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Versatile Link+ Transceiver Production Readiness

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The Versatile Link+ project is about to enter its production phase, ready for the Phase 2 HL-LHC detector upgrades. We present the status of the front-end part of the Versatile Link+ project: the Versatile Link+ Transceiver, which provides a low-mass, radiation tolerant, optical transmit- and receive module for tight integration in the upgrading HL-LHC detectors. We describe the development and thorough testing carried out with the transceiver prototypes and their sub-components and the design decisions that have led to the final production-ready prototype. The planned production schedule is also presented.

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1. Introduction

During the Phase 2 upgrades of the ATLAS and CMS experiments several detectors will be replaced to improve their physics performance. In particular, these upgrades aim to replace the innermost detectors that are exposed to the harshest radiation environments. To cope with the increasing data volume and the higher trigger rate, high-speed optical links will be deployed in large quantities as part of the upgrade programme. The tight space constraints and the high channel count of the on-detector electronics will require the development of a low-profile, multi-channel front-end component. During their expected lifetime these components will have to withstand high radiation levels (up to 1 MGy total dose and 1×10^{15} neutrons/cm^2 and 1×10^{15} hadrons/cm^2 total fluence) and operate over a wide temperature range (-35 °C to 60 °C) [1]. The Versatile Link+ (VL+ [2]) project has developed a custom front-end transceiver, VTRx+, that fulfills these requirements.

2. VTRx+ Transceiver

The VTRx+, Fig. 1, is a radiation hard small-footprint (20 mm × 10 mm) optoelectronic transceiver with four transmitting channels and one receiving channel all operating at 850 nm wavelength. The maximum data rates for the transmitting and receiving channels are 10.24 Gbps and 2.56 Gbps, respectively, which are compatible with the lpGBT (Low Power GigaBit Transceiver) data rates [3]. This full 4Tx+1Rx configuration suits the needs of many experiments, which have to send significantly more data from the detectors to the counting room (up-link) than in the other direction (down-link). However, in order to minimize the power consumption unused channels can be disabled and therefore configurations like 4Tx or 1Tx+1Rx are possible. The end-of-life power consumption is 6 mW (base) plus 50 mW per channel for Tx and 100 mW for Rx.

Electrical connectivity is realized using a 2 mm stacking height 40-pin connector, which results in a total height of 2.5 mm including the VTRx+ PCB. Other compatible host board receptacle variants are available: a 1.5 mm receptacle can be used on the host board if even thinner total height is required or a 4 mm receptacle if there is a need to place SMD components under the transceiver. VTRx+ transceivers will be delivered pigtailed with an MT-type connector, Fig. 1. The pigtail length can be chosen from a selection of predefined lengths. More details can be found from the VL+ application note [1].

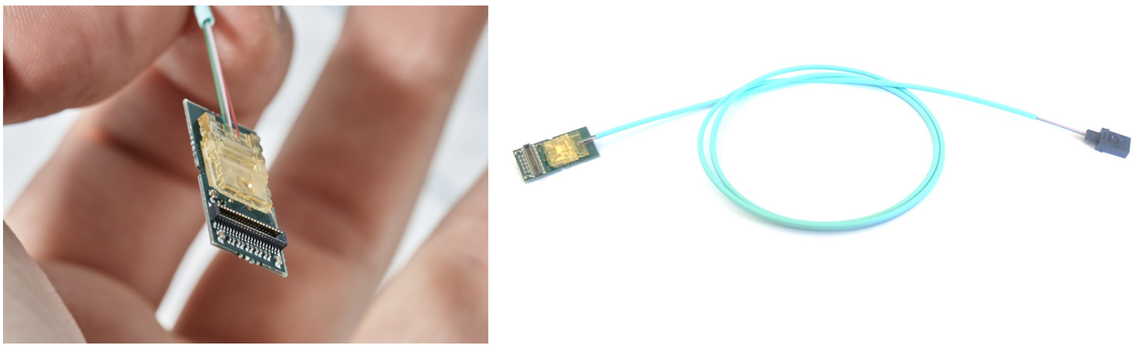

Figure 1: VTRx+ transceiver (left) and example pigtail with MT-connector (right).

2.1 Transmitter Components

The VTRx+ uses the LDQ10 quad laser driver [4] to generate bias and modulation currents for the lasers. Its performance has been tested up to 3 MGy (3×VL+ specification) with only slightly reduced output currents and practically unchanged high-speed performance [5], but the latest version of its I2C block showed insufficient SEU hardness during a neutron test. These issues have been reproduced during additional tests with two-photon laser and heavy ions. The necessary design modifications are being implemented.

A number of vertical-cavity surface-emitting laser (VCSEL) candidates from several manufacturers have been extensively tested across the specified temperature range and up to the required particle fluences. The main changes in VCSEL performance are increased threshold current and forward voltage, both in cold and under irradiation. Also optical output power is strongly reduced after exposure to high particle fluences, Fig. 2. All these effects reduce the available modulation range. Based on the test results we can select a VCSEL type with acceptable overall performance and to further improve the margins carry out wafer selection based on the forward voltage and component screening based on the optical output power. Even with these careful precautions it is

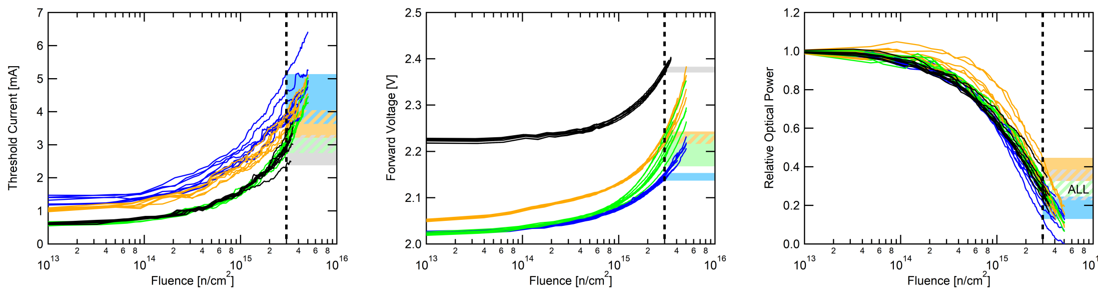

Figure 2: A selection of the best VCSEL candidates under 20 MeV neutron irradiation; colors represent different VCSEL types. Threshold current (left), forward voltage at 6 mA (middle), and relative optical power at 6 mA (right) as a function of neutron fluence. The shaded areas highlight the spreads in the results of different candidates at the specified fluence level (dashed lines) of 3×10^{15} neutrons/cm^2, which does not take into account the expected beneficial annealing of 50 %.

not possible to develop a transceiver that operates in our harsh environment for an extended period of time without any adjustment. Radiation damage in the VCSELs has to be compensated by adjusting the drive currents, and therefore different settings are required depending on the amount of exposure to particle radiation. As shown in Fig. 3, the LDQ10 allows the adjustment of both bias and modulation currents via I2C connection.

2.2 Receiver Components

The receiver side of the VTRx+ is composed of a GBTIA [6] transimpedance amplifier and an InGaAs photodiode. The GBTIA was already used in the VTRx devices (Phase 1 upgrades) and during development period it was thoroughly tested. Now it has been retested up to the radiation hardness requirements of VL+. The photodiode selection is mainly a decision between two available material families: GaAs and InGaAs photodiodes. Both can operate at 850 nm but they feature fundamental differences in their performance in our unique environment.

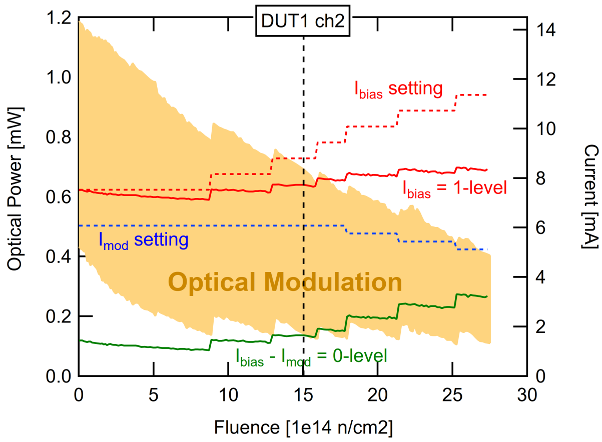

Figure 3: Example of drive current adjustment during VTRx$^+$ irradiation test. Dashed lines show the setting values and solid lines measured (1-level) and estimated (0-level) real modulation currents. The shaded area represents the optical modulation amplitude generated by these drive currents. The fluence limit of 1.5×10^{15} neutrons/cm^2 represent the end-of-life situation when the expected annealing (50 % of the radiation damage) is taken into account. The results predict that specified minimum optical modulation of 300 µW is achieved even at the end-of-life.

Already at normal operation temperatures the long wavelength responsivity cutoff of GaAs is close to the defined maximum wavelength of 860 nm. The cutoff wavelength shifts to shorter wavelengths when photodiodes are operated in cold and can cause significant penalty when temperature goes down to the lower end of the VL$^+$ specification range, as shown in the left of Fig. 4. Responsivity cutoff is not an issue with InGaAs photodiodes, which simplifies the system design and makes the receiver practically temperature insensitive. Fig. 4 right shows another important benefit from InGaAs photodiodes, which is their lower radiation induced responsivity loss at 850 nm wavelength. Unfortunately, the capacitance of InGaAs photodiodes increases when irradiated [7], which limits the high-speed performance. However, the used data rate of 2.56 Gbps instead of 5 Gbps, for which the GBTIA was designed, reduces the effect of the increased capacitance, and therefore the best overall performance is achieved with InGaAs photodiodes.

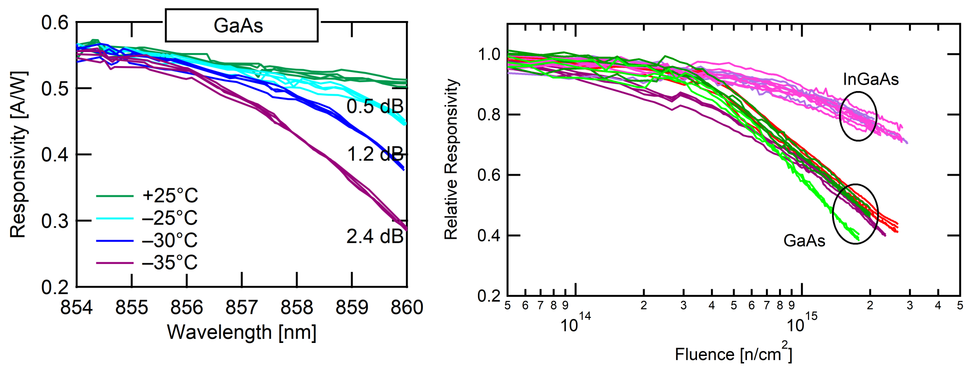

Figure 4: GaAs photodiodes have a significant drop in long wavelength responsivity when operated in cold (left). GaAs photodiodes have also worse radiation tolerance in terms of responsivity (right).

3. Schedule

During the VTRx+ development several prototype versions have been built leading to prototype series with the final pinout and footprint. These prototype series give the users an opportunity to test VTRx+ transceivers in their own systems and enables the VL+ collaboration to prepare for the series production. The ASICs and optical components for the series production will be purchased and tested in Q4/2019 and Q1/2020. The pre-series assembly is planned for Q2/2020 followed by extensive pre-production qualification. The series production is planned to be launched by the end of 2020. The final production quantity is estimated to be around 70,000 transceivers but the total quantity requires confirmations from the users. With the estimated production rate of 2,000–3,000 units per month the full series production is expected to be completed less in than three years.

4. Conclusion

The VL+ project has developed a radiation-hard transceiver, which meets the unique requirements of HL-LHC experiments and can be used as a part of a complete data link together with the lpGBT chipset and other components, such as fibers and back-end transceivers, defined by the VL+ project. Transceiver prototypes and their sub-components have been extensively tested. The penalties caused by the harsh environment are understood and either minimized by careful design and component selection or taken into account in the link power budget. The VTRx+ is ready for production in 2020.

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