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CMS Tracker Optical Control Link Specification

Part 1: System

Version 1.2, 7th March, 2003.

CERN EP/CME

Preliminary

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1. Introduction

1.1. General system description

This specification defines the design requirements for the digital optical link to be used in the control system of the various sub-detectors of the CMS detector [1.1] at the CERN [1.2] Large Hadron Collider (LHC). The system architecture is based on the token ring concept, with mixed optical and copper sections [1.3]. The system was originally developed for the Tracker subdetector [1.4], where the total number of redundant control rings is 320, corresponding to 2560 optical link channels. In the other subsystems, namely ECAL, preshower and pixels, the combined total number of digital links required is expected to be a similar to that for the Tracker.

The CMS optical control link is embedded into the control ring, as shown in Fig 1.1 taking the Tracker system as an example. The optical link is highlighted on the left of the figure, starting and ending at the backend transceiver module which is mounted on the Front End Controller board (FEC). Specifications for the FEC, and communication control unit (CCU) ASICs can be found in [1.5] and [1.6] respectively.

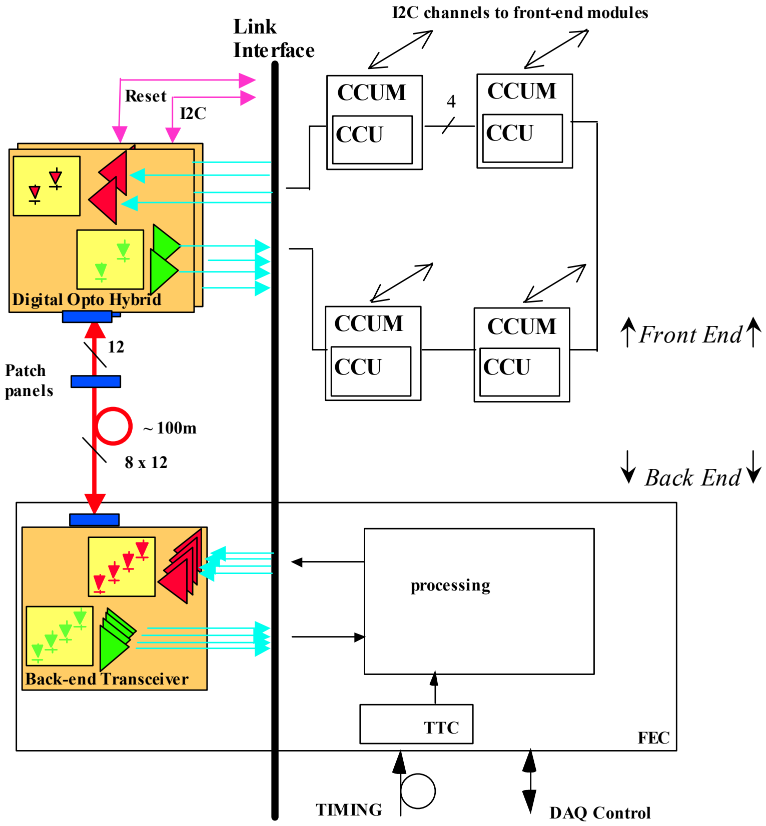

Fig. 1.1. Tracker control ring with optical link highlighted on the left.

The communication architecture proposed to control the embedded electronics is based on two layers. A more detailed description can be found for instance in [1.3]. The first layer (called the Ring) connects the FEC to the CCU modules (CCUMs) as well as connecting between CCUMs on the same ring. The protocol on this first layer is message-based and is implemented in a way similar to LAN networks. Four lines are required to transmit data (40Mb/s) and system clock (40MHz) with redundancy. Optical links are used to transmit data between the back-end (FEC) and the front-end digital optohybrid (DOH). The data is then communicated between CCUMs via electrical interconnections. The second layer of communication, between the CCUMs and the front-end chips, is entirely electrical and is based on the I^2C standard protocol.

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. Digital Opto-Hybrid
- 2.1 Laser Driver ASIC
- 2.2 Laser Transmitter
  - 2.2.1 Terminated Pigtail
    - 2.2.1.1 Buffered Fibre
- 2.3 PIN Photodiode
- 2.4 Digital Receiver ASIC
- 2.5 Digital Optohybrid Substrate

Part 3. Terminated Fibre Ribbon
- 3.1 Ruggedized Ribbon Harness
  - 3.1.1 Ruggedized Ribbon

Part 4. Terminated Multi-Ribbon Cable
- 4.1 Dense Multi-Ribbon Cable

Part 5. Back-End Opto-Transceiver Module

Part 6. Distributed Patch Panel
- 6.1 MU-sMU Adaptor

Part 7. In Line Patch Panel
- 7.1 MFS Adaptor

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. implementation		

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 hardware or software relying on these characteristics is being designed. Target specifications will eventually evolve into full specifications once the system definition is mature. Parameters still to be determined 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://cmstrackercontrol.web.cern.ch/CMSTrackerControl/docmain.htm
- CMS Tracker Optical Links: http://cms-tk-opto.web.cern.ch/
- FED developments: http://www.te.rl.ac.uk/esdg/cms_fed_pmc/index.html
- APV and MUX developments: http://www.te.rl.ac.uk/med/

1.4. Document history

Rev. 1.0, 17/12/02	Draft (KG)
Rev. 1.1, 24/1/03	Propagated changes from DOH and TRx specs. Power margins added.(KG)
Rev. 1.2, 7/3/03	Modified output termination based on TRx specs.(KG)

1.5. Contacts

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2. Technical requirement, part 1: system

2.1. Description

On the front-end DOH, labelled *(1)* in Fig. 2.1, the lasers are 1310nm InGaAsP/InP edge-emitters, pigtailed with single-mode 9/125/250/900µm fibre that is terminated with an MU connector. The receivers on the DOH are InGaAs/InP p-i-n photodiodes pigtailed in the same way as the lasers. Also mounted on the DOH are the LLD laser driver ASIC, and the RX40 receiver ASIC.

After the distributed patch panel *(5)*, which houses MU-sMU connections, the fibres attached to components on a given DOH (and its redundant back-up DOH) are then fanned into a 12-way ruggedized ribbon cable *(2)* using a compact fan-in element. In each ribbon there are 4 fibres transmitting light to the Tracker, 4 dark fibres, and 4 fibres transmitting light from the Tracker. The 12-fibre modularity matches that of the fibre-ribbon components used in the analogue readout link system at the relatively small expense of the additional dark fibre.

The optical cables follow the same routing (in the Tracker) as for the readout links and will share the same in-line patch panels *(6)*, using MFS connectors. Groups of eight ribbons are then fanned into 96-way dense multi-ribbon cables *(3)*, which then pass to the counting room.

At the back-end of the links in the counting room, 4+4 way transceiver modules *(4)*, each having a 12-way MPO optical interface *(7)*, will be mounted on the FEC.

Altogether, 2560 optical readout channels (optical fibres) will be implemented for control of the CMS Tracker and a similar, perhaps greater number is expected to be required for the other CMS sub-systems, including ECAL, Preshower and Pixels.

2.2. Block diagram

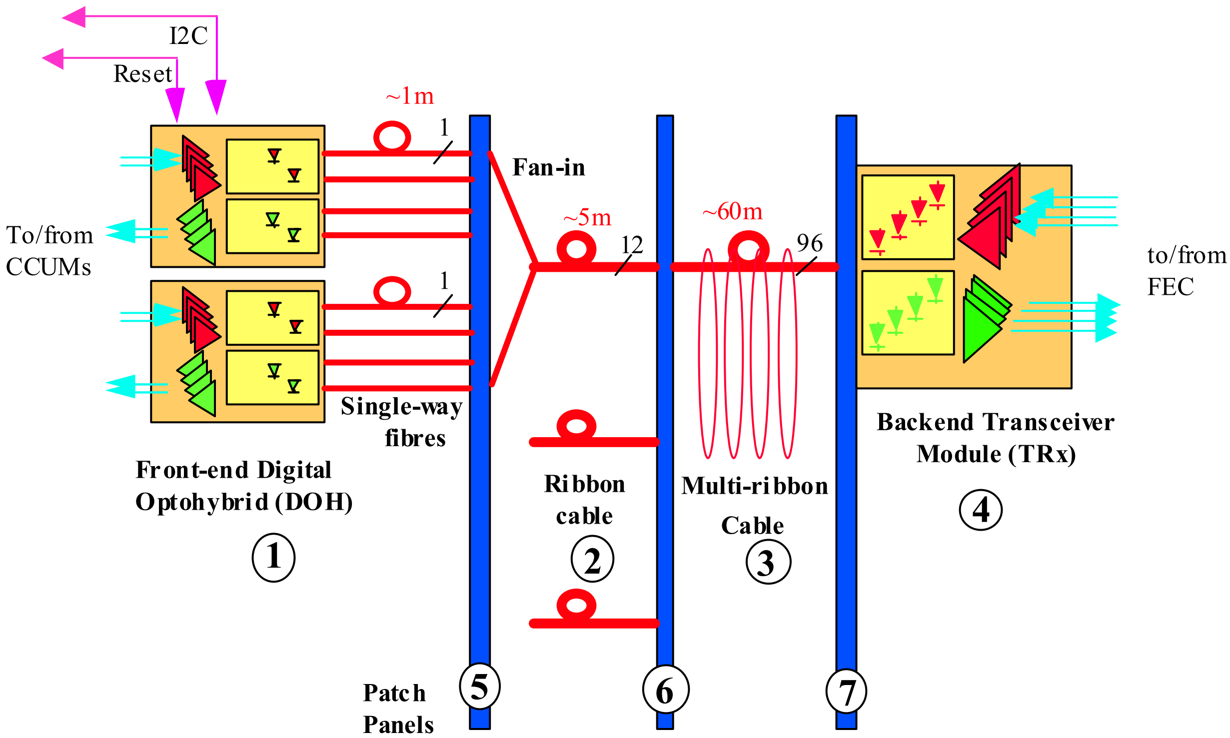


Fig. 2.1. Optical link block diagram

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

#	operational specifications	min	typ	max	unit	note
1.1	Total length		60		m	
1.2	Bit Rate	2		80	Mb/s	Balanced code
1.3	Bit Error Rate		10^{-12}	10^{-9}		
1.4	Skew			2	ns	Between any 2 fibres coming from the same hybrid, see glossary 3.1
1.5	Jitter			0.5	ns	rms, see glossary 3.2
1.6	Operation rate		4000		hrs/year	
	specs 1.7 to 1.10					reserved for future use

#	Front-end electrical specifications	min	typ	max	unit	note
1.11	Differential input voltage	±300			mV	Into 120Ω. Note that the LLD ASIC has an analogue transfer characteristic.
1.12	Input impedance		120		Ω	
1.13	Differential output voltage	±250	±400		mV	LVDS. Should be terminated differentially with 100Ω.
1.14	Reset Output		Active low			Generated by RX40 upon reception of 10 consecutive '0' levels on Data channel at DOH.
1.15	Reset action at front-end DOH					A reset is generated at LLD at power-up or when RX40 outputs a reset. Sets transmitter quiescent operating point to hard-wired start-up settings (spec 1.19)
1.16	Power supply	2.25		2.7	V	
1.17	Power dissipation		350		mW	Per DOH worst-case (i.e. half control ring)
1.18	I2C address		11100			Fixed
1.19	Default LLD laser I2C bias setting		$X_1X_2X_3$0000			Where $X_1X_2X_3$ = 011 = $48_{decimal}$ (TBD). Approximately 22mA. Value is selected during production.
1.20	Default LLD gain setting		12.5		mS	Hard-wired in LLD
1.21	Electrical connector	26-way male NAIS				See fig. 2.2 and Table 2.1 for connector pin assignment.
	Specs 1.22 to 1.30					Reserved for future use

#	Back-end electrical specifications	min	typ	max	unit	note
1.31	Differential input voltage	±400	±600		mV	LVPECL
1.32	Input impedance		100		Ω	Both inputs terminated internally with 50Ω to V_{tt}
1.33	Differential output voltage	±400	±600		mV	CML
1.34	Output impedance		100		Ω	Both outputs terminated externally with 1kΩ to V_{cc}
1.35	Power supply	3.1	3.3	3.5	V	
1.36	Power dissipation			2	W	Tx and Rx channels
	specs 1.37 to 1.40					reserved for future use

#	optical specifications	min	typ	max	unit	note
1.41	Wavelength	1260	1310	1360	nm	
1.42	Optical fibre between front-end digital optohybrid(2) and distributed patch-panel(6)	Single way tight-buffered single-mode fibre				Validated fibre.
1.43	Optical fibre between distributed patch-panel(6) and in-line patch-panel(7)	Single way buffered single-mode fibre fanned in to ruggedized 12-way single-mode ribbon.				Validated fibre. See Table 2.3 for fibre channel assignment. Ribbon coloured according to Bellcore spec.
1.44	Optical fibre between in-line patch-panel(7) and back-end patch-panel(8)	96-way dense multi-ribbon cable				Validated fibre. Table 2.3 for fibre channel assignment. Ribbon coloured according to Bellcore spec.
1.45	Distributed patch panel(6)	MU-sMU				Patch-panels distributed around the Tracker mechanical support structure
1.46	In-line patch-panel(7)	MFS				Patch-panels at the magnet cryostat level.
1.47	Back-end patch-panel(8)	MPO				Patch panels at TRx module(5) on FEC. Angle polished connectors
	specs 1.48-1.60					reserved for future use

2.4. Operating environment

#	environmental specifications	min	typ	max	unit	note
With reference to Fig. 2.1, the digital opto-hybrid (1) is situated inside the Tracker detector. Patch-panel (5) is at the edge of the Tracker detector mechanical support structure. Patch-panel (6) is at the magnet cryostat level. Patch-panel (7) is at the FEC crate front-panel, in the readout room. The transceiver module (4) is on the FEC board, in the readout room.						
1.61	Magnetic field resistance for items (1), (2), (3), (5), (6)	4			T	parallel to particle beam axis
1.62	Hadronic fluence for items (1), (2), (5)	2e14			1/cm^2	Integrated over lifetime[1], 90% charged particles, 10% neutrons[2.1]
1.63	Gamma radiation resistance for items (1), (2), (5)			1.5e5	Gy(Si)	Integrated over lifetime[1][2.1]
1.64	Hadronic fluence for items (3), (6)			1e12	n/cm^2 (1MeV)	Integrated over lifetime[2.1]
1.65	Gamma radiation resistance for items (3), (6)			100	Gy(Si)	Integrated over lifetime[2.1].
1.66	Temperature for items (1) through (7)	-20		70	°C	Operation and Storage
1.67	Operating humidity for items (1), (2), (5), (6)	Dry lab environment during testing and dry Nitrogen flow during operation				Tracker environment.
1.68	Operating humidity for items (3), (4), (7)			60	%RH	13°C dew point
1.69	Operation rate		4000		hours/year	
	Specs 1.70 to 1.80					reserved for future use

#	safety specifications		note
1.81	Optical	Optical fibre system hazard level 1	IEC 825-1, 825-2, See ref [2.2]
1.82	Material composition	Halogen-free material	CERN IS-41, see reference [2.3]
1.83	Fire	CERN standards for underground equipment	CERN IS23 and IS41, see reference [2.3].
1.84	Component flammability	Flame retardant material	IEC 332-1, IEC 1034, IEC 754-2, ABD 0032, CERN IS23, see reference [2.3].
	specs 1.85 to 1.99		reserved for future use

[1] Foreseen operating lifetime: nominal 10 years.

2.5. Other characteristics

- electrical interface at front end

Front-end Connector type: 26 way NAIS male connector.

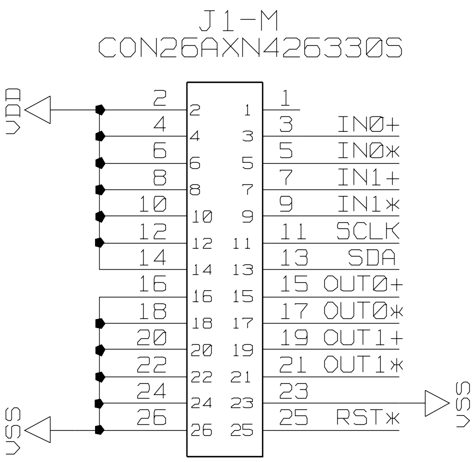


Fig. 2.2: NAIS connector pin assignment

Pin	Designation	Assignment
3,5	IN0	Clock IN from CCUM
7,9	IN1	Data IN from CCUM
11	SCLK	SCLK = I2C clock from CCUM controlling the DOH
13	SDA	SDA = I2C data from CCUM controlling the DOH
15,17	OUT0	Clock OUT to CCUM
19, 21	OUT1	Data OUT to CCUM
25	RST	reset generated by RX40 output to CCUM

Table 2.1: NAIS connector pin assignment

- electrical interface at back-end TRx:

Surface mount leadframe, to be soldered on FEC board.
External termination resistors on output lines.
Module and pin-out TBD (see Table 2.2)

Designation	Pin number	Fibre number in ribbon (preliminary)	Assignment
CK in A	TBD	1	CK (from FEC to CCUM ring A)
DA in A	TBD	2	DA (from FEC to CCUM ring A)
CK in B	TBD	3	CK (from FEC to CCUM ring B)
DA in B	TBD	4	DA (from FEC to CCUM ring B)
CK out A	TBD	12	CK (from CCUM ring A to FEC)
DA out A	TBD	11	DA (from CCUM ring A to FEC)
CK out B	TBD	10	CK (from CCUM ring B to FEC)
DA out B	TBD	9	DA (from CCUM ring B to FEC)

Table 2.2: Backend module pin assignment

- Optical fibre-ribbon channel assignment (preliminary)

Channel	Assignment
1	CK (from FEC to CCUM ring A)
2	DA (from FEC to CCUM ring A)
3	CK (from FEC to CCUM ring B)
4	DA (from FEC to CCUM ring B)
5	Dark
6	Dark
7	Dark
8	Dark
9	DA (from CCUM ring B to FEC)
10	CK (from CCUM ring B to FEC)
11	DA (from CCUM ring A to FEC)
12	CK (from CCUM ring A to FEC)

Table 2.3: Fibre ribbon channel assignment.

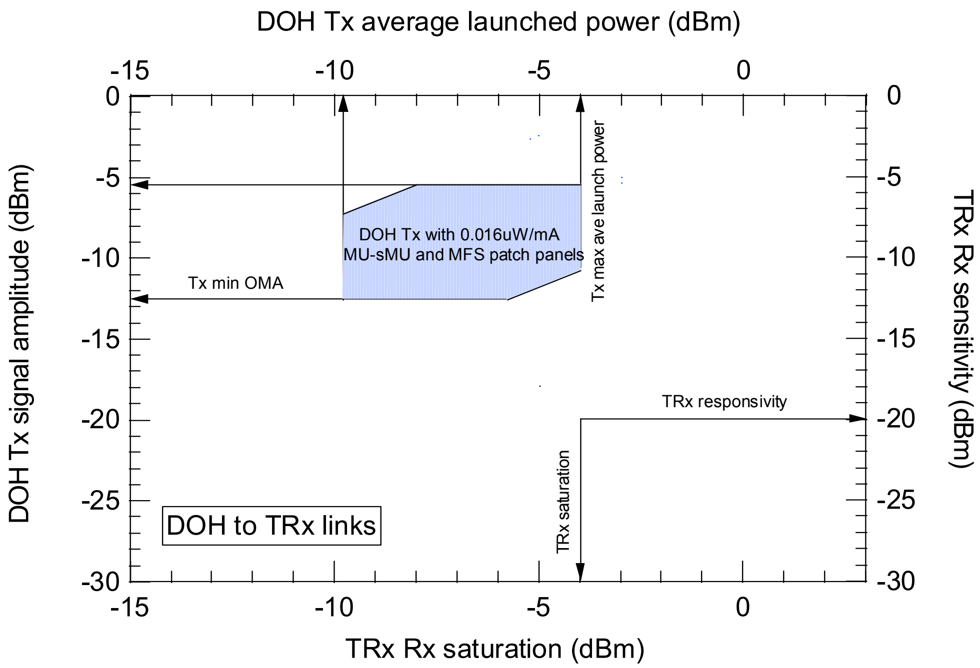
2.6. Testing

Final in-system testing procedure TBD.

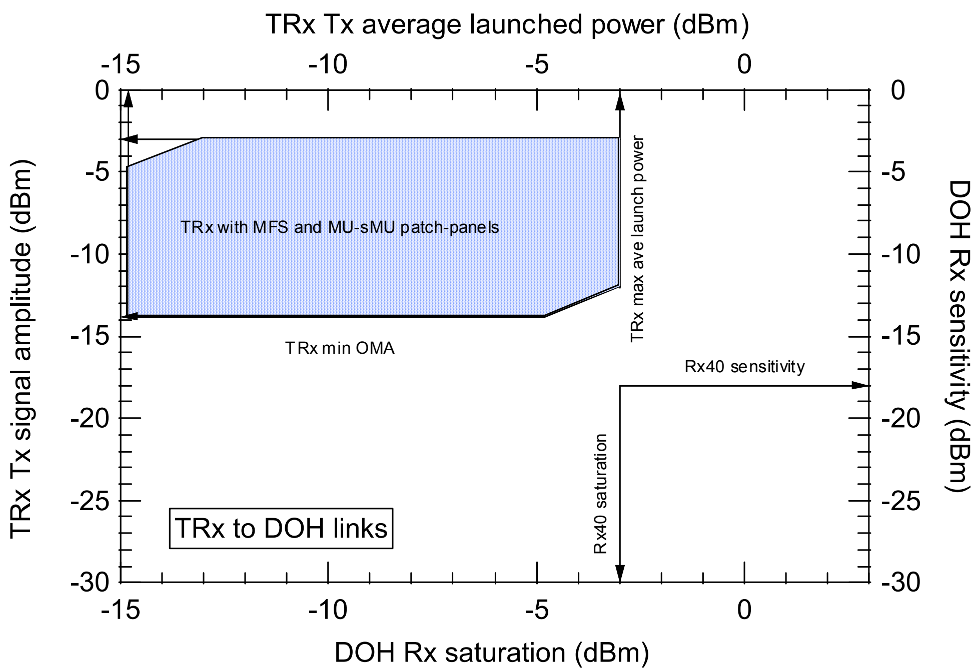
2.7. Implementation

The system implementation with components as specified provides the following optical power budget figures:

(a) For the DOH to TRx links, from front-end to FEC:



(b) For the TRx to DOH links, from FEC to the front-end:



3. Glossary

3.1. 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:

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

3.2. 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:

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

4. References

[1.1] http://cmsinfo.cern.ch/cmsinfo/Welcome.html
[1.2] http://www.cern.ch/
[1.3] A. Marchioro, " Specifications for the control electronics of the CMS Inner Tracker", Draft V2, CERN
[1.4] The tracker project, technical design report, CERN/LHCC 98-6
[1.5] A. Marchioro, "FEC specification", Draft, CERN
[1.6] A. Marchioro, "CCU specification", Draft, CERN

[2.1] M. Huhtinen, “Studies of neutron moderator configurations around the CMS inner tracker and Ecal”, CERN CMS TN/96-057, 1996.
[2.2] K. Gill, “Laser safety in the CMS Tracker optical links”, http://edms.cern.ch/document/338505/1.
[2.3] http://www.cern.ch/CERN/Divisions/TIS/safdoc/instr_en.html