ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

CMS Tracker Optical Readout Link Specification

Part 2: Analogue opto-hybrid

Version 3.2, 20 April, 2001

CERN EP/CME

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]

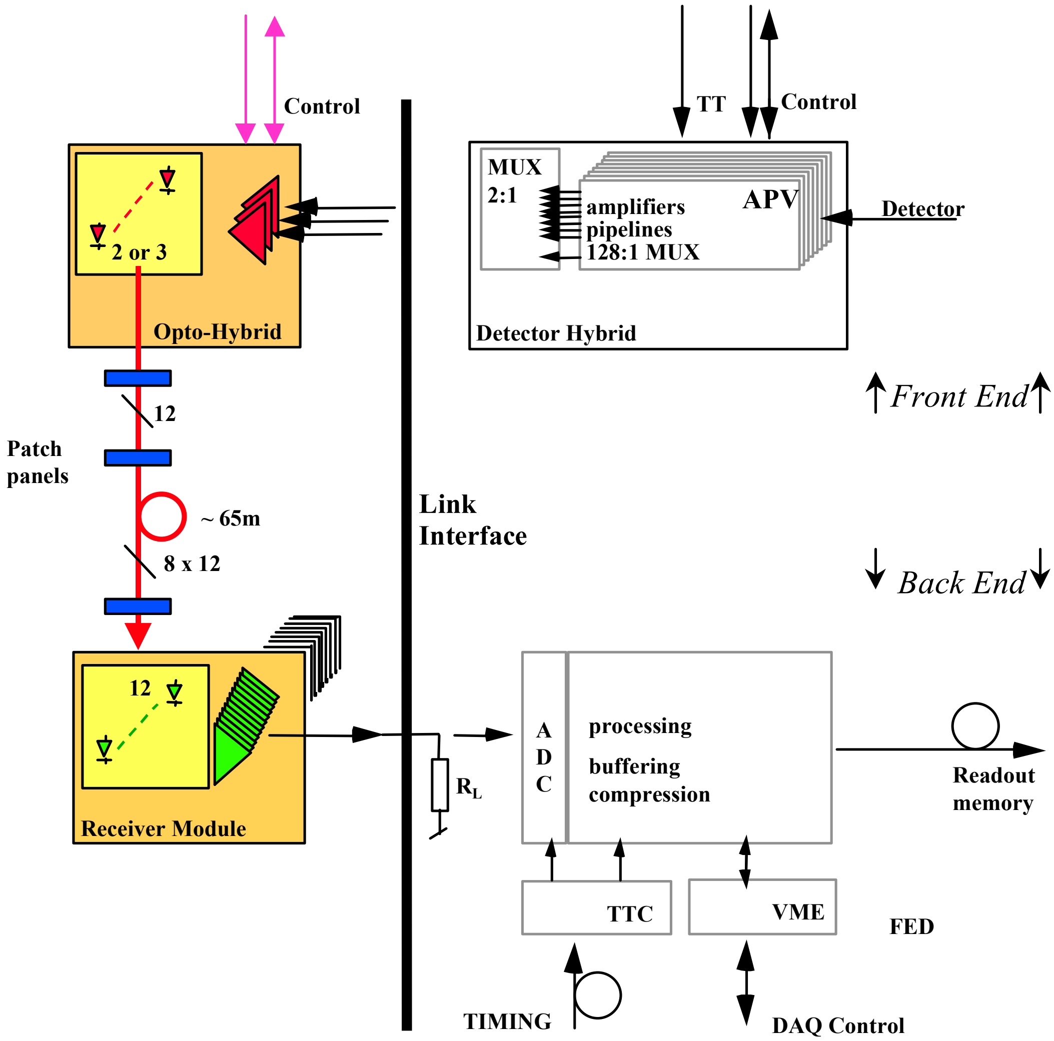

Fig. 1.1. Tracker readout chain with optical link highlighted on the left.

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	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, 15/08/00	Document (Rev2.3) split into independent parts. Testing section added.
Rev. 3.1, 25/08/00	Fibre bundle bend radius, globe top option
Rev. 3.2, 30/04/01	Document (Rev 3.1) brought in conformity with other specs

2. Technical requirement, part 2.2: Analogue Opto-Hybrid

2.1. Description

The analogue opto-hybrid converts the electrical signals from the front-end chips (APV/Mux) into optical. The laser drivers (see also part 2.1) pre-bias the lasers at their working point (quiescent state) and modulate them with a current proportional to the input signal. The laser transmitters (part 2.2) generate the optical power required to transfer the signal to the readout end. A fibre bundle (part 2.2.1) links the module to the first patch panel (6). Each transmitter serves 2 APV front-end chips, or 256 detector channels. Depending on geometrical position in the detector, the number of laser transmitters on the hybrid will vary between 2 and 3. To track components performance spread, ageing and irradiation induced damage, I2C control links are provided to the control modules and allow remote adjustments of the pre-bias point as well as of the laser driver gain.
About 19000 analogue opto-hybrids will be required for the CMS tracker detector readout links.

2.2. Block diagram

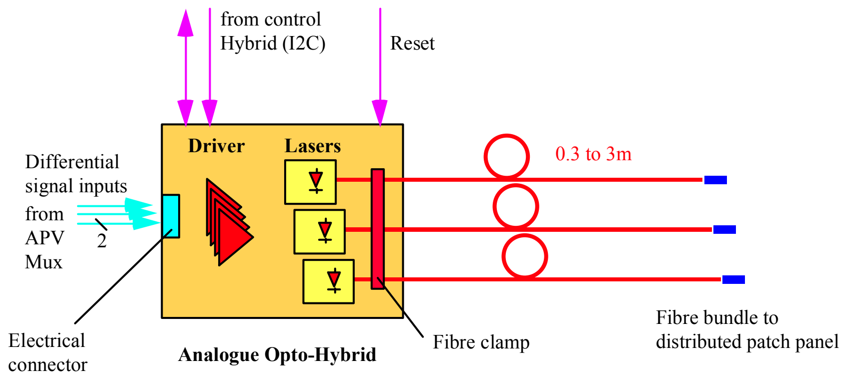


Fig. 2.1. Analogue opto-hybrid block diagram

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

Note: the laser transmitter is specified separately in the technical requirement part 2.2. The Analogue Opto-Hybrid Substrate is specified separately in the technical requirement part 2.3.

#	operational specifications	min	typ	max	unit	note
2.1	Number of channels	1		3		
2.2	Gain	0.13	0.2	0.29	µW/mV	Individually pre-settable for each channel via I2C
		0.19	0.3	0.43		
		0.26	0.4	0.58		
		0.32	0.5	0.72		
2.3	Peak signal to noise ratio	46	48		dB	Measured "in-system" for all gain settings, see glossary 3.1
2.4	Integral linearity deviation			1.5	%	in any 100mV and 200mV window within operating input range. Measured "in system", see glossary 3.2
				3	%	in any 400mV window within operating input range. Measured "in system", see glossary 3.2

2.5	Bandwidth	90			MHz	DC coupled
2.6	Settling time to ±1%			12	ns	see glossary 3.3
2.7	Skew			1.5	ns	between any 2 channels, see glossary 3.4
2.8	Jitter			0.5	ns	rms, see glossary 3.5
2.9	Crosstalk	-54			dB	see glossary 3.6
	specs 2.10 to 2.20					unused

#	electrical specifications	min	typ	max	unit	note
2.21	Max. operating* input voltage range	-0.3		+0.3	V	Differential, referred to V125
2.22	Input voltage range	-0.5		+0.5	V	Differential, referred to V125
2.23	Input impedance	100		 5	kΩ pF	
2.24	Quiescent operating point	user adjustable via IIC interface, 7bits pre-bias resolution (X_1 to X_7) X_1 to X_7 =0≡channel masked				defined at 0V input (see also 2.43)
2.25	Quiescent operating point after reset	Preset via 3 hardwired input bits X_7 X_6 X_5, corresponding to the 3 MSbs of the 7bit pre-bias register. The 4LSbs are reset.				Common to all channels. Internal pull-down resistors. X=0≡pad left open, X=1≡pad externally hardwired to V250.
2.26	Hardware Reset	Active low				
2.27	Power supply	2.25	2.5	2.7	V	V250-Vss
		1.12	1.25	1.4	V	V125-Vss
2.28	Power supply rejection ratio	30			dB	At 1MHz, for any pre-bias value between zero and half maximum. See glossary 3.8
2.29	Power dissipation		35		mW	per optical channel at min pre-bias
			260		mW	per optical channel at max pre-bias
	specs 2.30 to 2.40					unused

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

#	optical specifications	min	typ	max	unit	note
2.41	Wavelength	1285	1310	1335	nm	
2.42	Output power range	1.44	2	3.1	mW	at maximum pre-bias, 0V input
2.43	Pre-bias output resolution	11.2	17.2	24.5	μW	any LSB step over 7 bit range (see also 2.24)
	specs 2.44 to 2.60					unused

2.4. Operating environment

#	environmental specifications	min	typ	max	unit	note
2.61	Magnetic field			4	T	parallel to any axis
2.62	Hadronic fluence[1]			3e14	1/cm^2	Integrated over lifetime [2] 90% charged particles

						10% neutrons
2.63	Gamma radiation dose[1]			1.5e5	Gy(Si)	Integrated over lifetime [2]
2.64	Temperature	-20	-10	70	°C	Operation and storage
2.65	Operating humidity	dry Nitrogen flow				
	specs 2. 66 to 2. 80					unused

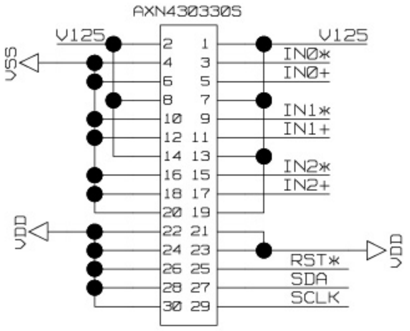
[1]The component resistance to radiation will be verified under the sole responsibility of CERN.
[2]Foreseen operating lifetime: nominal 10 years.

#	safety specifications		note
2.81	Optical	laser class 3A	IEC 60825-1 1998-01 IEC 60825-1 amendment 2 2001-01
2.82	Material composition	Halogen-free, flame retardant material	CERN IS41, see reference [2.2].
	specs 2.83 to 2.99		unused

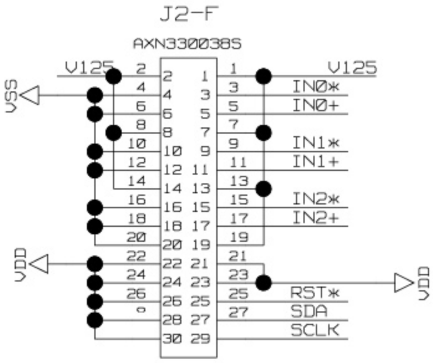
2.5. Other Characteristics

- electrical interface

SMD connector (30 pins) to detector hybrid, or to mother board (signal and control lines, power supply)



Header connector (TOB)



Socket connector (TIB, TEC)

- <u>optical interface</u>

Fibre type	9/125/250/900 µm
Fibre length	0.3-3m (dependent on hybrid geometrical position)
Number of fibres	1 to 3, arranged in bundle
Connector type	MU, to be inserted into connector shell (6)
Bundle orientation	parallel to hybrid plane
Bundle bend radius	>3cm
Fibre strain relief	fibres are clamped on opto-hybrid, design and material TBD

- <u>package</u>

Protection of the laser bond-wires can be envisaged as extension of the fibre clamp, or as globe-top: TBD
labeling TBD

- <u>Interface to cooling system</u>:

Via screw or metal tongue connected to heat spreading layer: TBD

- <u>Test Documentation and traceability</u>: TBD

- <u>Shipping and storage requirements</u>: TBD

2.6. Testing

#	Specification to be tested	Manufacturer		CMS Institute in charge	
		Product qualification	Lot validation (before delivery	Product qualification	Lot acceptance
2.1	Number of channels	♦	♦	♦	♦
2.2	Gain		♦	♦	♦
2.3	Peak signal to noise ratio		♦	♦	♦
2.4	Integral linearity deviation		♦	♦	♦
2.5	Bandwidth		♦[1]	♦[1]	♦[1]
2.6	Settling time to ±1%			♦	
2.7	Skew			♦	
2.8	Jitter			♦	
2.9	Crosstalk			♦	
2.21	Max. operating input voltage range		♦	♦	♦
2.22	Input voltage range		♦	♦	♦
2.23	Input impedance			♦	
2.24	Quiescent operating point		♦	♦	♦
2.25	Quiescent operating point after reset		♦	♦	♦
2.26	Hardware Reset		♦	♦	♦
2.27	Power supply			♦	
2.28	Power supply rejection ratio			♦	
2.29	Power dissipation			♦	
2.41	Wavelength				
2.42	Output power range		♦	♦	♦
2.43	Pre-bias output resolution		♦	♦	♦
2.61	Magnetic field			♦	
2.62	Hadronic fluence			♦	
2.63	Gamma radiation dose			♦	
2.64	Temperature			♦	
2.65	Operating humidity	♦			

[1]rise time and fall time measurement

2.7. Options

- Laser driver package type
- Globe-top protection of laser components

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

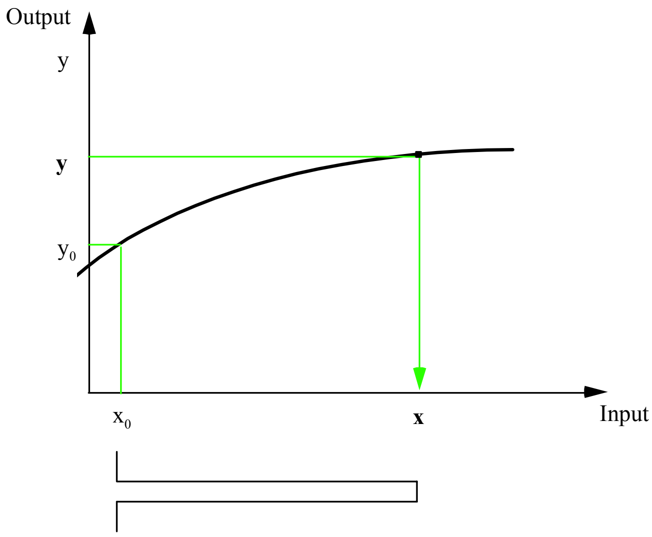


Fig. 3.1. Signal to noise ratio

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.

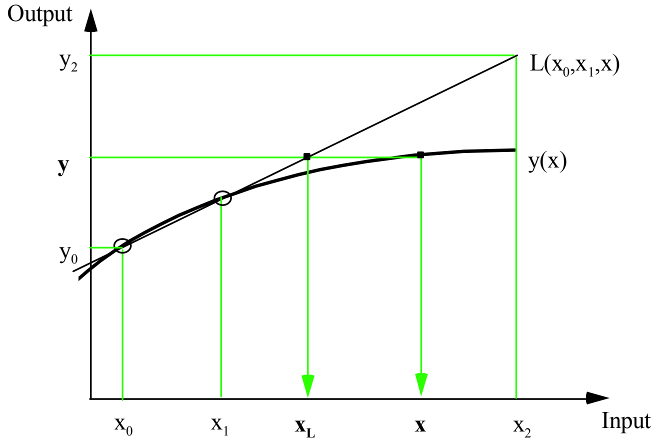


Fig. 3.2. Integral non-linearity

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

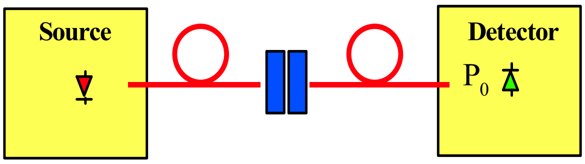
The crosstalk between two channels i and j is defined as the relative feedthrough from channel i to channel j at sampling time t_s=20ns when an ideal step signal is injected into channel i at t=0s.

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

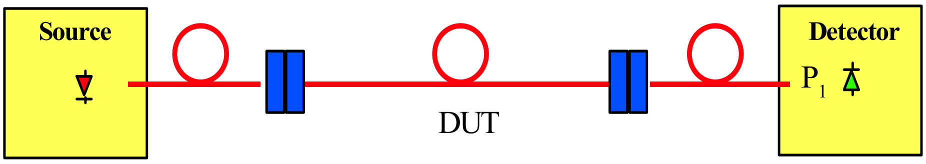
3.7. Insertion loss

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

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.

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

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
[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