Radiation test of commercial of the shelf (COTS) optical transceivers in the frame of the beam position monitor (BPM) consolidation project for the Large Hadron Collider (LHC)

M. Barros Marin, A. Boccardi, S. Can Ozdogan, S. Danzeca, R. Ferraro, A. Scialdone

CERN, Geneva, Switzerland

manoel.barros.marin@cern.ch

ABSTRACT

The consolidation of the Large Hadron Collider (LHC) beam position monitor (BPM) requires the deployment of about 5000 single-mode radiation-tolerant optical transmitters, working at 10 Gbps during 20 years of operation. While the use of the custom devices being designed at CERN remains the baseline for the project, 8 commercial of the shelf (COTS) optical transceivers have been evaluated as an alternative. This paper presents the results of the full characterization in radiation of these COTS devices, including cumulative effects and single event effects (SEE), evaluated during both data transmission and reception.

I. INTRODUCTION

This document presents the results from a radiation test performed at the Paul Scherer Institute (PSI) using a 200 MeV proton beam. All presented test data were recorded in the campaign of November 2022. The devices under test (DUTs) are 8 commercial off-the-shelf (COTS) single-mode optical transceivers from 4 different standards. These devices were irradiated up to a Total Ionizing Dose (TID) of 500 Gy and a Displacement Damage Equivalent Fluence (DDEF) of 8.51E11 1MeV neq.cm-2.

Motivation

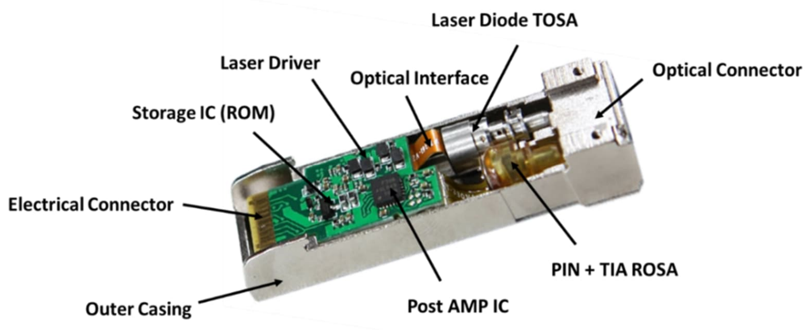
The objective of the campaign was to find a Commercial Off-The-Shelf (COTS) single-mode optical transceiver capable of reliable data transmission at 10 Gbps during HL-LHC operation in the arcs and alcoves.

Optical Transceivers

Based on the above-mentioned requirements, four different standards of optical transceivers were selected for the radiation tests (SFP+, SFP28, QSFP+ & QSFP28).

Main characteristics of the SFP+, QSFP+, SFP28 & QSFP28 standards			
Standard	#Channels	Line Rate/Channel (Gbps)	Connector Type
SFP+	1	~10	LC
SFP28	1	up to 25	LC
QSFP+	4	~10	LC
QSFP28	4	up to 25	LC

Both SFP and QSFP optical transceivers can be divided into three main blocks which are the transmitter (Tx), the receiver (Rx) and the control. The Tx is composed by an electro-optical interface named "Transmit Optical Sub-Assembly" (TOSA), featuring a laser diode and a laser driver. The Rx is composed by an opto-electrical interface named "Receiver Optical Sub-Assembly" (ROSA), featuring a PIN photodiode and a trans-impedance amplifier (TIA).



Additionally, the Rx may feature a post-amplifier that amplifies the electrical signal from the ROSA to increase the signal-to-noise ratio. Finally, the control block, accessed via an electrical serial bus named "Inter-Integrated Circuit" (I2C), is usually composed by one or more ICs that monitor and control the optical transceivers (e.g. measure optical power), as well as stores relevant information (e.g. vendor ID).

Devices Under Test (DUTs)

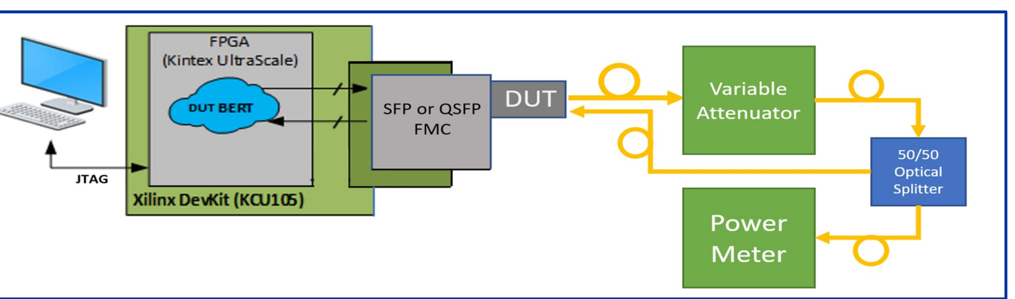
DUT	Model	Standard	Test types	#Samples	Vendor
DUT-1	DDCChh-QLCA	QSFP28	TID/DD (ΔTx_{Pavg}, $\Delta Rx_{Sensitivity}$, Δlifetime) SEE (SEU, SEFI, SEL)	1	Broadex Technologies
DUT-2	D1TThh-QLCA				Broadex Technologies
DUT-3	FTLC1156RDPL				Finisar
DUT-4	QFPQL010410D	QSFP+			Skylane Optics
DUT-5	D133bb-SLHC	SFP28			Broadex Technologies
DUT-6	FTLF1436P4BCV				Finisar
DUT-7	D13399-SLHA	SFP+			Broadex Technologies
DUT-8	ET5402-LR				Edge-Core Networks

II. TEST SETUP

To obtain the full characterization of the DUTs in terms of radiation tolerance, cumulative effects and SEE have been evaluated during both data transmission and reception. Each type of test required a dedicated setup. The main features of both test setups are described in the following subsections.

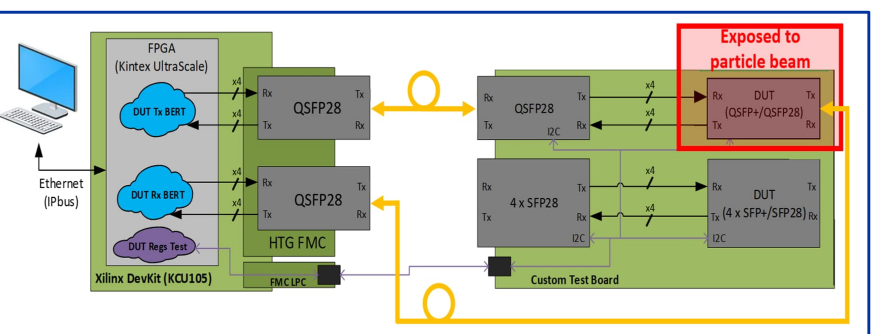
Cumulative Effects Test

Cumulative effects (e.g. TID, DD) have been evaluated through "offline" analysis. The aim of this test was to evaluate the impact of cumulative effects on the lifetime, optical power of the transmitter and sensitivity of the receiver by comparing measurements before and after irradiation.



SEE Test

SEE (e.g. Single Event Latch-up (SEL), Single Event Transient (SET), Single Event Upset (SEU)) have been evaluated through "online" analysis. The aim of this test was to evaluate the impact of SEE on the Bit Error rate (BER), loss of lock (LOL) and control registers by monitoring the DUT in real-time during irradiation. Based on the measurements of the online analysis, SEE cross-sections for the different DUTs have been calculated.



III. TEST PROCEDURE

Cumulative Effects Test

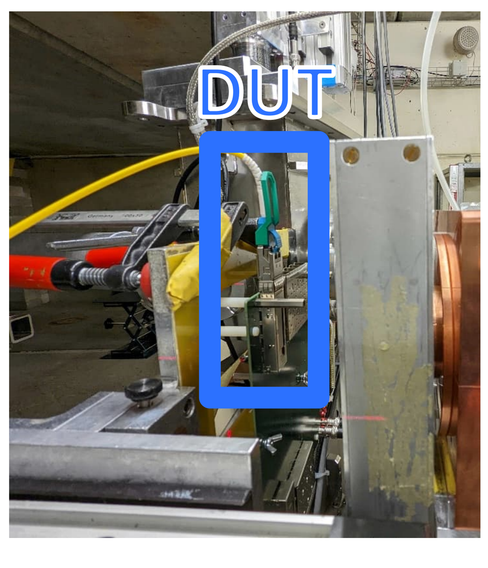
For the measurement of the optical power of the transmitter, the Average Output Power (Pavg) of the DUT was directly measured with the optical power meter (in dBm). The value given by the optical power meter required adjustment for losses of the optical link.

For the measurement of the sensitivity of the receiver, a Bit Error Rate Test (BERT) in the FPGA, generated a Pseudo-Random Bit Sequence (PRBS) which was sent as serial stream to the transmitter of the DUT. Then, the transmitted optical signal was attenuated and split in two. Half was sent to the receiver of the DUT and was checked by the BERT core. The other half was sent to an optical power meter. The sensitivity was set as the average optical power in the Rx at a BER < 5E-12 (following the industry standard).

SEE Test

The SEE test has been performed in real time, measuring the different parameters of interest of the DUT during irradiation. This test may be divided in three main subtests based on the parameters of the DUT to be measured.

- **The first subtest evaluated destructive effects. SEL has been monitored by measuring in real time the current consumption of the DUT. The power supply featured a current limitation that prevented the DUT to be destroyed in case of SEL.**
- **The second subtest evaluated the BER and Loss-Of-Lock (LOL) of the serial communication. The number of bit errors and their rate allow to differentiate the type of SEE. For instance, a single bit error indicates a Single Event Upset (SEU), or a LOL with no recovery indicates a SEFI.**
- **The third subtest evaluated internal EEPROM of the DUT. This memory is accessed via I2C interface and during irradiation it was periodicity read and its content stored in a file.**



IV. TEST RESULTS

Cumulative Effects Test

Offline Measurements						
DUT	Pre-Irradiation		Post-Irradiation		Delta Pre-Post Irradiation	
	Tx Pavg (dBm)	Rx@(BER<1e-12) (dBm)	Tx Pavg (dBm)	Rx@(BER<1e-12) (dBm)	Tx Pavg (dBm)	Rx@(BER<1e-12) (dBm)
DUT-1	6.41	-11.01	6.21	-11.06	0.20	0.05
DUT-2	8.45	-7.99	8.68	-8.31	-0.23	0.32
DUT-3	7.75	-9.62	7.54	-9.58	0.21	-0.04
DUT-4	5.88	-8.73	6.06	-8.52	-0.18	-0.21
DUT-5	-0.71	-8.34	-0.41	-8.15	-0.30	-0.19
DUT-6	-0.94	-9.12	-1.11	-9.25	0.17	0.13
DUT-7	-0.15	-12.76	-0.39	-13.01	0.24	0.25
DUT-8	-0.84	-15.90	-0.81	-16.15	-0.03	0.25

SEE Test

Cross Section (σ) (cm²/device)								
DUT	Soft SEL	I2C EEPROM			Loss of locks		Bit Errors	
		SEFI (& SEL/LOL)	SEFI	Short SEFI	LOL (& SEL)	LOL	Rx	Tx
DUT-1	9.15E-11	5.34E-11	2.29E-11	< 2.84E-11	9.15E-11	< 2.84E-11	2.34E-09	2.57E-10
DUT-2	5.64E-11	3.76E-11	5.64E-12	1.51E-11	5.64E-11	< 6.92E-11	1.27E-10	8.90E-10
DUT-3	1.11E-08	3.69E-09	<5.48E-9	<5.48E-9	3.69E-09	1.85E-09	No Data Acquired	
DUT-4	6.65E-10	3.99E-09	<2.46E-9	<2.46E-9	Continuous LOL		No Data Acquired	
DUT-5	3.69E-11	<3.69E-11	<3.69E-11	<3.69E-11	Continuous LOL		No Data Acquired	
DUT-6	1.18E-11	I2C Continuously Faulty			1.18E-11	<4.32E-12	3.52E-11	1.18E-12
DUT-7	1.18E-12	I2C Continuously Faulty			1.18E-12	4.70E-12	3.72E-08	<4.32E-12
DUT-8	9.25E-12	I2C Continuously Faulty			9.25E-12	<8.54E-12	SEFI after 250 Gy	

V. CONCLUSION

- **The cumulative effects test was successfully passed by all DUTs. The offline measurements performed before and after irradiation showed minimal variations in both Tx Pavg and Rx sensitivity (Δ < 0.5 dBm), as well as no impact in the lifetime of the components. Based on these results, it is reasonable to assume that cumulative effects would pose a negligible impact on these components during HL-LHC operation in the arcs and alcoves.**
- **The SEE test was passed by 2 DUTs (DUT-6 and DUT-7). It can be considered that the Tx of both components were not affected by SEE during the test. However, the I2C interfaces of both components presented extremely high sensitivity to SEFI. Based on these results, it is reasonable to assume that, both DUT-6 and DUT-7 could be selected as transmitters for applications during HL-LHC operation in the arcs and alcoves when online monitoring of the I2C EEPROM is not a requirement.**

Topical Workshop on Electronics for Particle Physics (TWEPP) 2023 – Geremeas, Sardinia, Italy (1-6 October 2023)