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Versatile Transceiver developments

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ABSTRACT: SLHC experiment upgrades will make substantial use of optical links to enable high-speed data readout and control. The Versatile Link project will develop and assess optical link architectures and components suitable for deployment at SLHC. The on-detector element will be a bidirectional opto-electronic module: the Versatile Transceiver (VTRx) that will be based on a commercially available module type minimally customized to meet the constraints of the SLHC on-detector environment in terms of mass, volume, power consumption, operational temperature and radiation environment. This paper brings together the status of development of the VTRx in terms of packaging, environmental testing and functional testing.

KEYWORDS: Radiation damage to electronic components; Optical detector readout concepts; Radiation-hard electronics; Front-end electronics for detector readout

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1 Introduction

Optical data transmission will be a key enabling technology for the experiment upgrades at SLHC. The development of optical links and the qualification of their commercially available constituent components represent a significant amount of effort that is being shared by the collaborative Versatile Link project [1] that unites link builders across several SLHC collaborations. The goal is to provide a bi-directional optical link to connect the front-end electronics of SLHC detectors to the back-end counting rooms. Sufficient bandwidth should be made available to allow the different traffic types (be it timing, readout and/or control data) to share the same transmission link. Different link flavours will be developed that are capable of operating over the installed single-mode or multi-mode fibre plants of the (S)LHC experiments. The component that will be placed at the front-end is the Versatile Transceiver (VTRx), which is a bi-directional optical module based upon a commercially standard transceiver module with minimal customization to make it suitable for use in SLHC detector front-ends. This customization includes the following: choice and assessment of components for environmental tolerance (e.g. radiation, temperature, magnetic field) and minimization of material, mass and power. In addition, functional testing is required to ensure that the VTRx will operate correctly when used in the Versatile Link. While the Versatile Link project aims at the development of the opto-electronic components, the associated GBT Project [2] covers the design of the chipset required to de-/serialize and encode the data to be transmitted. The optical datalink created by the two projects is shown in figure 1 for the point-to-point link case.

The radiation environment of SLHC will exceed that of LHC by almost an order of magnitude. This means that the radiation levels for qualification of components destined for the tracking

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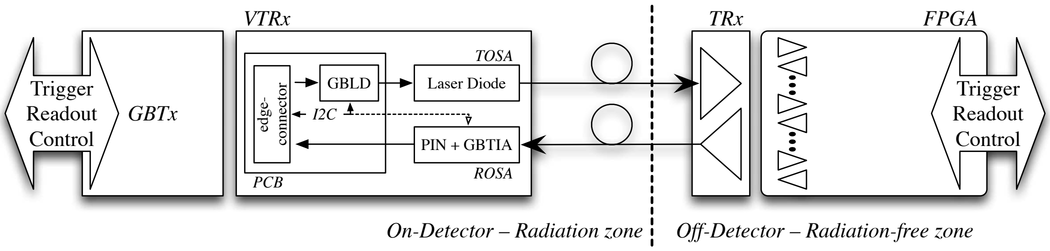

Figure 1. Overview of the point-to-point bi-directional optical link architecture for SLHC enabled by the components developed by the Versatile Link [1] and GBT [2] projects.

detector volume of SLHC detectors must be set to 500 kGy (Si) and 1.5 $\times 10^{15}$ 1 MeV neutron equivalents/cm^2 (Si) [1]. One of the difficulties in qualifying optoelectronic components for complex radiation environments such as the SLHC, containing a range of particle species and energies, is that the scaling to a particular radiation facility's particle and energy spectrum is not well established. Testing at multiple sources is thus required in order to fully qualify the components.

The Versatile Link project has been organised into three phases: Proof of Concept; Feasibility; and Pre-production Readiness. The second phase (Feasibility) will come to an end in April 2011, by which time we will have a complete set of specifications, shortlist of VTRx flavours (wavelength and fibre type), radiation test results from a number of different sources and a final prototype package containing radiation-resistant components.

In this paper we will describe the prototype development and show results of its functional performance. We also give a brief overview of recent radiation tests that have been carried out to test candidate components for the VTRx.

2 VTRx prototype

The VTRx is based upon the commercial SFP+ module standard which defines a small form factor (14 mm $\times$ 10 mm $\times$ 50 mm w$\times$h$\times$l) pluggable bi-directional optical transceiver. The SFP+ standard was chosen because it covers the target data-rate of the VTRx (4.8 Gb/s) that is set by the GBT serializer chipset [2]. The VTRx will use the radiation tolerant laser driver (GBLD) [4] and receiver amplifier (GBTIA) [5] sourced from the GBT chipset development. The GBLD will be housed on the VTRx circuit board and attached to a laser housed in a TOSA package that will be soldered to the circuit board via a flex cable. On the receiving side the GBTIA will be inserted into a ROSA package with the chosen photodiode. The VTRx circuit board has been designed and results of its testing are shown in section 2.1, both with a commercial laser driver and with the GBLD. The GBTIA ROSA has been prototyped and results are shown in section 3.1 for standalone testing as well as when mounted on the prototype VTRx.

2.1 VTRx PCB

Based upon experience gained with commercial ASIC evaluation boards and our own versions of such boards, we have designed our own SFP+ size-compatible test PCB. This VTRx prototype PCB has been designed to house: a commercial edge-emitting laser driver; a commercial TOSA; and the

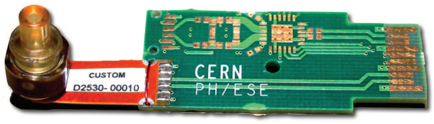

Figure 2. Photograph of GBTIA-ROSA mounted on VTRx prototype PCB.

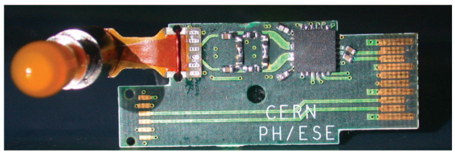

Figure 3. Photograph of a commercial edge-emitting laser TOSA mounted on VTRx prototype PCB.

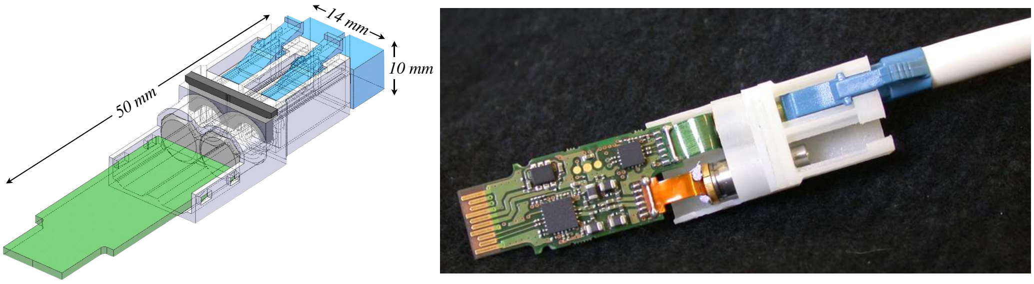

Figure 4. 3-D CAD model of the latch design (left) and photograph of the prototype object (right).

GBTIA-ROSA. TOSAs from different manufacturers are supported through the use of solder-in jumpers to define the polarity of the laser- and monitor photodiode connections at the flex of the TOSA. PCB circuit simulations that include the laser model developed previously [6] were carried out to confirm the correct functionality of the board including optimization of the bias/matching network. The bias network allows some flexibility in the matching of different TOSA types which overall allows the prototype PCB to function with a range of different devices.

The VTRx prototype has been fabricated and assembled in a Tx and Rx configuration to check the functionality of each side. Figure 2 shows the board assembled with the GBTIA-ROSA and figure 3 shows the board assembled with the laser driver, matching circuit and TOSA. Details of the performance are given in section 3.2.

2.2 LC connector latch design

In order to reduce the material of the overall VTRx we are pursuing the design of a plastic adapter to provide the interface between TOSA/ROSA and the LC-type optical fibre connector that is used with commercial SFP+ transceivers. We have designed such a part and had it fabricated using a rapid 3-D prototyping technique in order to evaluate its performance. The 3-D CAD model and photographs of the finished object are shown in figure 4.

The functionality of the latching mechanism was tested by evaluating the receiver sensitivity of a ROSA fitted to the prototype latch. The first design showed the equivalent of an attenuation penalty of several dB which indicated that the connector was not properly mated to the ROSA. A lateral reduction of 1mm in the direction of insertion was sufficient to recover the penalty and ensure correct functionality of the latch.

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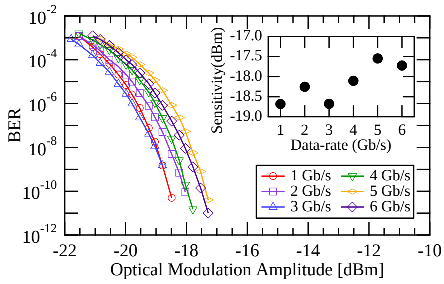

Figure 5. Effect of changing data-rate upon the sensitivity of the protoype GBTIA-based ROSA.

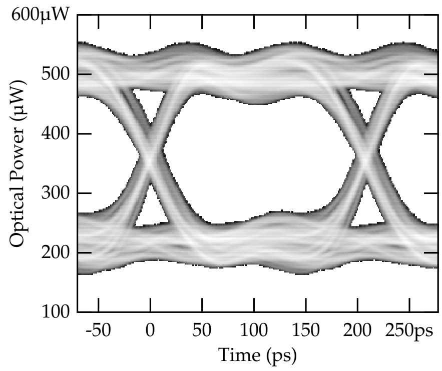

Figure 6. Optical output eye of the VTRx prototype in figure 3.

3 Functional testing

3.1 GBTIA-ROSA preliminary test results

The prototype VTRx shown in figure 2 has been evaluated by measuring the output electrical signals as a function of input optical power. The electrical output eye with typical input optical signal levels of a few hundred μW is very open at the target bit-rate of 4.8 Gb/s. A key performance metric of optical receivers is their sensitivity — the minimum optical modulation amplitude at which a Bit Error Rate (BER) of 10^{-12} or better is achieved. BER testing has been carried out on the GBTIA-ROSA at several data-rates, the results of which are shown in figure 5. The measured sensitivity of around -17 dBm meets the requirements of the Versatile Link [7]. One also observes the expected overall trend that the device sensitivity decreases with data-rate.

3.2 VTRx prototype preliminary test results

The transmit section of the prototype VTRx (see figure 3) has been evaluated by measuring the output optical eye diagram of an edge-emitting laser diode connected to a commercial laser driver. The output eye is shown in figure 6. The eye diagram can be analysed to extract the jitter present in the signal, which in this case corresponds to a total jitter (for BER $= 10^{-12}$) of 36 ps broken down into 1.14 ps (rms) of random- and 20 ps (pk-pk) of deterministic jitter. While these values taken in isolation appear to be sufficient for the Versatile Link, it is interesting to compare them to the output of the same laser mounted on the laser driver manufacturer's evaluation board. We observe both more jitter and more amplitude noise in the current VTRx prototype board and this will lead us to re-examine and optimize the layout of the VTRx prototype in a future iteration of the PCB.

4 Radiation test results

4.1 Single Event Upset test

A Single-Event Upset (SEU) test was carried out in a 60 MeV proton beam at the Paul Scherrer Institut (PSI), Villigen, CH in order to assess the performance of the GBTIA-ROSA. Concern had been raised by previous SEU tests including TIAs in the beam that burst errors would be generated

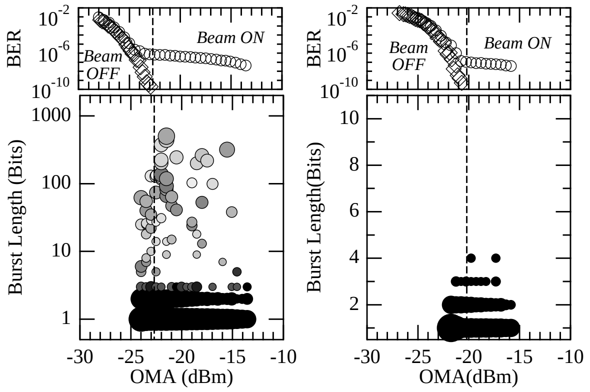

Figure 7. BER and burst error lengths measured during SEU test for a commercial ROSA (left) and the GBTIA-based ROSA (right). Circle size is proportional to rate of occurrence and lighter shading indicates a smaller fraction of bits in error during a burst.

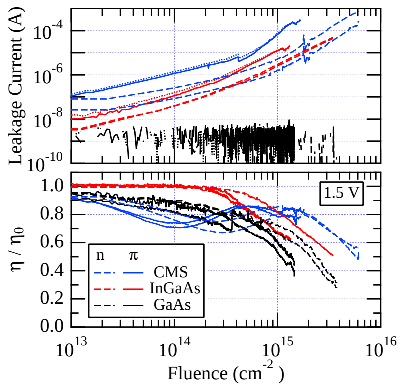

Figure 8. Relative change in responsivity (bottom) and leakage current (top) of p-i-n photodiodes under neutron and pion irradiation for a reverse bias of 1.5V.

that would not be correctable by the GBT's Forward Error Correction (FEC) algorithm [8]. Our test setup included ROSA packages containing: (i) a 60 μm PIN InGaAs photodiode; (ii) the same photodiode mounted together with the GBTIA; and (iii) a commercial ROSA containing an 80 μm GaAs ROSA and commercial TIA.

Figure 7 compares the length of error bursts as a function of input optical power for the commercial ROSA and GBTIA-ROSA where the respective TIA and photodiode were simultaneously exposed to the proton beam. The GBTIA is clearly much less susceptible to SEU than the commercial one since the burst length is limited to 4 adjacent bits in the former case compared to many hundreds of bits in the latter. This is excellent news for the GBT chipset as the proposed FEC is fully able to mitigate bursts shorter than 16 bits in length. The full test results will be the subject of a future publication.

4.2 Pion test

An irradiation test has been carried out in a 300 MeV/c pion beam with a similarly-large spectrum of devices as tested previously with 20 MeV neutrons [9]. As expected, we generally found the pions to be more damaging than 20 MeV neutrons. The two key parameters of interest when measuring radiation-induced photodiode degradation are the leakage- or dark current and the responsivity (photo-current per unit light power impinging on the device). Figure 8 compares the relative impact of 20 MeV neutrons and 300 MeV/c pions on the responsivity and leakage current of the devices tested. Results from the lasers are presented elsewhere [10].

In terms of leakage current, 300 MeV/c pions are found to be a factor of 2-4 more damaging for the InGaAs photodiodes. The newer smaller-diameter InGaAs samples have a smaller relative damage factor than the InGaAs devices deployed in link systems of the CMS detector. These latter devices have been used as a reference in our current test programme as they have been extensively studied in the past. As there is no measurable (in our test) increase in leakage current in the GaAs devices, we cannot calculate a relative damage factor for them. In terms of responsivity, 300 MeV/c pions are found to be a factor of 2 more damaging than neutrons for the GaAs devices, a factor of 2.5 for the CMS InGaAs devices and a factor of 1.8 for the newer InGaAs devices.

5 Summary and conclusions

We have shown details of the good progress being made with the design of the Versatile Transceiver for use in SLHC experiments as the front-end component of the Versatile Link. Both the packaging and circuit board are now close to a final prototype and could already meet the requirements. We have integrated the GBTIA into a ROSA package with a photodiode and shown that this has excellent performance. The performance of the GBTIA-ROSA has been measured to be satisfactory in the presence of a particle beam of similar intensity to the worst case SLHC application. An initial concern of this project was the radiation-resistance of optoelectronic components that are needed to build multi-Gb/s optical links for SLHC. We have now also verified (using 300 Mev/c pions) that such components are in fact more radiation tolerant than devices that are currently deployed in LHC link systems.

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