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 4.1: Dense Multi-Ribbon Cable

Version 3.4, 27 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]

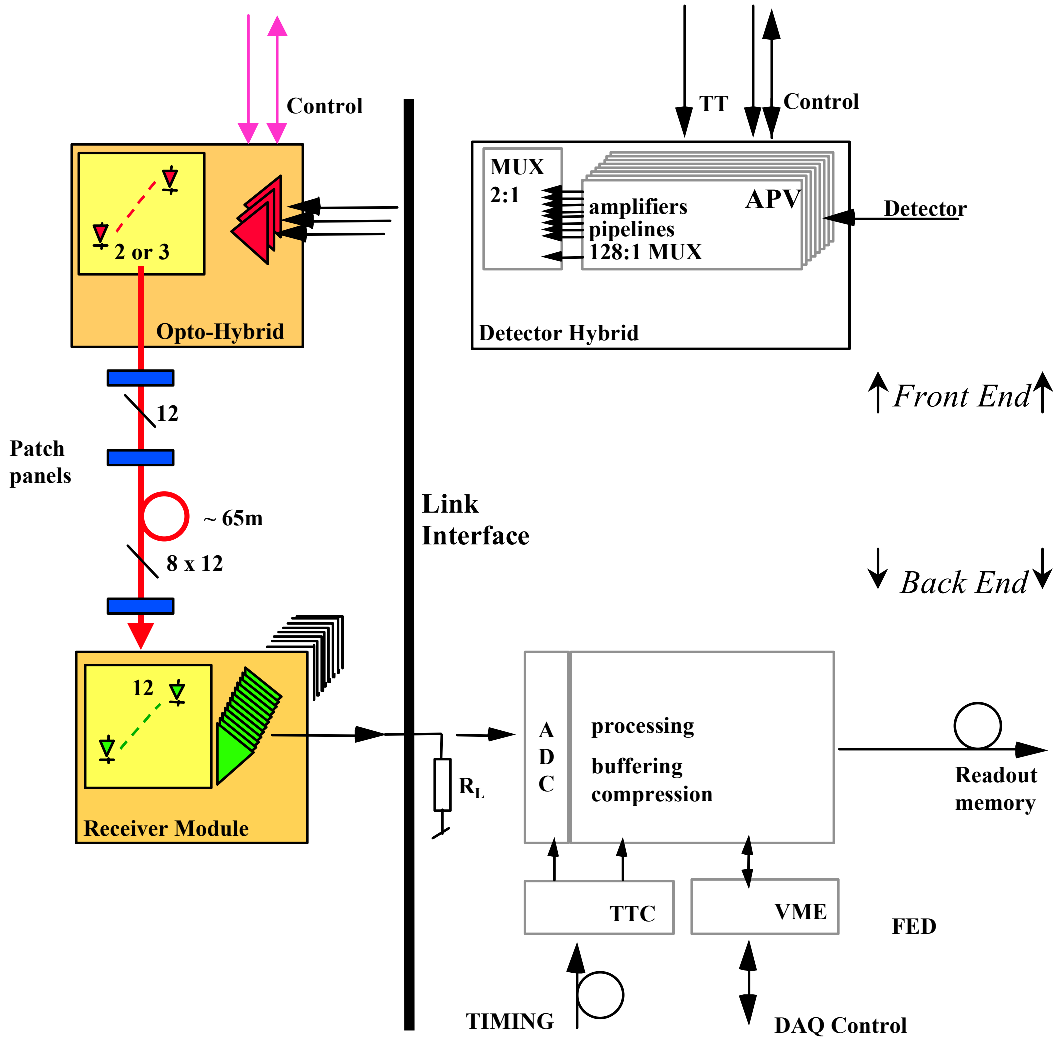

Fig. 1.1. Tracker readout chain with optical link highlighted on the left.

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, 25/08/00	Document (Rev2.3) split into independent parts.
Rev. 3.1, 05/09/00	MPO24 option added, cable length modified (4.42, 4.70)
Rev. 3.2, 21/09/00	Fibre cladding diameter tolerances decreased.
Rev. 3.3, 18/12/00	Split between terminated multi-ribbon spec (4) and dense multi-ribbon spec (4.1) Revision in conformity with IT2811
Rev. 3.4, 27/04/01	Cosmetic changes

2. Technical requirement, part 4.1: Dense Multi-Ribbon Cable

2.1. Description

The 96-fibre multi-ribbon cable (a bundle of eight 12-way ribbons protected by a low smoke, zero halogen sheath) links the in-line patch panel to the final break point of the system, which is situated on the receiver electronics. This cable crosses the concrete shield separating the detector volume from the counting room. It will be pulled manually across a cable duct and should withstand standard installation and operation conditions.
The multi-ribbon cable situation in the optical link cabling structure is highlighted in Fig. 2.1.

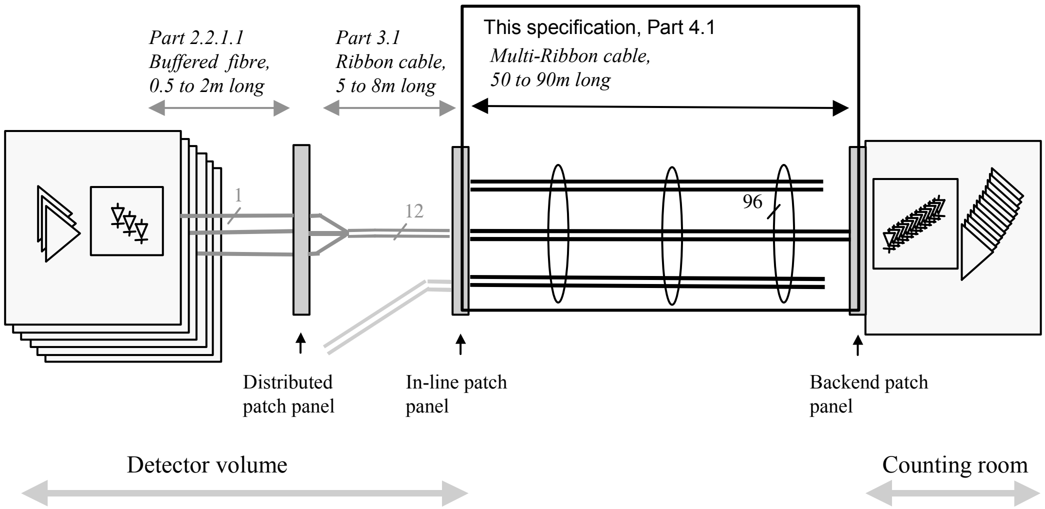


Figure 2.1, Dense Multi-ribbon Cable highlighted in the optical link cabling structure.

A total multi-ribbon cable length of approximately 45km will be required for the CMS Tracker. The terminated multi-ribbon cable is specified in part 4, the in-line patch-panel in part 7, and the back-end patch-panel in part 8 of the optical link technical requirement document.

2.2. Block diagram

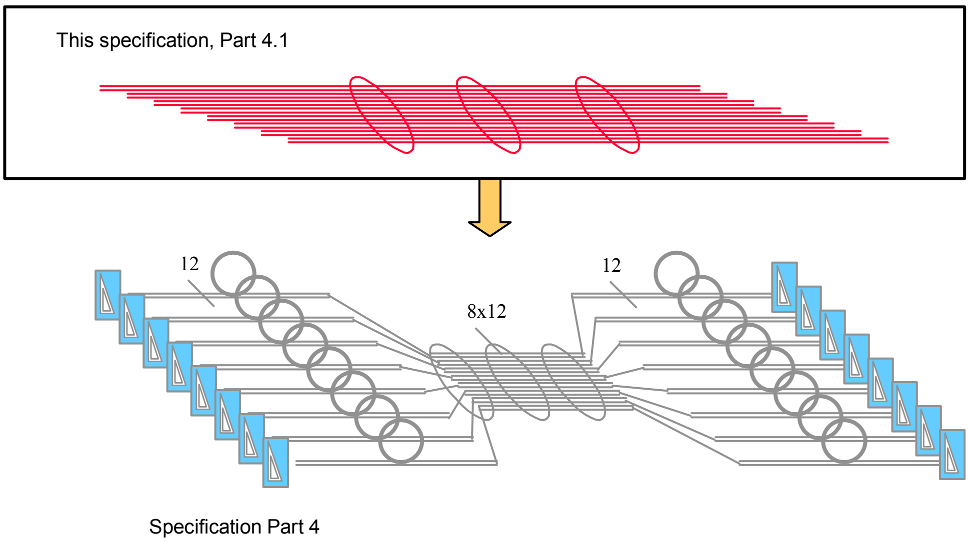


Fig. 2.2. Dense multi-ribbon cable and associated components block diagram

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

#	**Fibre specification**	min	typ	max	unit	note
						These specs identical to 3.1.1 to 3.1.9 (part 3.1, ruggedized ribbon)
4.1.1	Fibre type	Single-mode non-dispersion shifted				ITU G652
4.1.2	Fibre material	Phosphorus free				
4.1.3	Geometry	9/125/250			μm	
4.1.4	Cladding diameter	124	125	126	μm	
4.1.5	Primary coating diameter		250		μm	
4.1.6	Mode field concentricity error			0.4	μm	
4.1.7	Operation wavelength	1260	1310	1330	nm	
4.1.8	Fibre cut-off			1260	nm	
4.1.9	Attenuation			0.4	dB/km	
	specs 4.1.10 to 4.1.20					unused

#	**Ribbon specification**	min	typ	max	unit	note
						These specs identical to 3.1.21 to 3.1.32 (part 3.1, ruggedized ribbon)
4.1.21	Number of channels		12			
4.1.22	Overall dimensions	3100 x 320			μm	w x h, typical, TBD
4.1.23	pitch		250		μm	
4.1.24	Fibre to fibre skew			10	ps/m	
4.1.25	Bend radius	3			cm	perpendicular to ribbon plane, operation [1]
4.1.26	Torsion			5	turn/m	installation
				1	turn/m	operation [1]
4.1.27	Tensile loading			10	N	installation
				1	N	operation [1]
4.1.28	Compressive strength			3	N/cm	installation and operation [1]
4.1.29	Impact resistance			2	J	
4.1.30	Fibre colour-code	TBD				Each fiber to be individually identifiable, stable during lifetime [1]
4.1.31	Ribbon colour	Transparent				Stable during lifetime [1]
4.1.32	Ribbon marking	TBD				Each ribbon in cable to be individually identifiable, stable during lifetime [1]
	specs 4.1.33 to 4.1.40					unused

[1]Foreseen operating lifetime: nominal 10 years.

#	**Multi-ribbon cable specification**	min	typ	max	unit	note
4.1.41	Number of channels		96			
4.1.42	Cable diameter		8	10	mm	
4.1.43	Cable bend radius	8			cm	operation [1]
4.1.44	Cable torsion			1	turn/m	installation and operation[1]
4.1.45	Cable tensile loading			500	N	installation
				50	N	operation[1]
4.1.46	Cable compressive strength			50	N/cm	
4.1.47	Cable impact resistance			15	J	
4.1.48	Cable water resistance	occasional radial immersion				24hrs duration

4.1.49	Sheath colour	green	Stable during lifetime [1]
4.1.50	Sheath marking	TBD	Stable during lifetime [1]
	specs 4.1.51 to 4.1.80		unused

[1]Foreseen operating lifetime: nominal 10 years.

2.4. Operating environment

#	environmental specifications	min	typ	max	unit	note
4.1.61	Magnetic field			4	T	parallel to any axis
4.1.62	Hadronic fluence[1]			1e12	1/cm^2	Integrated over lifetime [2] Mainly neutrons
4.1.63	Gamma radiation dose[1]			100	Gy(Si)	Integrated over lifetime [2]
4.1.64	Temperature	-20	-10	70	°C	Operation and storage
4.1.65	Operating humidity			60	% RH	13°C dew point
	specs 4.1.66 to 4.1.80					unused

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

#	safety specifications		note
4.1.81	Material composition	Halogen-free material	CERN IS23, see ref. [2.2]
4.1.82	Fire behaviour	IEC 332-3, IEC 1034, IEC 754-2, ABD 0032	CERN IS23, see ref. [2.2]
	specs 4.1.83 to 4.1.99		unused

2.5. Other characteristics

- Test Documentation and traceability
- Shipping and storage requirements

2.6. Testing

#	Specification to be tested	Manufacturer		CERN		
		Product Qualification	Lot validation (before delivery)	Advance Sample Validation	Pre-production Qualification	Lot Accept-ance
Fibre						
4.1.1	Fibre type	♦	♦			
4.1.2	Fibre material	♦	♦			
4.1.3	Geometry	♦	♦	♦ [1,2]		
4.1.4	Cladding diameter	♦	♦			
4.1.5	Primary coating diameter	♦	♦			
4.1.6	Mode field concentricity error	♦	♦			
4.1.7	Operation wavelength	♦	♦		♦	♦
4.1.8	Fibre cut-off	♦	♦			
4.1.9	Attenuation	♦	♦		♦	♦
Ribbon						

4.1.21	Number of channels	♦	♦		♦	♦
4.1.22	Overall dimensions	♦	♦		♦	♦
4.1.23	pitch	♦	♦		♦ [1]	♦ [1]
4.1.24	Fibre to fibre skew	♦				
4.1.25	Bend radius	♦				
4.1.26	Torsion	♦				
4.1.27	Tensile loading	♦				
4.1.28	Compressive strength	♦				
4.1.29	Impact resistance	♦				
4.1.30	Fibre colour-code	♦	♦		♦	♦
4.1.31	Ribbon colour	♦	♦		♦	♦
4.1.32	Ribbon marking	♦	♦		♦	♦
Multi-Ribbon Cable						
4.1.41	Number of channels	♦	♦		♦	♦
4.1.42	Cable diameter	♦	♦		♦	♦
4.1.43	Bend radius	♦	♦		♦	♦
4.1.44	Torsion	♦	♦			
4.1.45	Tensile loading	♦	♦			
4.1.46	Compressive strength	♦	♦			
4.1.47	Impact resistance	♦	♦			
4.1.48	Cable water resistance	♦				
4.1.49	Sheath colour	♦	♦		♦	♦
4.1.50	Sheath marking	♦	♦		♦	♦
4.1.61	Magnetic field					
4.1.62	Hadronic fluence			♦ [2]		
4.1.63	Gamma radiation dose			♦ [2]		
4.1.64	Temperature	♦				
4.1.65	Operating humidity	♦				
4.1.81	Material composition	♦				
4.1.82	Fire behaviour	♦				

[1]splicing compatibility is checked
[2]pre-form sampling

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

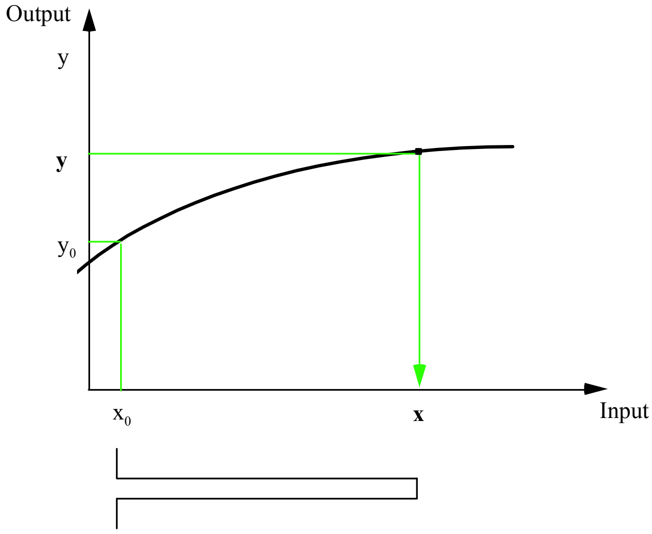


Fig. 3.1. Signal to noise ratio

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.

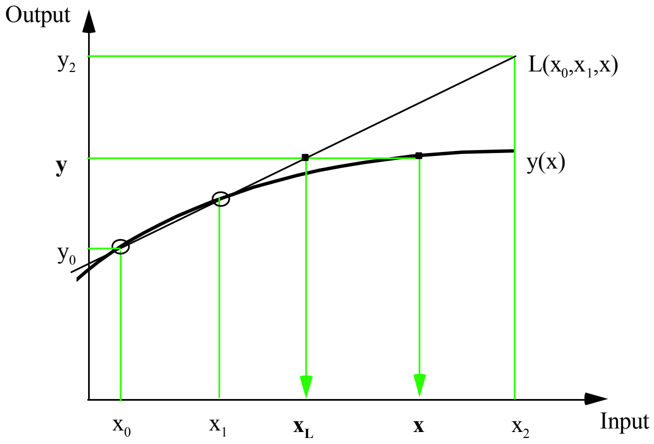


Fig. 3.2. Integral non-linearity

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

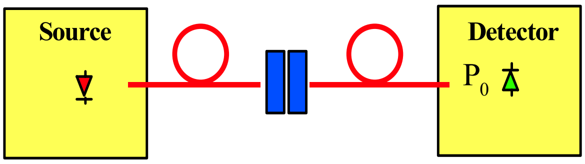
The crosstalk between two channels i and j is defined as the relative feedthrough from channel i to channel j at sampling time t_s=20ns when an ideal step signal is injected into channel i at t=0s.

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

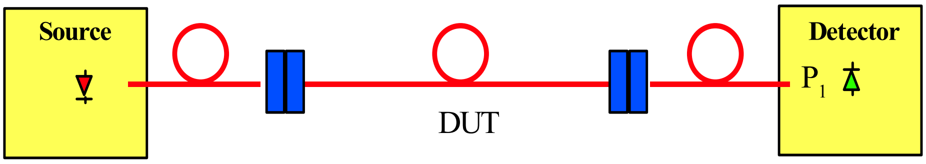
3.7. Insertion loss

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: $\mathrm{IL} = 10\mathrm{Log}\dfrac{\mathrm{P}_0}{\mathrm{P}_1}$

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