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System-level testing of the Versatile Link components

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Abstract: During the first upgrade phase of the Large Hadron Collider experiments, high-speed optical links will be deployed to achieve the bandwidth needed to exploit the increasing luminosity and to allow data acquisition at higher rates. The Versatile Transceiver (VTRx) and Versatile Twin Transmitter (VTTx) modules are in their final development phase before production. They support different link architectures and offer compatibility with either single-mode or multi-mode fibre plants. This paper describes the supported link configurations and presents the system-level testing of the VTRx and VTTx front-end modules with various commercial-off-the-shelf back-end components.

Keywords: Optical detector readout concepts; Radiation-hard electronics; Front-end electronics for detector readout

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Contents

1 Introduction

The Large Hadron Collider (LHC) will be upgraded in multiple phases in order to achieve higher luminosity and to improve its physics performance. These periods offer unique opportunities for LHC experiments to perform the necessary maintenance and upgrade tasks allowing them to follow the evolution of the accelerator. As part of their upgrade programme, some detectors will deploy high-speed optical links during Long Shutdown 2 (2017-2018) to deal with the increasing data volume and higher trigger rate. To satisfy the bandwidth requirements and to cope with the on-detector radiation levels, the Versatile Link common project [1, 2] proposes link architectures based on radiation-resistant, low-mass and low-power front-end components, the Versatile Transceiver (VTRx) and the Versatile Twin Transmitter (VTTx) modules together with commercial-off-the-shelf (COTS) back-end components. The choice of these components depends on the architecture of the readout system as well as on the fibre plant (single-mode or multi-mode) already present in the experiments. The supported architectures will be described in section 2.

The VTRx consists of several sub-components: a radiation-tolerant laser driver ASIC, a commercial Transmitter Optical Subassembly (TOSA), and a Receiver Optical Subassembly (ROSA), which houses a commercial PIN photodiode and a radiation-tolerant transimpedance amplifier ASIC. In the early phase of the project, all sub-components were extensively tested in the laboratory and in radiation facilities in order to qualify them for use in the VTRx/VTTx modules. In 2012, VTRx and VTTx modules were produced in small quantities and were thoroughly tested in order to confirm that they meet the Versatile Link specifications [3–5]. These functional and environmental tests were essential in order to prepare the mass production to be launched in 2014. In the meantime, future Versatile Link users have started to integrate the link with their prototype readout systems. To pave the path for all interested users we built system demonstrators allowing them to verify interoperability between the custom VTRx/VTTx modules and commercial back-end devices, and to evaluate the system-level performance. The Versatile Link optical power budget is detailed in section 3 and some application examples are shown in section 4.

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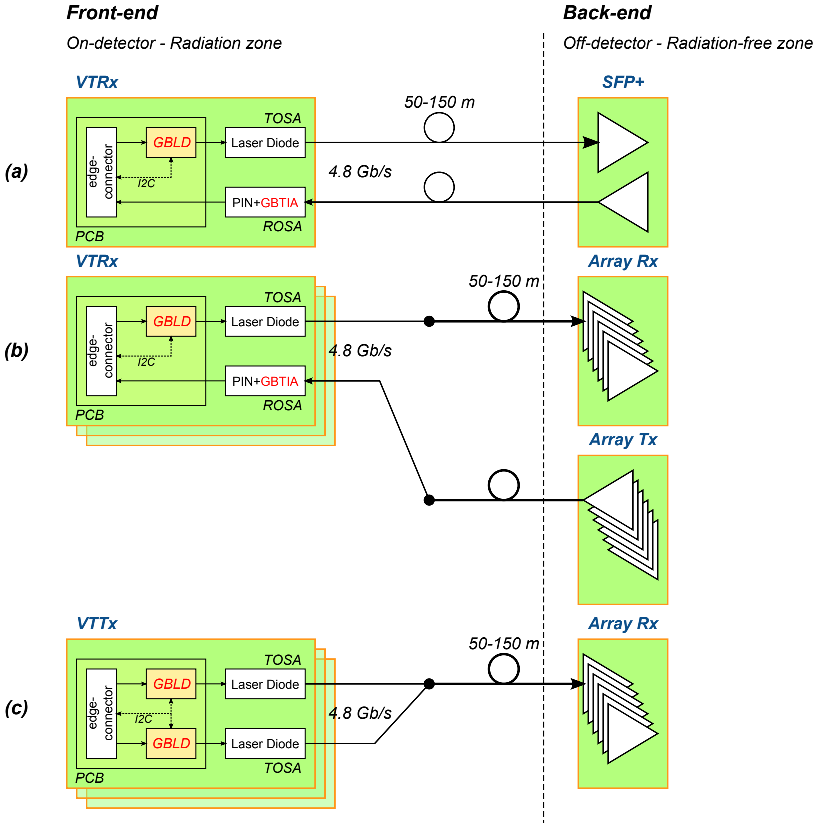


Figure 1. Proposed link architectures based on custom radiation-tolerant VTRx/VTTx modules and commercial back-end components.

2 Versatile Link architectures

The Versatile Link components support various link architectures which are summarized in figure 1. Depending on the detector topology and the bandwidth requirements different architectures are envisaged. The basic link architecture, shown in figure 1.a, consists of a radiation-tolerant VTRx module installed on the detector at the front-end and a commercial SFP+ module installed at the back-end. This architecture supports single-channel readout and control on the same bi-directional optical link. To increase the density at the back-end, several VTRx modules can be connected to a multi-channel optical transmitter or receiver component as shown in figure 1.b. Finally, systems having asymmetric bandwidth needs in the up- and downstream directions can use multiple VTTx modules each supporting two unidirectional transmit channels and connect them to an array receiver at the back-end as illustrated in figure 1.c. This solution is usually complemented by the basic link architecture (figure 1.a) for the downlink control path. The single-mode and multi-mode flavours of the VTRx allow users to implement architectures a and b using either single-mode or multi-mode fibre plants, while VTTx modules are foreseen only for multi-mode applications.

Table 1. Versatile Link fiber optic link loss budget.

Description	**Unit**	**MM_VTx_Rx**	**MM_Tx_VRx**	**SM_VTx_Rx**	**SM_Tx_VRx**
Transmitter OMA	dBm	-5.2	-3.2	-5.2	-5.2
Receiver sensitivity	dBm	-11.1	-13.1	-12.6	-13.1
Power budget	dB	**5.9**	**9.9**	**7.4**	**10.2**
Fiber attenuation	dB	0.6	0.6	0.1	0.1
Insertion loss	dB	1.5	1.5	2.0	2.0
Link penalties	dB	1.0	1.0	1.5	1.5
VTx radiation penalty	dB	0	–	0	–
VRx radiation penalty	dB	–	2.5	–	2.5
Fibre radiation penalty	dB	0.1	0.1	0	0
Margin	dB	**2.7**	**4.2**	**3.8**	**4.1**

3 Optical power budget

The Versatile Link implementations shown in section 2 are all based on a single common component, the VTRx or VTTx module, while the passive and back-end components need to be selected by the experiments depending on their specific constraints (topology, bandwidth etc.). It is the responsibility of the experiments to ensure compliance with the system-level specifications explained hereafter.

The system-level performance of an optical communication link is characterized by the optical link power margin which can be derived from the optical power budget. Table 1 shows the optical power budget for multi-mode (MM) and single-mode (SM) versatile links in both upstream (VTx_Rx) and downstream (Tx_VRx) directions. The values listed in the table are representative for a generic link and can be obtained from Versatile Link specifications [6]. The minimum optical modulation amplitude (OMA) of the versatile transmitter (VTx) and the maximum receiver sensitivity of the versatile receiver (VRx) as well as their associated radiation penalty are guaranteed for the CERN supplied VTRx or VTTx modules. However, back-end component specifications (OMA and sensitivity), fibre attenuation, and insertion loss will depend on the particular choice of components, while link penalties may depend on the exact link operating conditions (bitrate, fibre length) and environment (radiation level). Therefore, experiments are invited to do this calculation prior to the design and installation of their fibre optic system. In order to guide optical system designers in their engineering effort an application note has been made available by the Versatile Link project [7].

4 Application examples

As mentioned in section 1 the Versatile Link project is moving to the production phase and the focus on component- and module-level tests is shifting towards system-level testing. Using production-grade VTRx or VTTx modules and various commercial devices we can build system mock-ups which offer the possibility to assess link performance in more realistic conditions. A system-level

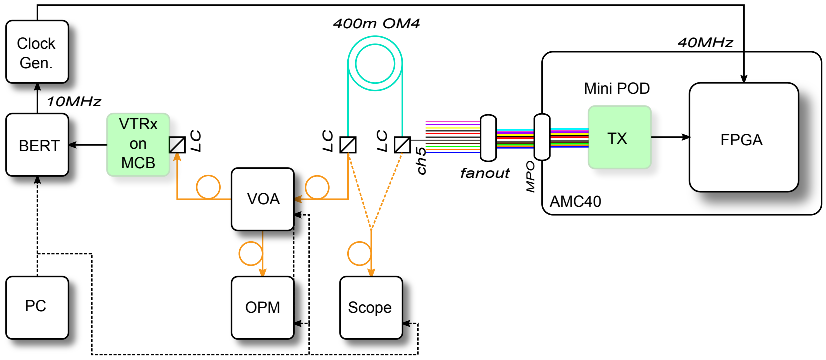


Figure 2. Experimental setup used to measure VTRx receiver sensitivity with or without 400 m OM4 fibre.

demonstrator using the Gigabit Link Interface Board (GLIB) for testing VTRx/VTTx modules with commercial SFP+ components has been already presented in [4]. This section will describe two application examples based on parallel optical devices at the back-end.

The upgrade of the LHCb experiment foresees the replacement of all on-detector optical link components with newer ones capable of operating at 4.8 Gb/s. The current optical link system spans a distance of approximately 100 m from the detector to a shielded underground area (counting room) housing the first part of the data acquisition system. The baseline for the upgrade is to simply replace the current optical links with higher-performance equivalents over similar distances. It may be advantageous for the upgraded system to dispense with the underground counting room and transmit data directly to and from the surface control room. This option would require a cable length of approximately 400 m. At the back-end, 12-channel optical transmitter and receiver engines, Avago MiniPODs, are installed on a prototype Advanced Mezzanine Card (AMC) [8].

The block diagram of the downstream test setup is shown in figure 2. For the receiver sensitivity measurement the channel under test was connected to a variable optical attenuator (VOA). The average optical power was measured using an optical power meter (OPM) at the monitoring tap of the attenuator. In order to measure the fibre induced penalty, the 400 m OM4 fibre was inserted between the TX module and the VOA. The test pattern (PRBS-7) was generated by the FPGA on the AMC40 board. The received data were checked and the bit error rate (BER) was calculated at the output of the VTRx module using an Agilent N4903B bit error rate tester (BERT). The LeCroy SDA-100G sampling oscilloscope (Scope) connected either at the output of the 12-way optical fanout cable or at the far end of the 400 m OM4 fibre was used to measure the optical eye diagram parameters. To maintain proper synchronization the FPGA reference clock (40 MHz) is derived from a generator which is locked to the internal reference clock of the BERT.

To measure the BER in the upstream direction we mounted a MiniPOD receiver on a custom carrier board as shown in figure 3. The carrier board allowed us to configure the MiniPOD receiver through its serial control interface. This was necessary, because MiniPOD receivers implement a squelch function, which prevents the device from receiving noisy data by switching off the receiver outputs when the intensity of the incoming optical signal drops below a certain threshold. To measure the receiver sensitivity at 4.8 Gb/s this feature had to be disabled, however, at the time of the test the FPGA firmware of the AMC40 did not allow to do that.

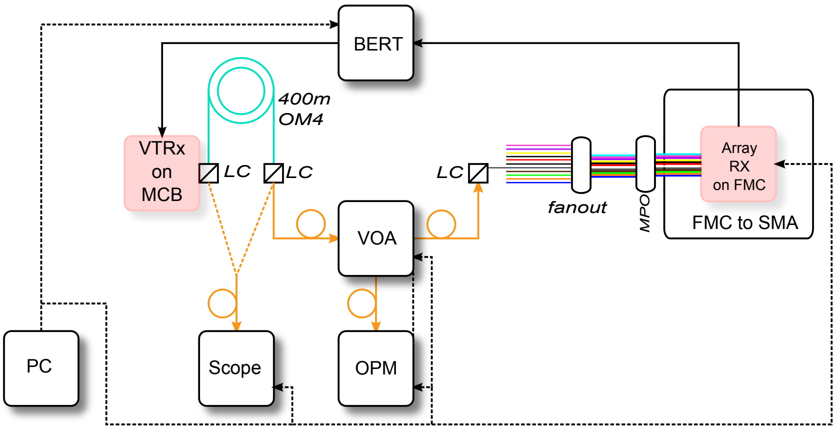
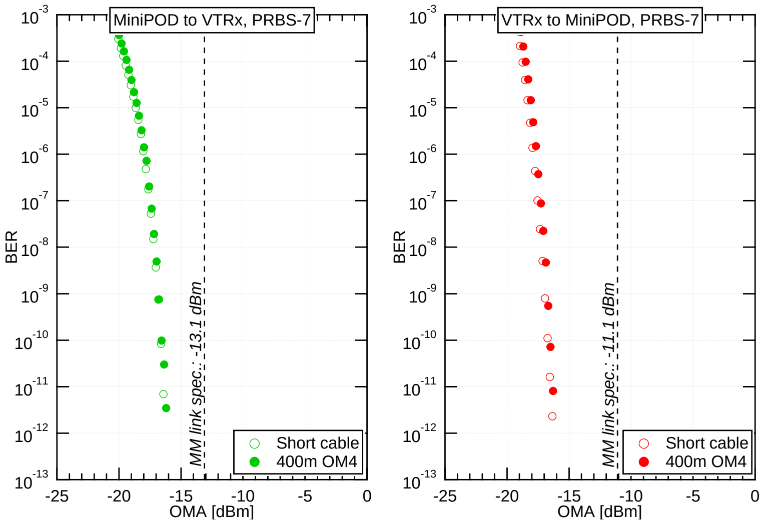


Figure 3. Experimental setup used to measure MiniPOD receiver sensitivity with or without 400 m OM4 fibre.



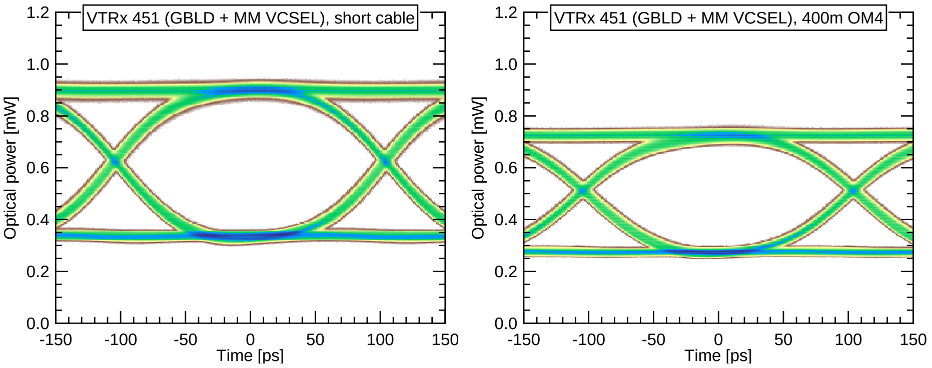
(*a*) (*b*)

Figure 4. Bit error rate curves measured in the downstream (a) and upstream (b) directions using either a short optical fibre (open circles) or 400 m OM4 fibre (full circles).

The results of the downstream and upstream BER measurements are shown in figure 4.a and figure 4.b, respectively. In both cases, the two curves show the measurement results with and without 400 m OM4 fibre. The multi-mode receiver sensitivity specifications are comfortably met in both cases and the fibre penalty related to the use of 400 m OM4 fibre is negligible at this data rate.

To see the impact of fibre penalty on the time-domain waveform, the optical eye diagram has been captured at the output of the VTRx and at the end of the 400 m OM4 fibre. The results in figure 5 show that the long fibre induces attenuation as expected, but the signal is not distorted confirming that this type of cable has enough bandwidth to transfer data at 4.8 Gb/s over 400 m.

The second example is not related to any specific Versatile Link application, but it demon-



(*a*) (*b*)

Figure 5. Transmitter eye diagrams of a multi-mode VTRx prototype. The plot on the left (a) was measured using only a short fanout cable, while the plot on the right (b) shows the eye diagram at the end of a 400 m OM4 fibre section.

strates a solution which could be adopted by experiments having a legacy single-mode system. The back-end interface is based on a 12-channel parallel optical receiver module from Fitel operating at 1060 nm wavelength and sensitive in the long wavelength range typically used in single-mode systems. To demonstrate feasibility the receiver was tested with single-mode sources operating at 1300 nm wavelength.

The sensitivity of the Fitel-based single-mode system was measured using the test setup shown in figure 6. The transmitter (TX) driven by a Pattern Generator (PG) producing a Pseudo-Random Bit Sequence (PRBS-7) is connected to a Variable Optical Attenuator (VOA). The output of the attenuator is connected to the tested receiver channel through an optical fanin. The electrical output of the RX module is sampled by an Error Detector (ED), which compares the received data with the expected pattern and calculates the BER. In order to calculate the optical modulation amplitude of the received signal, the average optical power is measured using an Optical Power Meter (OPM) attached to the monitoring output of the VOA. The extinction ratio of the transmitter was measured using the high-speed sampling oscilloscope.

The transmitter used during the tests was either the Tx part of a single-mode VTRx working at 4.8 Gb/s or a CMS Pixel Opto Hybrid (POH) prototype working at 400 Mb/s. According to the receiver data sheet, the sensitivity can be further improved at lower data rates (i.e. below 6.25 Gb/s) by using the bandwidth control of the receiver. This setting allows to optimize the bandwidth of the TIA input stage. Reducing the bandwidth can limit the broadband noise at the TIA input which in turn can reduce the bit error rate. Therefore, the receiver sensitivity was measured using high- and low-bandwidth receiver settings on receiver channels 1,6,7 and 12.

The results of the BER tests using a single-mode versatile transmitter and a POH prototype are shown in figure 7.a and figure 7.b, respectively. In both cases, these results confirm that the sensitivity specifications are met and that reduced receiver bandwidth can improve the sensitivity by 2–3 dB.

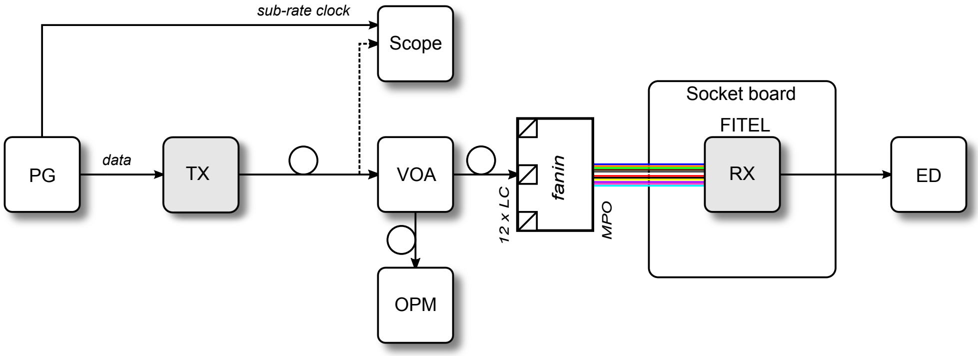
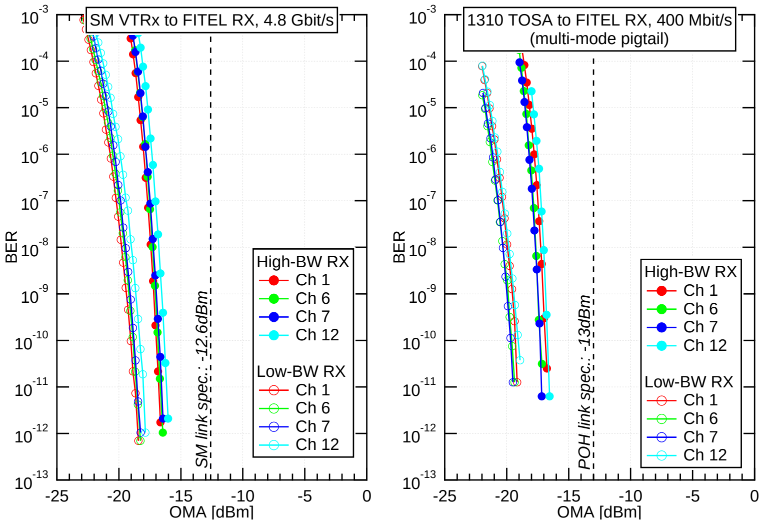


Figure 6. Experimental setup used for measuring the receiver sensitivity of a Fitel parallel optical module.



(*a*) (*b*)

Figure 7. Receiver sensitivity measured on channel 1,6,7 and 12 of a Fitel receiver using a single-mode VTRx working at 4.8 Gb/s (a) and a CMS Pixel Opto Hybrid prototype working at 400 Mb/s (b). In both cases, the two sets of curves show the receiver sensitivity using two different receiver bandwidth settings.

5 Summary

In 2014, the Versatile Link project will launch the production of the Versatile Transceiver (VTRx) and Versatile Twin Transmitter (VTTx) modules. The Versatile Link system specifications have been presented and are available for system engineers designing optical links with VTRx/VTTx components. Test setups based on production-grade Versatile Link components and commercial back-end components have been assembled to demonstrate feasibility and to measure system-level link performance. Results indicate that the systems operate with ample margin and will therefore meet the requirements of the interested experiments.

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