Optical data link evaluation criteria and test procedures

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This document describes the evaluation criteria and test procedures for optical data links that are developed to read out the detector front-end electronics in particle physics experiments. The tests have two parts: the in-lab functional evaluation and the irradiation resistance measurements. A standardized test setup and a test center (lab) with necessary equipment are proposed.

I. The in-lab tests:

The in-lab functional evaluation must answer the following questions:

1. The link's recommended range of data transmission rate.
2. The input data standard (CMOS or LVDS) and its timing diagram.
3. The reference clock standard and jitter budget (at a bit error rate of 10^{-12}).
4. The output data standard and its timing diagram. Recovered clock jitter.
5. The serializer jitter transfer function and the system's jitter tolerance.
6. Eye diagram at TP1, TP2 and TP3 (see diagram below) and from these, the rise (20% - 80%) and fall times and eye mask test.
7. The maximum transmission range over a certain type of fiber at the specified data rate.
8. The optical power at TP2 and TP3.
9. The sensitivity of the ORx (at BER of 10^{-12}), hence the optical power budget is measured.
10. The system parameters: power voltages and consumption of each component and a powering up scheme.
11. The system operation environment (temperature, humidity, vibration, magnetic field, if applicable).
12. Reliability and life measurements at component and system level.

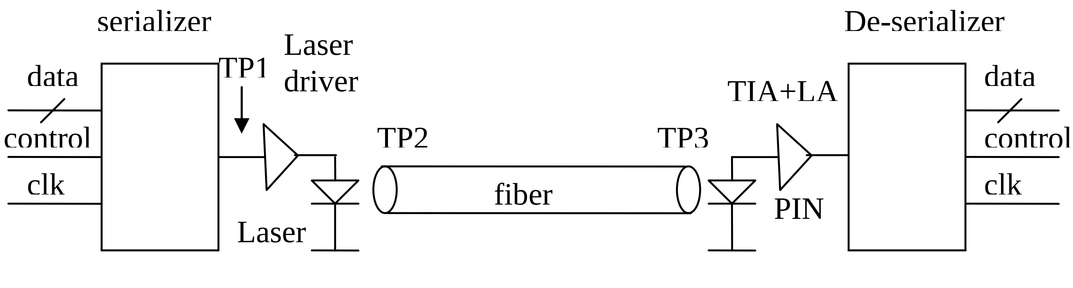

Fig.1. Optical data link block diagram.

The evaluation criteria for jitter tests (transfer function, system jitter tolerance), the signal rise/fall times, and the eye mask tests are to be adapted from IEEE Gigabit Ethernet standard or fiber optics standard with the closest match in serial date transmission rate. The optical power budget should be designed in such a way that the transmitting optical power fulfills the eye-safe requirements (European and the US standards) and in the meantime maximizes the optical power budget. Typically a 10 dB optical power budget is recommended. This is mostly an issue of the ORx sensitivity at component level and in the system implementation level.

Reliability and life tests are usually performed at an elevated temperature (but still within the maximum operational range), with all the other parameters (power voltage, humidity, etc) set at recommended values.

II. Reference optical links:

Reference optical links are to be designed and built at 1.25 (1.6), 2.5 and 3.125 Gbps with four modular boards: the serializer board, the OTx board (laser driver + laser), ORx board (PIN + TIA and limiting amplifier) and the deserializer board. The connection between the serializer board and the OTx board, the ORx board and the deserializer board are 50 ohm cable with SMA connectors; the connection between the OTx board and the ORx board will be radiation resistant fiber. The laser and PIN diode are to be soldered to their boards. They should be able to be easily replaced with other lasers or PINs. As for the laser side, bias and modulation currents should be adjustable in such a way that one can use a VCSEL or an Edge Emitter Laser.

In this design philosophy, one can easily replace one of the four modular boards to construct a “custom” link to evaluate a component or a subassembly under development and test that in a complete link system. This construction also allows for irradiation test of a component, especially in an online SEE measurement that requires a complete link system to be functional during the irradiation test.

The reference links also serves as baseline link designs and system implementation for user projects.

Reference links with speed in the neighborhood of 10 Gbps have to be specially designed and constructed. Is there such a need to construct a 10 Gbps reference link?

III. The irradiation tests:

The irradiation tests should be performed at component level (example: serializer, laser driver, laser and fiber. And the counter part on the receiver side should this side be placed in radiation environment). Total ionizing dose (TID) effect and single event effect (SEE) tests should be carried out and preferably be carried out separately with X-ray or gamma for TID, and with neutron or proton (above 60 MeV) for SEE. Power consumption of each component under irradiation should be monitored in both TID and SEE tests. For optical fibers, only TID test is necessary. If possible, a system level radiation induced bit error rate (BER) should be measured with all components that will be working in radiation environment being irradiated at the same time.

A separate document details the irradiation test procedures and acceptance criteria will be needed. Simplified acceptance criteria are:

1. At the total ionizing dose estimated for the designed link life time, radiation induced power consumption increase (from measuring the supply currents) is negligible or considered acceptable.
2. No single event latch-up or the latch-up can be reset through a system reset pin or power cycle.
3. Single event upset (SEU) rate is considered acceptable. SEU consists of frame loss and single bit flip. Both error types need to be measured and assessed according to the application. Frame loss error should to be distinguished from the single bit flip error. The best place to detect and distinguish these two types of errors is in the FPGA where errors are recorded. Studies need to be carried out in different reference links to develop FPGA code for this task. Code exists for G-Link and TLK receiver chips.
4. The system should run error free after the TID and SEE tests.
5. If annealing is required in the TID test, the annealing time needs to be normalized to the total dose with a safety factor to compensate the low dose effect.

Test systems (PCBs) can be designed in such a way that they can accommodate both in-lab tests and irradiation tests, with all reference links.

IV. A standardized test setup:

A standardized test setup may be adapted to save time in testing and to easily compare the test results. A block diagram of the test setup may look like in the following diagram.

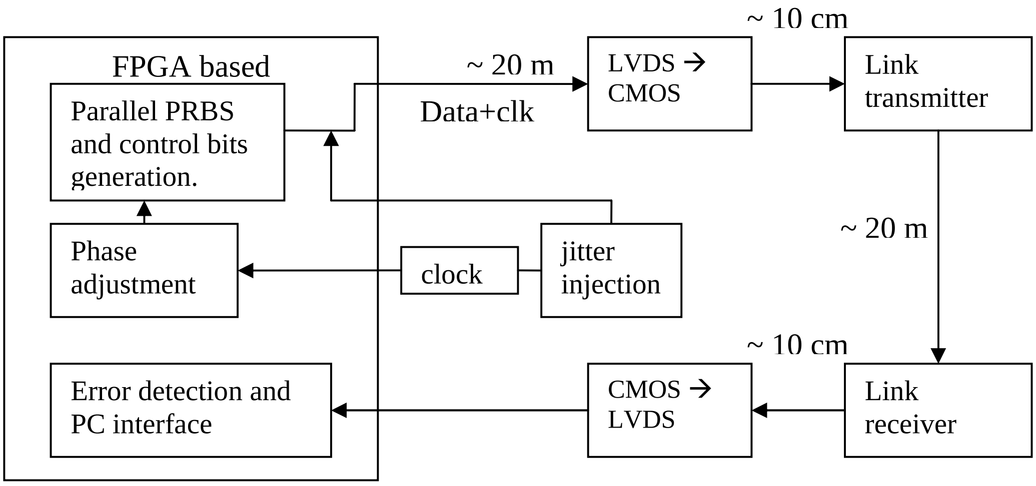

Fig.2. Block diagram of the test setup that can be used for both in-lab and irradiation tests.

A portable multi-channel (12 channels per board) linear regulator based DC power with current monitoring capability on each channel with large dynamic range can also be adapted to complete the test setup for TID test.

Most software used in the tests can be standardized as well. These are the PRBS generation, error detection and PC interface, including the GUI (LabVIEW based) on the PC for controlling, monitoring and data logging.

This test system can be adapted from the existing package developed at SMU.

V. A test center (lab) with the following test equipment and support:

Test centers with adequate equipment can be set up for optical link R&D work for CMS and ATLAS upgrade.

The test equipment should include normal lab equipment plus the specialized instruments:

1. Multi-GHz clock and function generator with jitter injection.
2. Multi-GHz real-time oscilloscope with matching (differential) probes.
3. Sampling oscilloscope with electrical and optical heads and with jitter analysis software.
4. Serial Bit Error Rate Tester (BERT).
5. Logic analyzer.

Test centers should also provide a limited staff support related to the equipment, software and firmware the center provides. This support should also include development and modification of software towards special test needs.

VI. Summary:

Test centers with adequate equipment and supporting staff need to be established. Specially designed reference optical links need to be developed for component and subassembly tests. A standardized test system (software and hardware) also needs to be developed with standardized testing procedure.

The goal of this effort is the following:

1. Develop and maintain expertise on multi-gigabit per second optical link system. Provide knowledge base and baseline designs for optical links.
2. Best use of very expensive equipment for multi-gigabit optical link development.
3. Standardize reference links and a test system to save on testing cost and time.
4. Standardize test procedures to easily compare test results among collaborators.
5. Overall to save on R&D cost on optical links for future HEP experiments.