ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
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Laboratoire Européen pour la Physique des Particules
European Laboratory for Particle Physics

CMS Tracker Optical Readout Link Specification

Part 5: Analogue Opto-Receiver Module

Version 1.7, 30 January 2003

CERN EP/CME

EDMS DOCUMENT
CMS-TK-ES-0008

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 at the CERN Large Hadron Collider (LHC) [1.1,1.2]. 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]

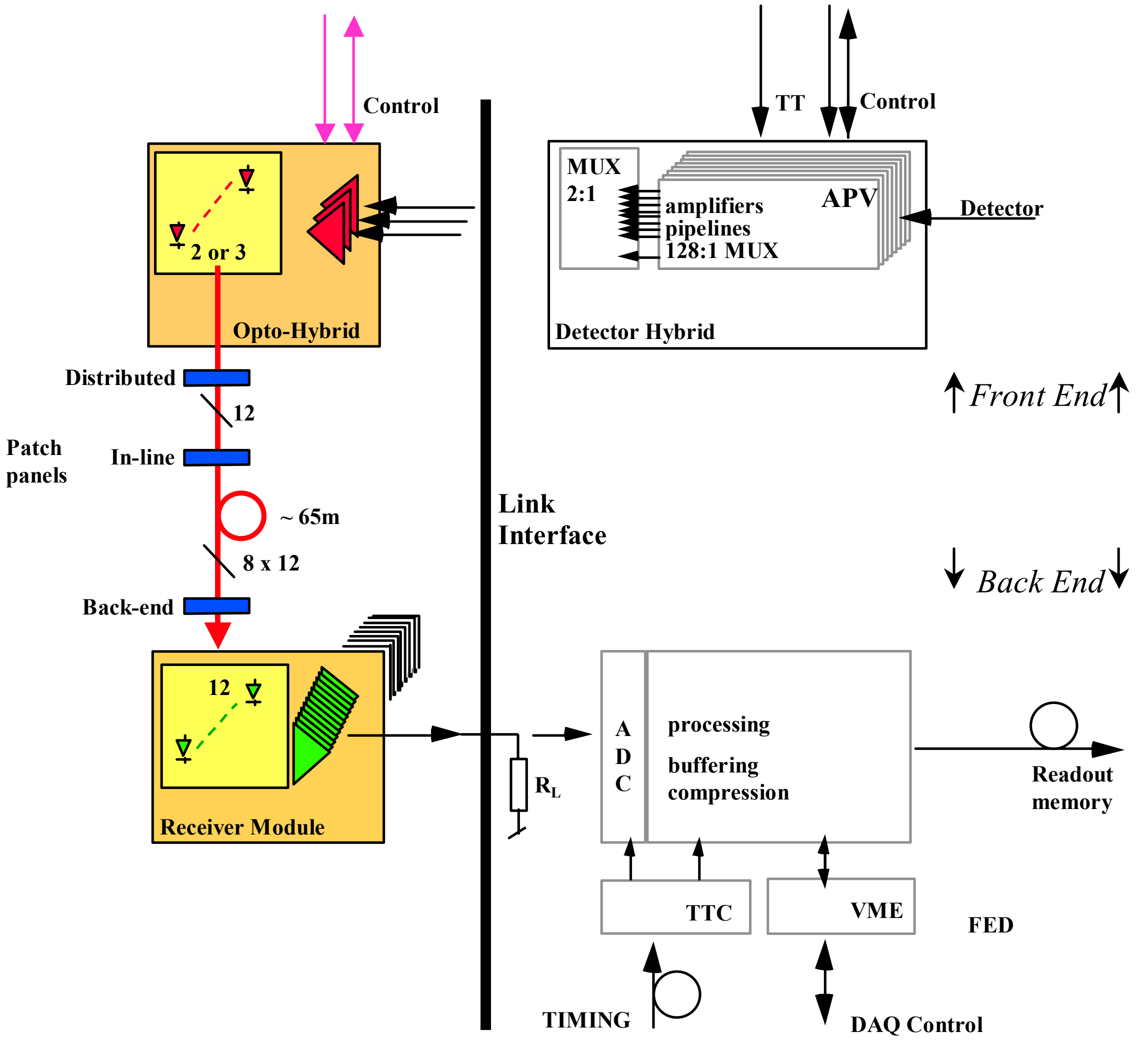

Fig. 1.1. Tracker readout chain with optical link highlighted on the left.

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-hybrids via short lengths of copper (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 harness
  - 3.1.1 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 MFS Adaptor

Part 8. Backend Patch Panel

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		

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://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. Contact

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1.5. Document history

Rev. 1.1, 30/04/01	based on market survey document
Rev. 1.2, 06/08/01	brought in conformity with IT-2810/EP/CMS
Rev. 1.3, 13/03/02	brought in conformity with current-mode amplifier spec, part 5.1.
Rev. 1.4, 21/03/02	Spec 5.25 modified, section 2.5 modified.
Rev. 1.5, 18/06/02	Spec 5.3 adjusted, sections 2.5, 2.7 modified.
Rev. 1.6, 12/11/02	brought in conformity with HXR9004 ASIC spec. Fig. 1.1 modified (8 control inputs), spec 5.37 modified (C1,C2 inputs), section 2.5 modified (100nF//100pF decoupling capacitors), section 2.6 modified (5.37), section 2.7 modified (inputs C1, C2).
Rev. 1.7, 30/01/03	Section 2.7, NGK module drawing POR00L12SLX added (delivery R3)

2. Technical requirement, part 5: Analogue Opto-Receiver Module

2.1. Description

The 12-channel analogue opto-receiver module consists of a package housing a 12-channel pin-photodiode array bonded to a 12-channel current-mode amplifier array. The amplifier chip, designed and supplied by a CERN appointed supplier, is described in part 5.1 of the Optical Readout Link Specification. The optical interface to the module is via a 12-channel angle polished MPO12 connector. The connector receptacle is part of the package. The electrical connections to the module are achieved with a surface mount leadframe.

2.2. Block Diagram

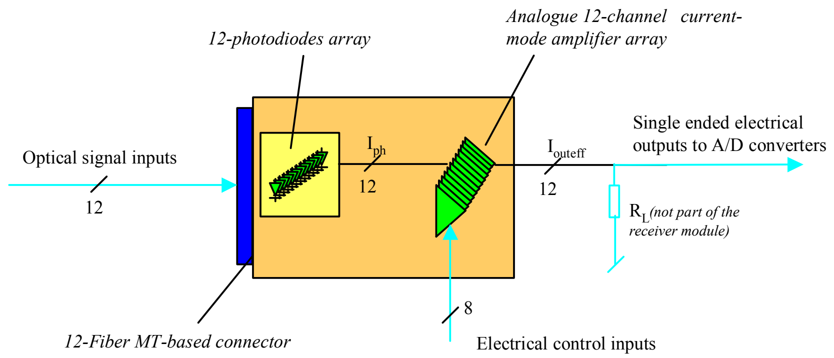


Fig. 1.1. Analogue receiver block diagram

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

The following specifications shall be met by all 12 channels of each Receiver Module.

Specifications in Italic are directly linked to the CERN-supplied current-mode amplifier ASIC described in part 5.1 of the Optical Readout Link Specification. Each one of these *specifications* is rated according to the level of testing expected from the manufacturer during pre-production and production: a-grade *specifications* shall be tested based on a simplified quasi-digital test sequence, b-grade *specifications* shall not be tested.

#	operational specifications	min	typ	max	unit	note
5.1	Number of channels		12			
5.2	Number of electrical pins		43			TBD, 12 single ended outputs
5.3	Module size	39.95 x 33.3 x 9.5			mm^3	h x w x t
5.4	Receiver ASIC approximate size	2575 x 3765 x 535			μm^3	h x w x t
5.5 [a)]	*Module responsivity*	*27*	*34*	*42*	*A/W*	*Light into MPO12 receptacle. Current sourced into R_L*
5.6 [b)]	*Integral linearity deviation*			*1*	*%*	*In any 140 μW operating input range positioned anywhere in input range.* *See glossary 3.1*
	specs 5.7 to 5.20					unused

[a)]*Only simplified testing required during production*
[b)]*No testing required during production*

#	electrical specifications	min	typ	max	unit	note
5.21 [a)]	Module bandwidth	200			MHz	Excluding ASIC
			100			*Including ASIC*
[b)]	*Module output settling time to ±1%*			*15*	*ns*	*Including ASIC,* *Optical input pulse rise time t_r<2ns.* *See glossary 3.2*
5.22	Output track capacitance			5	pF	Total capacitance seen by ASIC on each output signal line when mounted inside Receiver Module
5.23	Pin diode rise/fall time			2	ns	Into 50 Ω load
5.24	Pin diode capacitance	0.6		1.2	pF	Including connection to ASIC
5.25 [a)]	*Module output skew*			*1.5*	*ns*	*See glossary 3.3*
5.26 [a)]	*Module output jitter*			*0.5*	*ns*	*Rms* *See glossary 3.4*
5.27 [b)]	*Crosstalk*		*-60*		*dB*	*See glossary 3.5*
5.28	Pin diode dark current		0.1	1	nA	
5.29	Pin diode absolute maximum photo current	3			mA	
5.30	Pin diode absolute maximum forward current	5			mA	

5.31	Pin diode absolute maximum reverse voltage	20			V	
5.32 b)	*Effective output current range*	*2*		*24.6*	*mA*	*Within output voltage range*
5.33 b)	*Output voltage range*	*0.4*		*3*	*V*	*ESD protected outputs*
5.34 b)	*Equivalent input noise*			*118*	*nW*	*Rms in 100MHz bandwidth @ Pin=0μW, X_0 X_1 X_2 X_3 =0010*
5.35 b)	*Load Resistance R_L*	*50*	*100*	*200*	*Ω*	*Within output voltage range*
5.36 b)	*Output Loading*			*1.6*	*ns*	*τ =C_L*R_L , C_L includes Receiver Module track capacitance*
5.37 a)	*Control inputs* X_0 X_1 X_2 X_3 X_4 X_5	*CMOS compatible, active high*				*Chip-internal pull downs* *Ipheff = Iph – Iphoff* *Iphoff = X_0*25+X_1*50+X_2*100 – X_3*200μA* *Iouteff=Iout+Ioutoff* *Ioutoff=X_5*2.5+X_6*5 mA*
	Control inputs C_1 C_2	*CMOS compatible, active high*				*Chip-internal pull ups* *Cs =tunable pin-diode compensation* *Cs = C_0*100+C_1*200+C_2*400fF* C_0 =0 (bonded internally to Vee) tbd
5.38	Power supply	4.5	5	5.5	V	
5.39	Power dissipation			3	W	Including dissipation into R_L
	Spec 5.40					unused

[a)] *Only simplified testing required from the manufacturer during production*
[b)] *No testing required from the manufacturer during production*

#	Optical specifications	min	typ	max	unit	note
5.41	Wavelength		1310		nm	
5.42	Optical input range		235		μW	Per channel
5.43	Absolute maximum optical input power	3			mW	Per channel
5.44	Pin diode responsivity	0.7	0.85	1	A/W	Light into MT-interface
5.45	Connector receptacle		MPO12			Angle polished
5.46	Module optical return loss	40			dB	
	specs 5.47 to 5.60					unused

2.4. Operating environment

#	environmental specifications	min	typ	max	unit	note
5.61	Storage temperature	-20		70	°C	
5.62	Operating temperature	0		70	°C	
5.63	Operating humidity			60%	RH	13 °C dew point
	Specs 5.64 to 5.80					unused

#	safety specifications		note
5.81	Material composition	Halogen-free material	CERN IS41, see ref. [2.2]
	Specs 5.82 to 5.99		unused

2.5. Other Characteristics

- electrical interface

Surface mount leadframe, to be soldered on printed circuit board.
External 50 to 200 Ω termination resistors on output lines.

- optical interface

MPO12-based connector receptacle, angle polished

- Exchange of test and traceability documentation:

Excell file on CD-ROM or sent by e-mail.

- Shipping and storage requirements:

Shipping in 8-module trays, storage according to best practice

- ASIC and wire bond protection inside Receiver Module:

Hermetically sealed modules

- ASIC power supply de-coupling capacitors inside Receiver Module:

100nF//100pF between Vcc1 and Vee, and between Vcc3 and Vee

- Receiver Module mounting and handling requirements:

Modules to be handled with standard ESD precautions. Soldering conditions: Max. 260ºC during 30s 3 times

- Receiver Module cooling recommendations:

Forced air cooling, 3m/s.

- Labelling:

Human readable S/N on lid.

2.6. Testing

#	Specification to be tested	Manufacturer		CERN	
		Product qualification	Lot validation (before delivery)	Product qualification	Lot acceptance
5. 1	Number of channels			♦	♦
5.2	Number of electrical pins			♦	♦
5.3	Module size			♦	♦
5.4	Receiver ASIC size				
5.5 a)	*Module responsivity*		(1)	♦	♦
5.6 b)	*Integral linearity deviation*			♦	♦
5.21 a)	Module bandwidth		(2)	♦	♦
b)	*Module output settling time to ±1%*				
5.22	Output track capacitance				
5.23	Pin diode rise/fall time				
5.24	Pin diode capacitance				
5.25 a)	*Module output skew*	(2)		♦	
5.26 a)	*Module output jitter*		(2)	♦	
5.27 b)	*Crosstalk*			♦	
5.28	Pin diode dark current				
5.29	Pin diode absolute maximum photo current				
5.30	Pin diode absolute maximum forward current				
5.31	Pin diode absolute maximum reverse voltage				
5.32 b)	*Effective output current*			♦	♦
5.33 b)	*Output voltage range*			♦	♦
5.34 b)	*Equivalent input noise*			♦	♦
5.35 b)	*Load Resistance* R_L			♦	
5.36 b)	*Output Loading*			♦	
5.37 a)	*Control inputs* X_0 X_1 X_2 X_3 X_4 X_5		(3)	♦	♦
	Control inputs C_1 C_2		(3)	♦	♦
5.38	Power supply			♦	♦
5.39	Power dissipation			♦	♦
5.41	Wavelength			♦(4)	♦(4)
5.42	Optical input range			♦	♦
5.43	Absolute maximum optical input power			♦	
5.44	Pin diode responsivity				
5.45	Connector receptacle			♦	♦
5.46	Module optical return loss			♦	♦
5.61	Storage temperature				
5.62	Operating temperature				
5.63	Operating humidity				
5.81	Material composition				

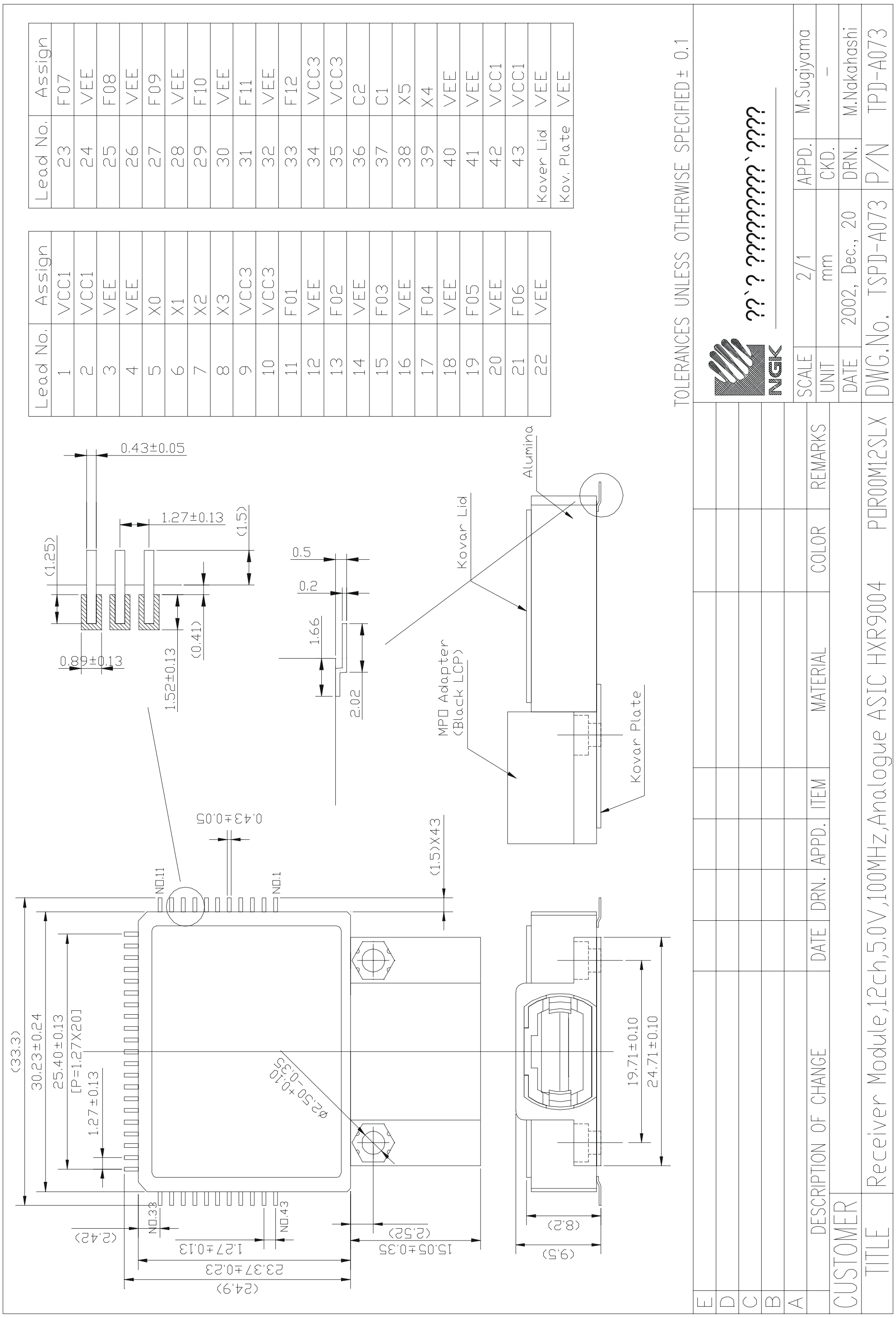
Others					
	In system test			♦	

[a)]*Only simplified testing required from the Manufacturer*
[b)]*No testing required from the Manufacturer*

(1) Responsivity and input range of Receiver Modules with ASIC can be checked with a digital optical input sequence of known amplitude (Popt=100µWpp within linear input range, f=40Mb/s, λ=1310nm).
(2) Bandwidth (measured as pulse rise-time) skew and jitter of Receiver Module with ASIC can be checked with a digital optical input sequence of known frequency (Popt=100µWpp, f=20Mb/s, λ=1310nm).
(3) Effect of control inputs X_0-X_5 can be checked DC with or without optical input, by measuring the change in power supply current for various X_0-X_5 settings. Control inputs C_0-C_2 to be checked by visual inspection of bonds (TBD).
(4) Wavelength used for testing is ~1310nm.

2.7. Implementation

Opto-Receiver Module POR00L12SLX as proposed by NGK



3. Glossary

3.1. Integral Non-Linearity

The integral non-linearity INL is defined as the operating-range-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.

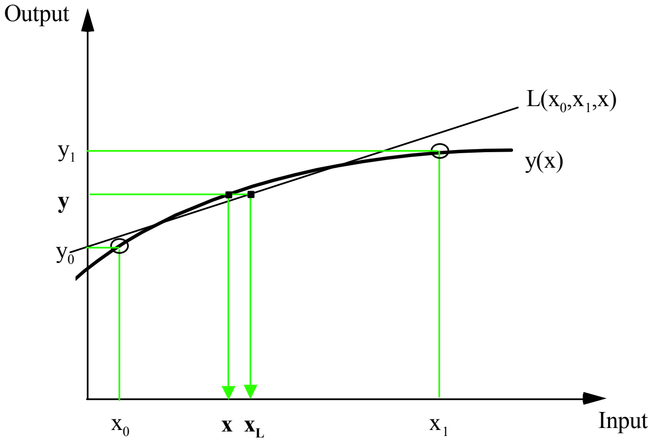


Fig. 3.2. Integral non-linearity

The linear regression is calculated by fitting the transfer characteristic in the linear range $]x_0, x_1]$ (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 operating range x_1 - x_0:

$$INL = \frac{x - x_L}{x_1 - x_0}$$

The operating range can be anywhere within the full input range.

3.2. Settling time

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

3.3. 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:

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

3.4. 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:

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

3.5. 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.

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

4. References

[1.1] http://cmsinfo.cern.ch/Welcome.html/

[1.2] http://www.cern.ch/, or http://public.web.cern.ch/Public/

[1.3] The tracker project, technical design report, CERN/LHCC 98-6, CMS TDR 5, http://cmsdoc.cern.ch/ftp/TDR/TRACKER/tracker.html http://edms02.cern.ch/tmpfiles/edms_tmp_1708833_addendum.pdf

[1.4] R. Halsall, "FED specifications", Draft, RAL, http://www.te.rl.ac.uk/esdg/cms-fed/

[1.5] APV 25 User guide, RAL http://www.te.rl.ac.uk/med/projects/High_Energy_Physics/CMS/APV25-S1/pdf/User_Guide_2.2.pdf MUX User guide, RAL http://www.te.rl.ac.uk/med/projects/High_Energy_Physics/CMS/APVMUXPLL/pdf/UserGuide.pdf

[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.

[1.7] A. Marchioro, " Specifications for the Control Electronics of the CMS Inner Tracker", Draft V2, CERN, http://cmstrackercontrol.web.cern.ch/CMSTrackerControl/documents/RocSpecsV2.pdf

[1.8] A. Marchioro, "FEC specification", Draft, CERN

[1.9] A. Marchioro, "CCU specification", Draft, CERN, http://cmstrackercontrol.web.cern.ch/CMSTrackerControl/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