification is broken down into eight independent parts, each describing and specifying a different level or function in the system:

- Part 1. System
- Part 2. Analogue Opto- Hybrid
 - 2.1 Laser Driver
 - 2.2 Laser Transmitter
 - 2.2.1 Terminated Pigtail
 - 2.2.1.1 Buffered Fibre
 - 2.3 Analogue Opto-Hybrid Substrate
- Part 3. Terminated Fibre Ribbon
 - 3.1 Ruggedized Ribbon
- Part 4. Terminated Multi-Ribbon Cable
 - 4.1 Dense Multi-Ribbon Cable
- Part 5. Analogue Opto-Receiver Module
 - 5.1 Analogue Receiving Amplifier
- Part 6. Distributed Patch Panel
 - 6.1 MU-SR Adaptor
- Part 7. In Line Patch Panel
 - 7.1 Connector shell
- Part 8. Backend Patch Panel
 - 8.1 Connector shell

Each part has the following structure:

- | | | | |
|-------------------------|-----------------------------|-------------|---------------|
| 1. Introduction | 2. Technical requirement | 3. Glossary | 4. References |
| 1.1. System description | 2.1. description | | |
| 1.2. Document structure | 2.2. block diagram | | |
| 1.3. Related WWW sites | 2.3. specification | | |
| 1.4. Contact | 2.4. operating environment | | |
| 1.5. Document history | 2.5. other characteristics | | |
| | 2.6. testing | | |
| | 2.7. option (when required) | | |

Due to the preliminary nature of this document, the specification section (section 2.3) of each system part is labelled "target specifications". CERN should be consulted before any hard- or software relying on these characteristics is being designed. Target specifications will eventually evolve into full specifications once the system definition is mature. Still to be determined parameters are labelled TBD.

1.3. Related WWW sites

- CERN laboratory: <http://www.cern.ch/Public/>
- CMS project: <http://cmsinfo.cern.ch/Welcome.html>
- CMS Tracker Technical Design Report: <http://cmsdoc.cern.ch/ftp/TDR/TRACKER/tracker.html>
- CMS Tracker Electronic System: <http://pcvlsi5.cern.ch:80/CMSTControl/>
- CMS Tracker Optical Links: <http://cms-tk-opto.web.cern.ch/>
- FED developments: http://hepwww.rl.ac.uk/cms_fed/
- APV and MUX developments: <http://www.te.rl.ac.uk/med/>

1.4. Contact

All questions regarding this document should be addressed to:

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1.5. Document history

Rev. 0.4, 02/08/96	Draft
Rev. 1.0, 04/09/97	Major rework, single document covering all system parts
Rev. 2.0, 05/06/98	Rework, document distributed
Rev. 3.0, 21/08/00	Document (Rev2.3) split into independent parts.
Rev. 3.1, 05/09/00	testing section amended.
Rev. 3.2, 21/09/00	Fibre cladding diameter tolerances decreased, AR coating parameters specified.
Rev. 3.3, 12/10/00	Fibre coating diameter spec added
Rev. 3.4, 18/12/00	Split between terminated pigtail spec (2.2.1) and buffered fibre spec (2.2.1.1).
	Revision in conformity with IT2811.
Rev. 3.5, 26/04/01	Spec(2.2.1.1.65) modified.

2. Technical requirement, part 2.2.1.1: Buffered Fibre

2.1. Description

The buffered fibre carries the light out of the laser transmitter (to be mounted on the opto-hybrid) to the distributed patch-panel situated at the edge of the sensors support structure (rods or petals). It consists of 9/125/250/900µm buffered single mode fibre. Its situation in the optical link cabling structure is highlighted in Fig. 2.1.

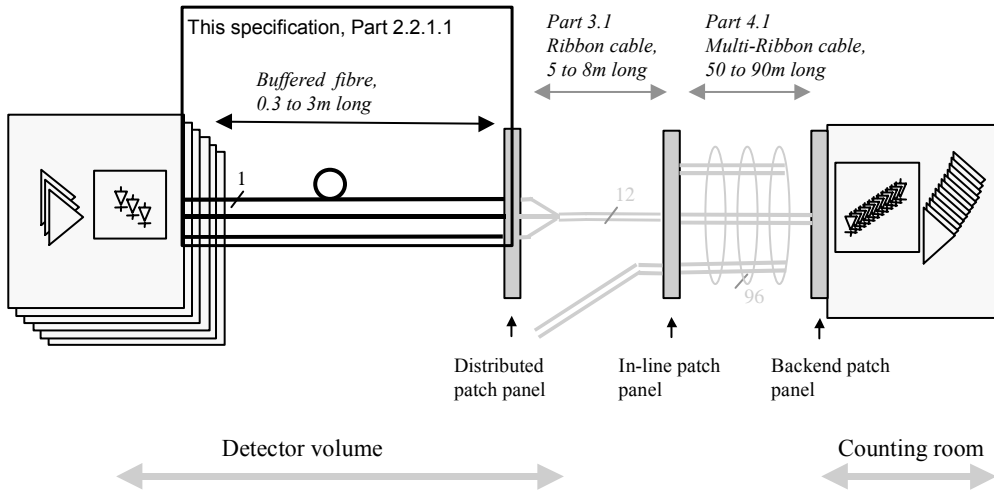


Figure 2.1, Buffered fibre highlighted in the optical link cabling structure.

A total buffered fibre length of approximately 50km will be required for the CMS Tracker. The terminated pigtail is specified in part 2.2.1, the laser transmitter in part 2.2, and the distributed patch-panel in part 6 of the optical link technical requirement document.

2.2. Block diagram

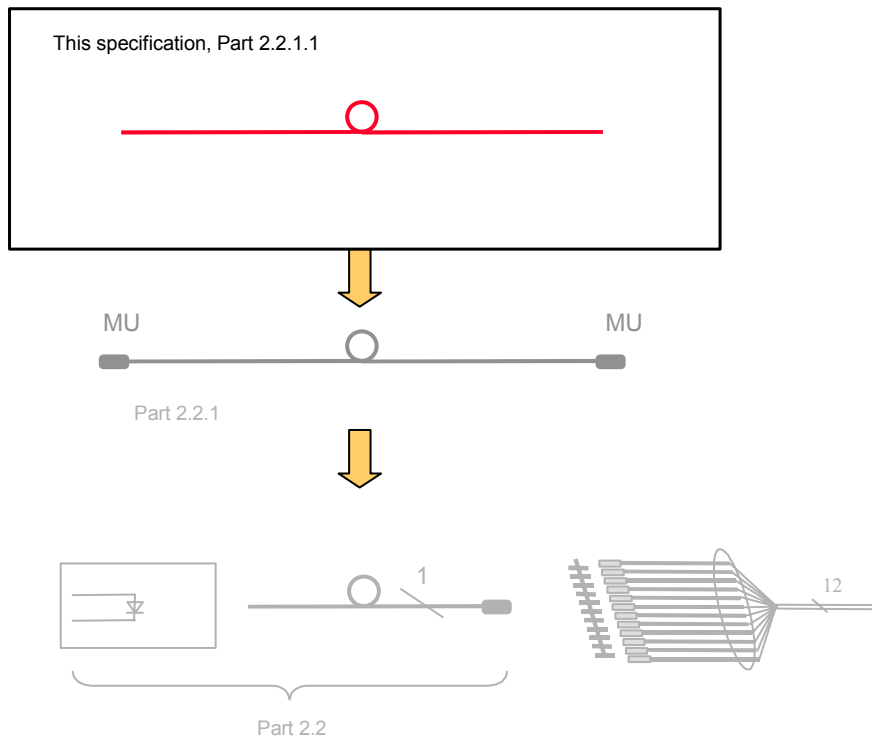


Fig. 2.2. Buffered Fibre and related components block diagram

2.3. Target Specifications (@25°C unless otherwise noted)

#	Fibre specification	min	typ	max	unit	note
2.2.1.1.1	Fibre type	Single-mode non-dispersion shifted				ITU G652
2.2.1.1.2	Fibre material	Phosphorus free				
2.2.1.1.3	Geometry	9/125/250			µm	
2.2.1.1.4	Cladding diameter	124.7	125	125.3	µm	TBD
2.2.1.1.5	Primary coating diameter		250		µm	It must be possible to strip the buffered fibre to this diameter
2.2.1.1.6	Mode field concentricity error			0.3	µm	
2.2.1.1.7	Operation wavelength	1260	1310	1330	nm	
2.2.1.1.8	Fibre cut-off			1260	nm	
2.2.1.1.9	Attenuation			0.4	dB/km	
	specs 2.2.1.1.10 to 2.2.1.1.20					reserved for future use

#	Buffered Fibre specification	min	typ	max	unit	note
2.2.1.1.21	outer diameter		900		µm	Loose tube, semi-tight or tight buffer, see option 2.7, TBD
2.2.1.1.22	bend radius	3			cm	operation ¹
2.2.1.1.23	torsion			5	turn/m	installation
				1	turn/m	operation ¹
2.2.1.1.24	tensile loading			10	N	installation
				5	N	operation ¹
2.2.1.1.25	compressive strength			5	N/cm	installation and operation ¹
2.2.1.1.26	impact resistance			5	J	
2.2.1.1.27	buffer colour	green				TBD, stable during lifetime ¹
2.2.1.1.28	buffer marking	none				
	specs 2.2.1.1.29 to 2.2.1.1.60					reserved for future use

¹Foreseen operating lifetime: nominal 10 years.

2.4. Operating environment

#	environmental specifications	min	typ	max	unit	note
2.2.1.1.61	Magnetic field			4	T	parallel to any axis
2.2.1.1.62	Hadronic fluence ¹			3e14	1/cm ²	Integrated over lifetime ² 90% charged particles 10% neutrons
2.2.1.1.63	Gamma radiation dose ¹			1.5e5	Gy(Si)	Integrated over lifetime ²
2.2.1.1.64	Temperature	-20	-10	70	°C	Operation and storage
2.2.1.1.65	Operating humidity	Dry lab environment during testing and dry Nitrogen flow during operation.				
	specs 2.2.1.1.66 to 2.2.1.1.80					reserved for future use

¹The component resistance to radiation will be controlled under the sole responsibility of CERN (see section 2.6 of this document). No testing, validation or qualification is pre-required from the suppliers.

²Foreseen operating lifetime: nominal 10 years.

#	safety specifications		note
2.2.1.1.81	Material composition	Halogen-free material	CERN IS23, see ref. [2.2]
2.2.1.1.82	Fire behaviour	IEC 332-1, IEC 1034, IEC 754-2, ABD 0032	CERN IS23, see ref. [2.2]
	specs 2.2.1.1.83 to 2.2.1.1.99		reserved for future use

2.5. Other characteristics

- Test Documentation and traceability: TBD
- Shipping and storage requirements: TBD

2.6. Testing

#	Specification to be tested	Manufacturer		CERN		
		Product Qualification	Lot validation (before delivery)	Advance Sample Validation	Pre-production Qualification	Lot Acceptance
Fibre						
2.2.1.1.1	Fibre type	◆	◆			
2.2.1.1.2	Fibre material	◆	◆			
2.2.1.1.3	Geometry	◆	◆	◆ ^{1,3}		
2.2.1.1.4	Cladding diameter	◆	◆		◆ ²	◆ ²
2.2.1.1.5	Primary coating diameter	◆	◆		◆ ²	◆ ²
2.2.1.1.6	Mode field concentricity error	◆	◆		◆ ²	◆ ²
2.2.1.1.7	Operation wavelength	◆	◆		◆	◆
2.2.1.1.8	Fibre cut-off	◆	◆			
Buffered Fibre						
2.2.1.1.9	Attenuation	◆	◆		◆	◆
2.2.1.1.21	Buffer outer diameter	◆	◆		◆	◆
2.2.1.1.22	Bend radius	◆	◆		◆	◆
2.2.1.1.23	Torsion	◆	◆		◆	◆
2.2.1.1.24	Tensile loading	◆	◆			
2.2.1.1.25	Compressive strength	◆	◆			
2.2.1.1.26	Impact resistance	◆	◆			
2.2.1.1.27	buffer colour	◆	◆		◆	◆
2.2.1.1.28	buffer labelling	◆	◆		◆	◆
2.2.1.1.61	Magnetic field					
2.2.1.1.62	Hadronic fluence			◆ ³		
2.2.1.1.63	Gamma radiation dose			◆ ³		
2.2.1.1.64	Temperature	◆				
2.2.1.1.65	Operating humidity	◆				
2.2.1.1.81	Material composition	◆				
2.2.1.1.82	Fire behaviour	◆				

¹splicing compatibility is checked

²coupling to laser is checked

³pre-form sampling

2.7. Options

Depending on choice of laser manufacturer, different types of fibre buffer may be required: loose tube, semi-tight or tight-buffered fibre (specs 2.2.1.1.21). The final choice of buffer will be made in agreement with the laser manufacturer.

3. Glossary

This glossary is common to all parts of both the control link and the readout link specification. Some definitions may thus not be relevant to the part under consideration.

3.1. Signal to noise ratio

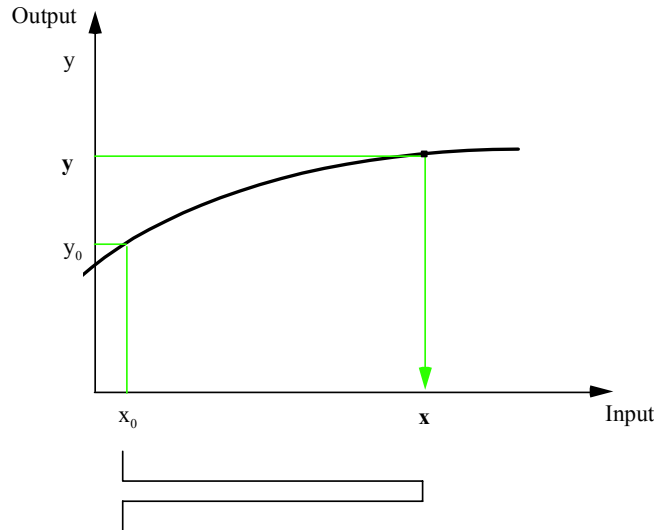


Fig. 3.1. Signal to noise ratio

The signal is defined as $\Delta y = y - y_0$, where y_0 is the system quiescent working point.

The rms noise y_{rms} is defined as the noise spectral density integrated over the full optical link bandwidth.

The signal to noise ratio (SNR) is defined as:

$$SNR = 20 \text{Log} \frac{\text{Signal}}{\text{rmsNoise}} = 20 \text{Log} \frac{|\Delta y|}{y_{rms}}$$

The peak signal Δy_{peak} is the largest amplitude which can be handled by the optical link in its linear operating range.

The peak signal to noise ratio (PSNR) is defined as:

$$PSNR = 20 \text{Log} \frac{|\Delta y_{peak}|}{y_{rms}}$$

3.2. Integral Non-Linearity

The integral non-linearity INL is defined as the full-scale-normalized error one makes when, for a given link output signal y , the link input signal is assumed to be the linearized value x_L instead of the real value x .

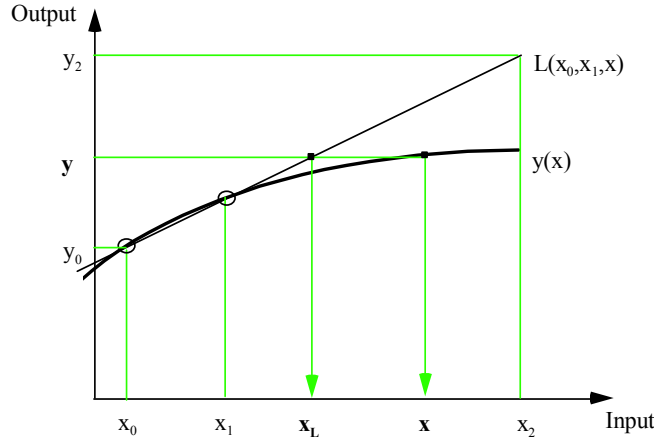


Fig. 3.2. Integral non-linearity

The linear regression is calculated by fitting the transfer characteristic in a linear operation window $[x_0, x_1]$ (alternatively $[y_0, y_1]$ in the output range).

INL is defined as the error one makes when approximating x by x_L , normalised by the full-scale signal:

$$INL = \frac{x - x_L}{x_2 - x_0}$$

3.3. Settling time

The settling time is defined as the time required for a step response signal to settle to $\pm 1\%$ of its end value.

3.4. Skew

The skew is determined by measuring, for two channels, the average time $\overline{t_{50}}$ required for a step response signal to reach 50% of its end value. The skew between channels i and j is defined as:

$$t_{skew} = \overline{t_{50, j}} - \overline{t_{50, i}}$$

3.5. Jitter

The rms jitter is defined as the rms deviation of the time t_{50} required for a step response signal to reach 50% of its end value:

$$t_{jitter} = \sqrt{\overline{(t_{50} - \overline{t_{50}})^2}}$$

3.6. Crosstalk

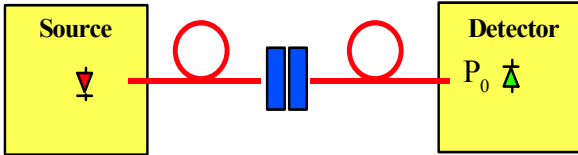
The crosstalk between two channels i and j is defined as the relative feedthrough from channel i to channel j at sampling time $t_s=20\text{ns}$ when an ideal step signal is injected into channel i at $t=0\text{s}$.

$$\text{Crosstalk} = 20 \text{ Log} \left| \frac{\text{Out}_j}{\text{Out}_i} \right|_{t_s=20 \text{ ns}}$$

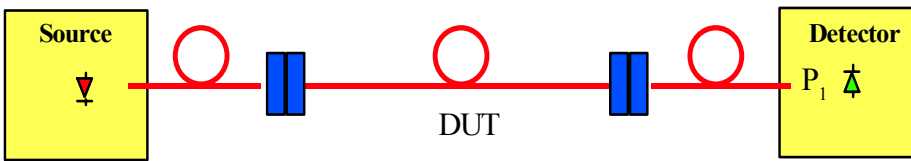
3.7. Insertion loss

The insertion loss (IL) is defined as the Log of the ratio of optical powers measured before (P0) and after (P1) insertion of the device under test (DUT). In case the DUT is a single connector, optical power (P0 and P1) is measured with a large area detector in a receptacle.

a) Launched power measurement (P0)



b) Transmitted power measurement (P1)



$$IL = 10 \text{Log} \frac{P_0}{P_1}$$

c) Insertion loss:

3.8. Power supply rejection ratio

The power supply rejection ratio (PSRR) is defined as the amplitude of a sinusoidal disturbance Δd injected into the power supply rail and causing a ripple Δy on the output of the device under test, divided by the input signal Δx which would cause an identical ripple Δy .

$$PSRR = 20 \text{Log} \frac{\Delta d}{\Delta x}$$

4. References

- [1.1] <http://cmsinfo.cern.ch/cmsinfo/Welcome.html>
- [1.2] <http://www.cern.ch/>
- [1.3] The tracker project, technical design report, CERN/LHCC 98-6, CMS TDR 5
- [1.4] R. Halsall, "FED specifications", Draft, RAL, http://hepwww.rl.ac.uk/cms_fed/
- [1.5] M. French, "APV specifications", Draft, RAL, <http://www.te.rl.ac.uk/med/>
- [1.6] G. Hall, "Analogue optical data transfer for the CMS tracker", Nuclear Instruments and Methods in Physics Research A, Vol. 386, pp. 138-42, 1997, http://pcvlsi5.cern.ch:80/CMSTControl/documents/Geoff/Readout_summary.pdf
- [1.7] A. Marchioro, " Specifications for the Control Electronics of the CMS Inner Tracker", Draft V2, CERN, <http://pcvlsi5.cern.ch:80/CMSTControl/manuals.htm>
- [1.8] A. Marchioro, "FEC specification", Draft, CERN
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- [2.1] M. Huhtinen, "Studies of neutron moderator configurations around the CMS inner tracker and Ecal", CERN CMS TN/96-057, 1996.
- [2.2] http://www.cern.ch/CERN/Divisions/TIS/safdoc/instr_en.html