Versatile transceiver production and quality assurance

L. Olantera, S. Detraz, C. Sigaud, C. Soos, J. Troska, F. Vasey and M. Zeiler

CERN,
CH-1211 Geneva, Switzerland

E-mail: lauri.olantera@cern.ch

ABSTRACT: The Versatile Link project has developed a radiation-hard optical link for LHC phase 1 detector upgrades. The project has reached its final stage and we have launched in 2016 the production of the Versatile Transceivers and Versatile Twin Transmitters. This paper provides an update of the production status and a detailed description and results of the quality assurance programme, which includes qualification and acceptance testing at CERN and production testing at the manufacturers’ premises.

KEYWORDS: Manufacturing; Optical detector readout concepts

© CERN 2017, published under the terms of the Creative Commons Attribution 3.0 License by IOP Publishing Ltd and Sissa Medialab srl. Any further distribution of this work must maintain attribution to the author(s) and the published article’s title, journal citation and DOI.
1 Introduction

The LHC detector upgrades planned for LHC long shutdown 2 will increase the bandwidth requirements on the optical links. The Versatile Link common project [1] has developed an optical link architecture operating at 4.8 Gbps that utilizes radiation-hard, low-mass and low-power opto-electronic transceiver modules, which are available in three versions: single-mode and multi-mode Versatile Transceiver (VTRx SM and VTRx MM) operating at 1310 nm and 850 nm, respectively, and multi-mode Versatile Twin Transmitter (VTTx) operating at 850 nm (collectively referred to as VTXx). The choice among these versions depends on the architecture of the readout system as well as on the fibre plant already present in the experiments.

The VTXx modules are to be deployed in the upcoming phase 1 upgrades by several CERN experiments, including Alice, Atlas New Small Wheel and Liquid Argon Calorimeter, CMS HCAL/ECAL/GEM, LHCb, as well as CBM, and the LHC machine. In total around 35000 modules are being built and tested, all of which go through the VTXx quality assurance (QA) programme [2] before they are delivered to the end users.

2 Production and QA testing programme

The front-end components in the LHC experiments, including VTRx and VTTx modules, are situated in an extremely harsh environment where they have to withstand high radiation doses and strong magnetic fields. VTRx prototypes have previously been thoroughly tested during the
development process and the selected parts have been validated for the final production [3]. The production process flow and phases are shown in figure 1.

First, the component manufacturers produce TOSA and ROSA (transmitter and receiver optical sub-assembly) component pre-series using dies from selected wafers. CERN carries out Component Qualification before the assembly house builds a module pre-series using the qualified components. After the module pre-series has been delivered to CERN, it goes through a four-step Module Pre-series Qualification. Only after a successful module qualification is the series production launched. The QA programme continues throughout the series production: in production testing each module is tested at the assembly house. All production test data are saved into a database which allows monitoring the production testing remotely and querying test results of each module. In lot acceptance tests random samples of produced components and assembled modules are tested at CERN.

![Production and testing flow](image)

**Figure 1.** Production and testing flow. All three flavors Versatile Twin Transmitter (VTTx), Versatile Transceiver Single-Mode (VTRx SM), and Versatile Transceiver Multi-Mode (VTRx MM) go through the same production process.

### 2.1 Tests and parameters

The following tests are carried out repeatedly during the QA programme and they provide the parameters for validation.

**Transmitter measurements**

- **LIV**: light-current-voltage curves show optical output power and forward voltage of the laser as a function of bias current. From these curves threshold current, slope efficiency, and operation voltage can be extracted.

- **OSA**: optical spectrum analysis shows the optical output power of the laser as a function of wavelength. Central wavelength and spectral width can be extracted from the optical spectrum.

- **EYE**: eye diagram is measured by transmitting a test pattern (PRBS7) with the DUT and capturing the optical output signal using a high-speed oscilloscope. Dynamic parameters such as modulation amplitude, rise and fall times and total and deterministic jitter can be measured from the eye diagram.
Receiver measurements

- **BER**: bit error rate curves show the rate of errors in the receiver output as a function of the input optical modulation power. BER curves are measured by attenuating the input signal and counting the errors for each attenuation step. From these curves the sensitivity for a given BER level can be determined.

- **RSSI**: received signal strength indicator shows the photo current generated by the diode for a given input optical power. The ratio of these two values is the responsitivity of the device.

- **EYE**: receiver eye diagram is captured and the same parameters are extracted in a similar fashion to the transmitter eye diagram measurement.

3 Test phases and main results

3.1 Component qualification

The first phase of the QA programme is qualification testing of the optoelectronic components: TOSAs and ROSAs. The component qualification includes four steps: functional tests in standard laboratory conditions, temperature tests across the specified temperature range of $+60$ to $-30^\circ$C, magnetic field tests ($4$ T), and irradiation tests ($5 \times 10^{14}$ n/cm$^2$ and $100$ kGy). The steps and tests carried out at each step are shows in table 1. For qualification tests, 30 components were randomly selected from each wafer to be used during the production.

3.1.1 Results of TOSA qualification

All measured parameters met the specifications in the functional tests: nicely overlapping LIV curves are shown in figure 2a. However, the eye diagram measurements revealed that two devices had worse amplitude performance than the others. This was caused by shorts in the TOSAs. These failures should have been screened by the manufacturer: for the series production the manufacturer improved the screening process.

In temperature tests two parameters had special importance: the threshold current limits the modulation current range from below and the operating voltage limits the modulation current from above. Threshold currents did not increase excessively at extreme temperatures (figure 2b), but operating voltages at low temperatures were over the room temperature specification limit (figure 2c). This could have reduced the modulation at low temperature, but tests with full modules did not show issues in this regard.

| Step (samples)   | TOSA               | ROSA               |
|------------------|--------------------|--------------------|
| Functional (30)  | LIV, OSA, EYE      | BER, RSSI          |
| Temperature (14) | LIV, EYE           | BER, RSSI          |
| Magnetic (3)     | LIV                | RSSI               |
| Irradiation (16) | LIV                | RSSI               |

Table 1. Component qualification steps.
Figure 2. (a) TOSA LIV curves from functional tests in normal laboratory conditions, (b) threshold and (c) operating voltage behavior across the temperature range of +60 to −30°C.

No significant effect on performance was observed in magnetic field tests and in irradiation tests devices degraded as expected and met the specifications (figure 3).

3.1.2 Results of ROSA qualification

All ROSAs passed the qualification tests (magnetic field test is pending) without any problems. ROSAs did not show any significant temperature dependence, and were not affected by total ionising dose. A fluence of $5 \times 10^{14}$ n/cm$^2$ resulted in a responsivity drop to 75% of the pre-irradiated values (figure 4). This was worse than earlier tests had shown and was an unexpected result but it is acceptable for use in VTRx modules. Additional tests are planned in 2017 to clarify this discrepancy.

3.2 Production testing

After a successful component qualification the assembly house produces the pre-series and carries out 100% production testing. Each module goes through an automated test procedure, which measures the main parameters from both transmitting and receiving channels. Due to the time
restrictions the tests cannot be as comprehensive as during qualification, but the tests guarantee the correct functionality of the modules. Every module has an identification number laser marked on its plastic cover and the test data is saved with this information. Therefore, it is possible to trace the results from the database for a given module.

3.3 Module qualification

The pre-series module qualification has the same four steps as the component qualification: functional, temperature, magnetic field, and irradiation testing. They ensure that the full assembly performs as specified. In order to investigate the reliability of the assembly additional temperature tests are carried out:

- Temperature cycling: 500 cycles, −40 to +85°C.
- High Temperature Storage: 2000h at +85°C.
3.3.1 Module qualification results

So far VTTx module qualification has been completed except for the full module irradiation. The overall yield was 100%: no failures were observed in any of the tests. The only issue was faced in the temperature tests when the modules were operated at a low temperature. Some modules did not produce good quality eye diagram and the dynamic performance did not meet the specifications when the default settings were used. This issue was easy to mitigate by just changing the setting values according to the environment the modules were operated in. However, this may not always be acceptable solution, and therefore the issue was investigated in detail. The results are explained in the next section.

VTTx performance did not degrade in temperature cycling or during the high temperature storage. As an example, measured modulation amplitudes during the cycling and storage tests are shows in figure 5. VTRx module qualification is still ongoing.

---

**Figure 5.** Modulation amplitudes during (a) temperature cycling and (b) high temperature storage. No failures nor significant degradation in performance were observed. Measured changes in the amplitude are due to laboratory temperature variations during the measurements.

3.3.2 GBLD bias current gain

Both bias and modulation current generated by a GBLD laser driver [4] can be controlled by changing its register settings. In ideal situation the currents generated by a GBLD are identical to the setting values, but this is not necessarily the case with the real devices. We call the ratio between the real current and the setting value current gain. An example of a GBLD with higher than 1 bias current gain is shown in figure 6.

A problem with the GBLD bias current gain was observed in the VTTx temperature tests. In some modules the laser operated close to or below threshold when the default settings were used. This could have been caused by either too large modulation current or too small bias current. Around 1500 GBLDs were manually tested and the bias and modulation current gain distributions showed clearly that the bias current gain causes the problem: the real generated bias current fluctuated around ±40% of the nominal setting.
This means that a significant portion of the modules will not operate according to the specifications at extreme temperatures with the default settings. Therefore all GBLD chips were re-tested and screened based on their bias current gain. Only Grade A are used for VTRx production, where transmitter operation at turn on must be guaranteed, and Grade B for VTTx production, figure 6. This GBLD grading ensures that no failures will occur in the VTXx series production due to insufficient bias current gain.

![Diagram of bias current gain](a)

![Distribution of GBLD bias current gain](b)

**Figure 6.** (a) Bias current gain is the ratio between the real generated bias current and the setting value. (b) Distribution of GBLD bias current gain and the limits used for the screening.

### 3.4 Lot acceptance

Modules are delivered to CERN monthly in lots of 1500 VTTx modules and 1000 VTRx modules. For lot acceptance, only the functional testing step of the module qualification procedure (visual inspection, LIV, EYE, OSA, BER) is carried out with a randomly selected set of 40 modules from each lot. So far, four VTTx lots have been received and tested, and no failures have been observed in lot acceptance.

### 4 Summary

The production of Versatile Link transceivers (VTRx and VTTx) has started in the spring of 2016. The optoelectronic components have been qualified by CERN and module pre-series have been built by the assembly house, which also carries out 100% production testing.

VTTx pre-series has passed the qualification tests at CERN, no failures in any of the module qualification tests, and the series production has been launched. The qualification of VTRx pre-series is being finalised. The problem with transmitter drive currents found in QA tests was caused by the performance variations in the GBLD laser driver chip. The problem was solved by re-testing and screening the GBLDs.

At the moment we are ramping up the production and solving practical issues in the assembly process to maximize the yield. The latest, fourth, VTTx production lot was assembled and tested.
at the assembly house with a yield of 98%. The production is expected to reach full capacity (1500 VTTx and 1000 VTRx modules per month) in Q4 2016.

References

[1] CMS collaboration, *The versatile link, a common project for super-LHC*, *2009 JINST* 4 P12003.

[2] C. Soos, L. Olantera and J. Troska, *VTRx Quality Assurance Programme*, https://edms.cern.ch/document/1551734 (2016), available upon request.

[3] J. Troska, Seif El Nasr-Storey, S. Detraz, L. Olanterä, P. Stejskal, C. Sigaud et al., *Laser and photodiode environmental evaluation for the Versatile Link project*, *2013 JINST* 8 C02053.

[4] G. Mazza et al., *The GBLD: a radiation tolerant laser driver for high energy physics applications*, *2013 JINST* 8 C01033.