ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
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Laboratoire Européen pour la Physique des Particules
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CMS Tracker Optical Readout Link Specification

Part 1: System

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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 10 millions, to be multiplexed and read-out by approximately 40000 optical links (plus spares). 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]

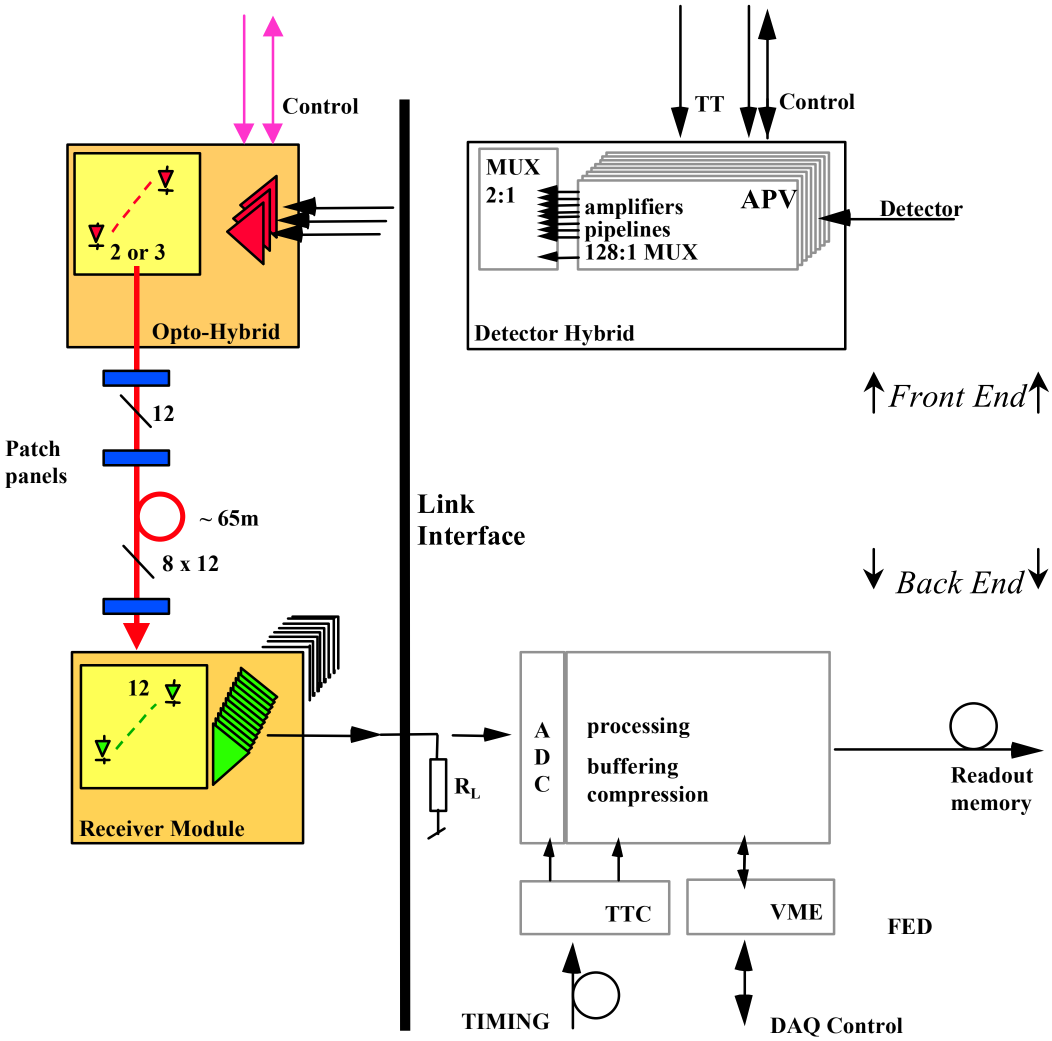

Fig. 1.1. Tracker readout chain with optical link highlighted on the left.

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

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, 19/08/99	Document (Rev2.3) split into independent parts.
Rev. 3.5, 15/08/00	Intro/coda modified, specs 1.3 and 1.4 made typical, spec 1.6 modified.
Rev. 3.6, 09/04/01	Specs updated, test section added.
Rev. 3.7, 24/04/01	Connector pinout added for Tx side.

2. Technical requirement, part 1: system

2.1. Description

Analogue signals generated by the front-end electronics are transmitted (Analogue Opto hybrids (2)) by the optical links to the front-end driver readout units (receiver modules (5)) situated in an underground cavern adjacent to the detector. Semiconductor lasers are used as transmitters, while pin photodiodes serve as receivers. Fibre ribbon (3) is used inside the detector, while fibre ribbon cables (4) are used in the ducts through the detector concrete shield. For ease of testing, installation and maintenance, three patch panels (6,7,8) are foreseen, two in-line ones (6,7) and one back-plane one (8). Altogether, about 40000 point to point optical readout channels (optical fibres) will be implemented.

2.2. Block diagram

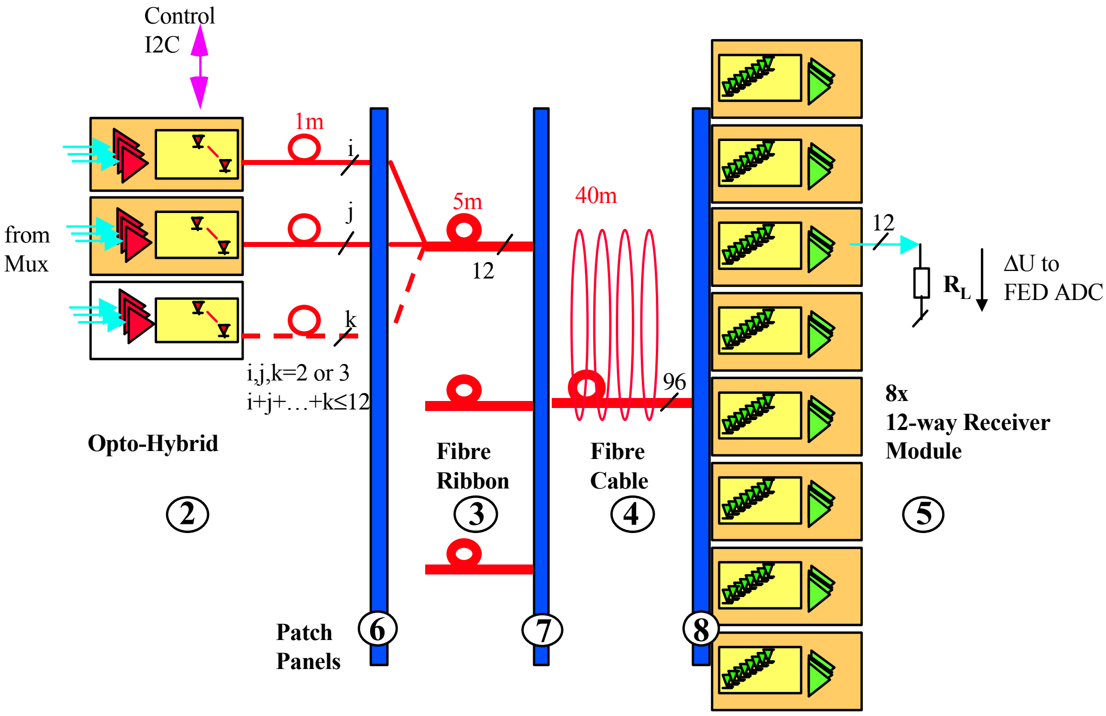


Fig. 2.1. Optical link block diagram

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

#	operational specifications	min	typ	max	unit	note
1.1	Total length	30		120	m	
1.2	Single ended gain	0.25	0.8	2.5	V/V	With nominal driver (7.5mS) and receiver (4kΩ) gain settings.
		0.3	0.8	1.3	V/V	With equalized driver gain settings (12.5mS for weak link, 5mS for strong link).
1.3	Peak signal to noise ratio		48		dB	see glossary 3.1
1.4	Integral linearity deviation		1		%	in any 100, 200 and 400mV window within input range, see glossary 3.2
1.5	Bandwidth	70			MHz	DC coupled
1.6	Settling time to ±1%		18	20	ns	see glossary 3.3
1.7	Skew			2	ns	Between any 2 fibres coming from the same hybrid, see glossary 3.4
1.8	Jitter			1	ns	rms, see glossary 3.5
1.9	Crosstalk		-48		dB	see glossary 3.6
	specs 1.10 to 1.20					unused

#	electrical specifications	min	typ	max	unit	note
1.21	Operating* input voltage	-300		+300	mV	Differential, $In^+ – In^-$
1.22	Input voltage	-500		+500	mV	Differential, $In^+ – In^-$
1.23	Input impedance		100		Ω	
1.24	Operating* output voltage range ΔU	180	480	800	mV	With equalized driver gain settings. Single-ended, output terminated with R_L=100Ω to Vee.
1.25	Output voltage	0.4		3	V	Single-ended, output terminated with R_L=100Ω to Vee.
1.26	Output loading		1.6	2.5	ns	$\tau = C_L * R_L$
1.27	Quiescent operating point	user adjustable via a) IIC interface (front-end) and b) Rx module control logic (FED)				defined at 0V input signal
1.28	Tx hybrid power supply	2.25	2.5	2.7	V	Vss-Vdd
1.29	Rx module power supply	4.5	5.0	5.5	V	Vcc-Vee
	specs 1.30 to 1.40					unused

* The operating range is defined as the range where linearity is specified (see also glossary 3.2)

#	optical specifications	min	typ	max	unit	note
1.41	Wavelength	1285	1310	1335	nm	
	specs 1.42 to 1.60					unused

2.4. Operating environment

#	environmental specifications	min	typ	max	unit	note
The analogue opto-hybrid (2) is situated inside the tracker detector. Patch panel (6) is at the edge of the tracker detector mechanical support structure. Patch panel (7) is at the magnet cryostat level. Patch panel (8) is at the FED crate front-panel, in the readout room. The receiver module (5) is on the FED board, in the readout room.						
1.61	Magnetic field for items (2), (3), (4), (6), (7)			4	T	Parallel to particle beam axis
1.62	Hadronic fluence for items (2), (3), (6)			3e14	$1/cm^2$	Integrated over lifetime[1], 90% charged particles, 10% neutrons, see Fig. 2.1, and ref [2.1]
1.63	Gamma radiation dose for items (2), (3), (6)			1.5e5	Gy(Si)	Integrated over lifetime[1], see Fig. 2.1
1.64	Hadronic fluence for items (4), (7)			1e12	n/cm^2 (1MeV)	Integrated over lifetime[1], dominated by neutrons, see Fig. 2.1
1.65	Gamma radiation dose for items (4), (7)			100	Gy(Si)	Integrated over lifetime[1], see Fig. 2.1
1.66	Temperature					Operation and Storage
	for items (2), (3), (6), (7)	-20	-10	70	°C	
	for items (4), (5), (8)	-20	+25	70	°C	
1.67	Operating humidity for items (2), (3), (6), (7)	Dry lab environment during testing and dry Nitrogen flow during operation				
1.68	Operating humidity for items (4), (5), (8)			60	%RH	13°C dew point
1.69	Operation rate		4000		hrs/year	
	Specs 1.71 to 1.80					unused

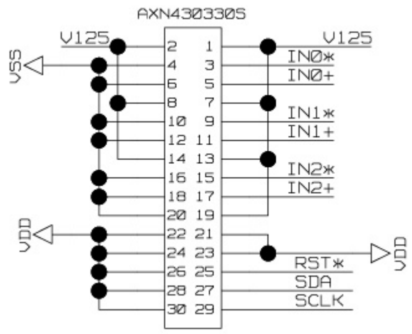
[1] Foreseen operating lifetime: nominal 10 years.

#	safety specifications		note
1.81	Optical	Laser system hazard level k x 3A	IEC 60825-1 1998-01, 60825-2 2000-05
1.82	Material composition	Halogen-free material	CERN IS41, see reference [2.2].
1.83	Fire behaviour	Flame retardant material	IEC 332-1, IEC 1034, IEC 754-2, ABD 0032 CERN IS23, see reference [2.2].
	specs 1.84 to 1.99		unused

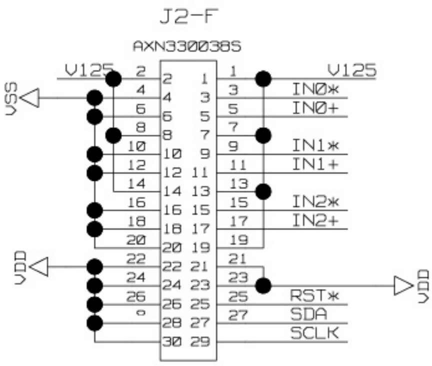
2.5. Other Characteristics

- electrical interface on Tx side

Plug in connection to detector hybrid signal, control and power supply lines



Header connector (TOB)



Socket connector (TIB, TEC)

- electrical interface on Rx side

Solder connections on FED board to ADC, power supply and control

2.6. Testing

#	Specification to be tested…	…during Tracker commissioning
1.1	Total length	
1.2	Single ended gain	♦
1.3	Peak signal to noise ratio	♦
1.4	Integral linearity deviation	♦
1.5	Bandwidth	♦
1.6	Settling time to ±1%	
1.7	Skew	♦
1.8	Jitter	
1.9	Crosstalk	

1.21	Operating input voltage	♦
1.22	Input voltage	♦
1.23	Input impedance	
1.24	Operating output voltage range ΔU	♦
1.25	Output voltage	♦
1.26	Output loading	
1.27	Quiescent operating point	♦
1.28	Tx hybrid power supply	
1.29	Rx module power supply	
1.41	Wavelength	

2.7. Options

- The link gain can be tuned by the user at the laser driver level (via control system) and at the receiver level (by changing the termination resistor). The dynamic range will be affected accordingly.
- The link quiescent operating point can be tuned by the user at the laser driver level (via control system) and at the receiver level (in groups of 12 channels by changing the Rx-module control bits). The dynamic range and link performance will be affected accordingly.

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

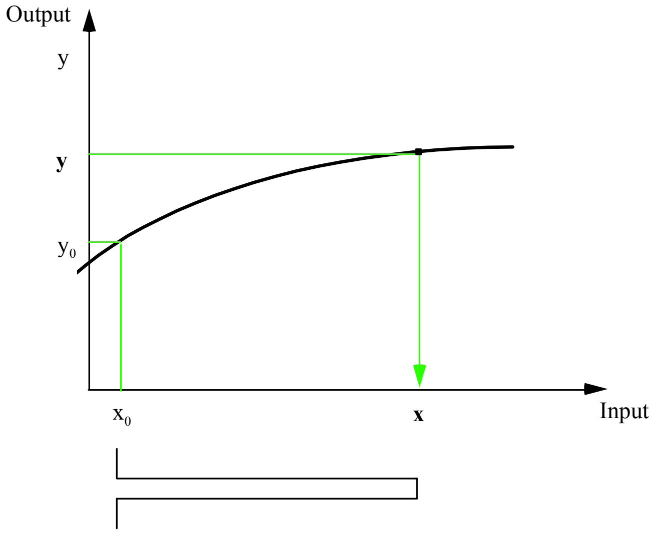


Fig. 3.1. Signal to noise ratio

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:

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

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:

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

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.

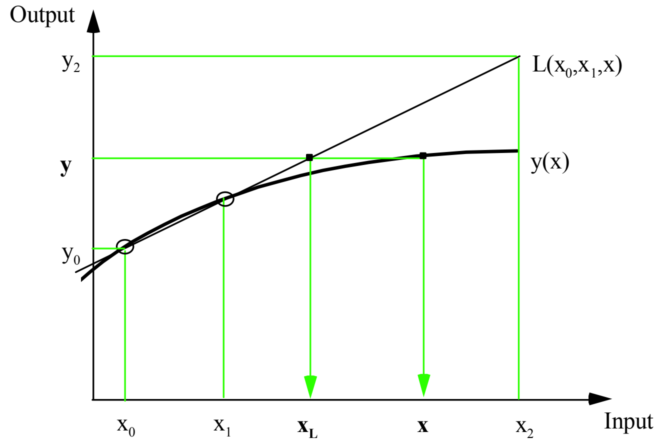


Fig. 3.2. Integral non-linearity

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 ±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:

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

3.6. Crosstalk

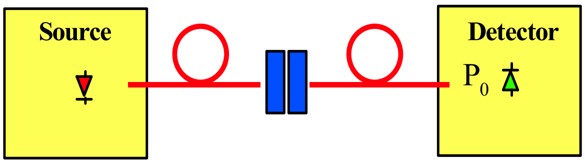
The crosstalk between two channels i and j is defined as the relative feedthrough from channel i to channel j at sampling time t_s=20ns when an ideal step signal is injected into channel i at t=0s.

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

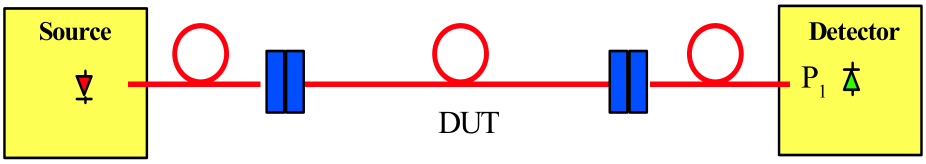
3.7. Insertion loss

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)



c) Insertion loss: $\mathrm{IL} = 10\mathrm{Log}\frac{\mathrm{P_0}}{\mathrm{P_1}}$

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 .

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

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

[1.9] A. Marchioro, "CCU specification", Draft, CERN, http://pcvlsi5.cern.ch:80/CMSTControl/documents/Sandro/Ccu260598.pdf

[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