

The Gigabit Optical Transmitters for the LHCb Calorimeters

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Abstract

This report presents the boards developed for the optical data transmission of the calorimeter system of the LHCb experiment and test results.

We developed two types of transmission boards: the single-channel and the multi-channel ones. Multi-channel boards can be equipped with a variable number of transmitters, depending on the need, with a maximum allowed of 12 channels. Each optical channel allows transmitting 32 bit data at 40.08 MHz.

The boards have been designed and built using radiation hard devices produced at CERN.

The optical links have been qualified using the eye diagram and the BERT at 1.6Gbps.

I. INTRODUCTION

The report describes the optical links developed for the data transmission of the LHCb calorimeter system. They are used to establish high speed (1.6Gbps) connections over long distances of about 100 m among the front-end electronics cards of the calorimeter system, the L0 trigger system and the DAQ boards.

The optical transmitters are built as mezzanines boards, i.e. as cards to be plugged to carrier-boards (to the CROC calorimeter boards, to the SPD control boards and to the validation cards). They get power, control signals and reference clock from the underlying carrier-boards. To plug the mezzanines boards to the carrier-boards we plan to use the high-speed connectors by Samtec.

To transmit 32 bits patterns at 40.08MHz through the optical fibers we use the GOL chip [2] (Gigabit Optical Link), radiation hard, produced by the CERN Microelectronic Group. The data transfer rate, running the transmitter at 40.08MHz, including header and parity bits, using the 8B/10B encoding mode, is of about 1.6 GHz per link.

The reference clock will be generated by the carrier-board and distributed to the GOL chips from a clock distributor. The jitter introduced by these devices is guaranteed to be less than 2ps RMS.

As optical transducer in the single-channel transmitter boards we use the VCSEL [3] (Vertical Cavity Surface Emitting Laser) laser diode (1mW at 6mA) by ULM

Photonics. It operates on multimode optical fibers at a wavelength of 850nm and is equipped with SMA type fibre connector.

In the multi-channel boards we use a parallel transmitter made by Agilent. The optical transducer is the SNAP12 standard compliant, equipped with the MPO/MTP ribbon fibre connector interface. It operates on multimode optical fibre at a wavelength of 850 nm.

The start up of the GOL is managed by means of the CRT4T power switches.

Special care has been spent in projecting the PCBs and in placing the bypass capacitors, in order to minimize the noise level and the bit error rate.

The report will describe the test performed on the prototypes to fully qualify the optical link. The link has been qualified using the eye diagram and the BERT. The results show that the BER is better than 10^{-13} as expected.

II. MEZZANINE SINGLE-CHANNEL

The block diagrams of the mezzanine boards are shown in the following figures.

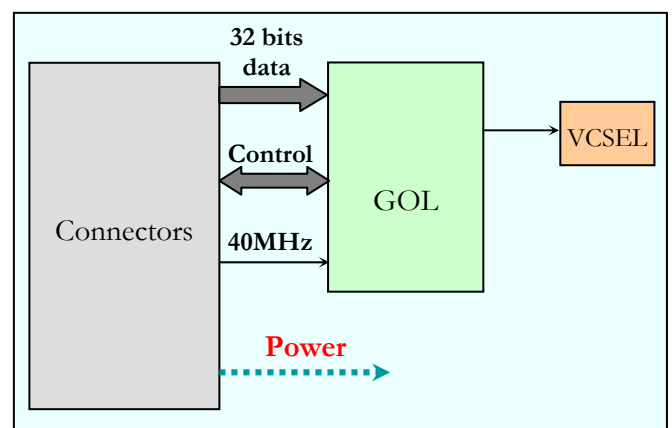


Figure 1: Block diagram of the single-channel mezzanine

In order to plug the single-channel mezzanine board to the carrier-board we plan to use the high-speed connectors by SAMTEC 0.635 mm Hi-Speed Header [5], two connectors, QTS-025-01-L-D-A, located in the bottom layer of the mezzanine board.

The height of the connectors determines the distance between the mezzanine and the carrier-board. The distance in this case is of 5 mm.

To transmit 32 bits patterns at 40.08MHz through the optical fibers we will use the GOL chip (Gigabit Optical Link), produced by the CERN Microelectronic Group. The data transfer rate, running the transmitter at 40.08 MHz, including header and parity bits, using the 8B/10B encoding mode, is of about 1.6 GHz per link.

Optical transducer of the single-channel mezzanine boards we plan to use the VCSEL (Vertical Cavity Surface Emitting Laser) laser diode ULM850-05-TN-USMBOP (1mW at 6mA and 3.3 V anode biasing), made by the ULM Photonics. The VCSEL laser diode will operate on multimode optical fibers at a wavelength of 850nm. It will be equipped with the SMA type fiber connector.



Figure 2: Picture of single-channel mezzanine

III. MEZZANINE MULTI-CHANNEL

The block diagrams of the mezzanine boards are shown in the following figures.

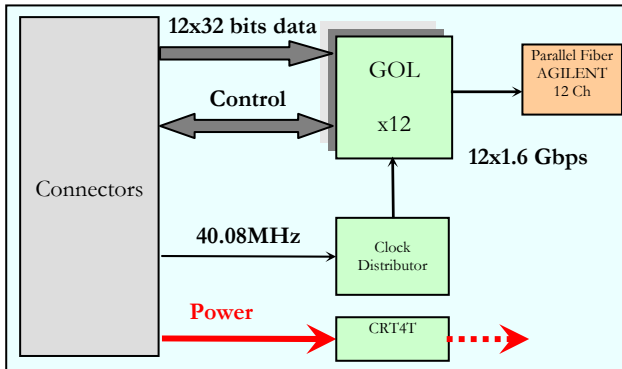


Figure 3: Block diagram of the multi-channel mezzanine

To plug the multi-channel mezzanine board to the carrier-boards we plan to use the high-speed connectors by SAMTEC 0.635 mm Hi-Speed Header, two connectors, QTS-125-03-L-D-A, located in the bottom layer of the mezzanine board.

The distance between the multi-channel mezzanine and the carrier-board in this case is 11 mm.

To transmit 32 bits patterns at 40MHz through the optical fibers we will use the GOL chip (Gigabit Optical Link).

The reference clock will be generated by the carrier-board and distributed to the GOL chips through the connectors without any clock filter. In order to distribute the clock to the GOL chips in the multi-channel case we will use a clock distributor. As a clock distributor we plan to use a 1:20 differential PECL clock driver, made by On Semiconductor,

model type NB100LVEP221FA. The jitter introduced by this device is guaranteed to be less than 2ps RMS.

The quality of the clock used to drive the GOL is a critical parameter.

The GOL maximum tolerable jitter value is 100 ps (peak-to-peak).

The clock signal from the LHC TTC (Timing Trigger and Control) system to the GOL is distributed to the Optical Transmitter board from the Carrier Board through the connector clock pin and then distributed by the NB100LVEP221FA.

The quality of the clock measured at the GOL clock pin after having passed through the entire distribution chain shows rather a good σ value of about 7 ps.

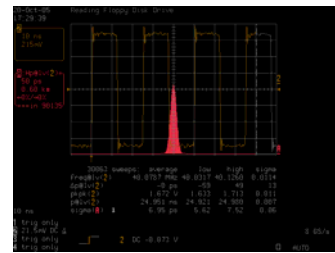


Figure 4: The quality of the jitter at the pin clock of the GOL improves $\sigma = 6.95$ ps

As optical transducers of the multi-channel mezzanine boards we will use a parallel fibre optical link transmitter, made by Agilent. The optical transducer model type is the HFBR 772BH [4], SNAP12 standard compliant. It will be equipped with the MPO/MTP ribbon fibre connector interface. It will operate on multimode optical fibre at a wavelength of 850 nm.

To implement the GOL power switch, two PMOS devices are used in parallel in order to reduce the “on” resistance of the switch (this reduces the voltage drop across the switch). An NMOS device is additionally used to short the GOL power to ground when the power switch is open. This device guarantees that the GOL power supply rail is pulled to ground even in the presence of active inputs [2].

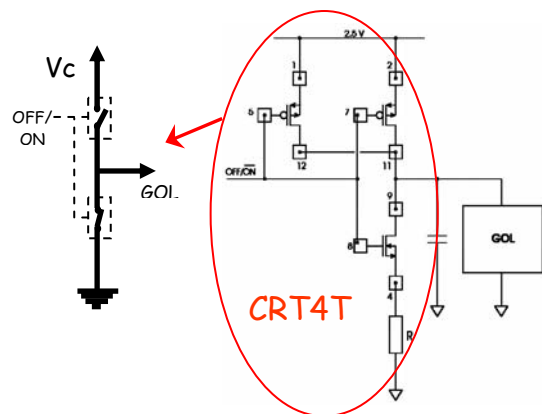


Figure 5: Using the CRT4T as a power supply switch for the GOL

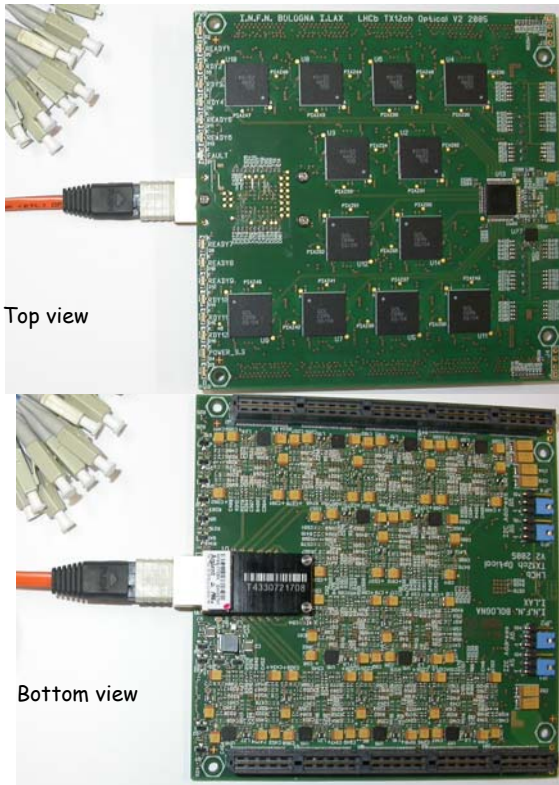


Figure 6: Picture of multi-channel mezzanine

IV. MEASUREMENTS

To qualify the optical transmitters [7] we have tested the main functionalities of the boards: synchronization capabilities of each optical channels, level of the bit error rate while operating in normal conditions, reset capabilities in case of error; we evaluated the effects of the optical pulse attenuation on the quality of the transmission channel by measuring the corresponding bit error rate in data transmission. We also studied the electrical behaviour of the mezzanine boards in a range from ambient to maximum operating temperature.

The setup used for testing purposes is shown in the block diagram.

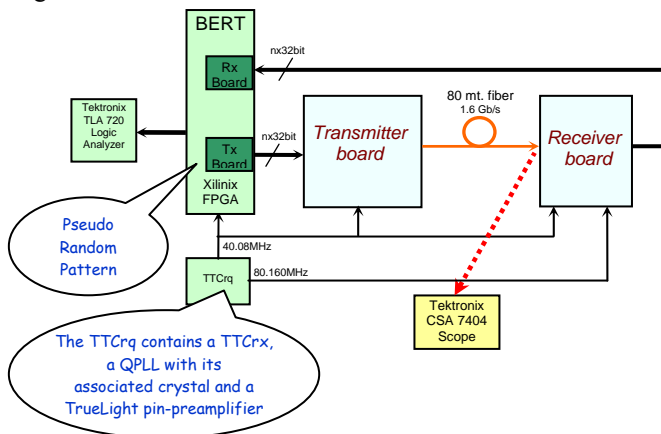


Figure 7: Comparison between transmitted and received patterns

$$BER = \frac{\text{bits_received_in_error}}{\text{total_bits_received}}$$

Table 1: BER vs. Time

BER	n(bits)	Time
10^{-12}	$2.3 \cdot 10^{12}$	30 min
10^{-13}	$2.3 \cdot 10^{13}$	5 h
10^{-14}	$2.3 \cdot 10^{14}$	50 h

To reach a sensitivity of 10^{-12} in measuring the transmission error probability with this technique, when no error is detected during the entire data transmission, aiming a confidence level of 90%, lasts about 30 minutes.

The “Q” value has been measured with the digital scope embedded software (see figure 8), specifically developed by Tektronix for eye-diagram analysis.

An approximation of the effective Bit Error Rate (BER) can be obtained as follows:

$$BER = \frac{1}{2} \operatorname{erfc} \left(\frac{\sqrt{SNR}}{\sqrt{2}} \right) \approx \frac{e^{-\frac{Q^2}{2}}}{\sqrt{(2 \cdot \pi) \cdot Q}}$$

This formula returns estimated values better than 10^{-13} .

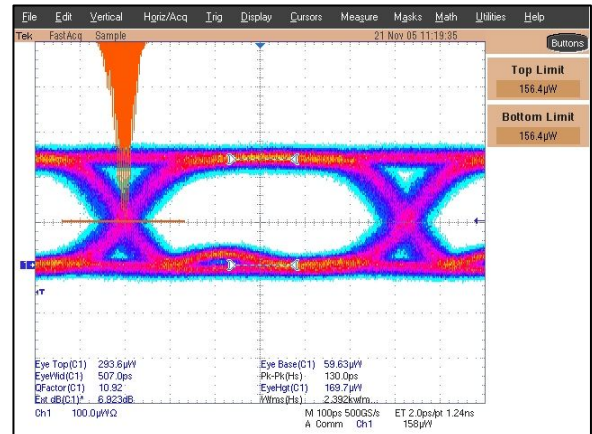


Figure 8: Eye diagram measured with the Tektronix CSA7404 digital scope

Attenuation of the light pulses has been varied to establish the range within the transmission is errors free. Data shall go through 100m long cables and two optical patch panels.

Table 2: BER vs. Optical Attenuation

Attenuation (dB)	Eye Top (µW)	Time (hours)	Errors (C.L. 95 %)
0	462,8	24	$<10^{-13}$
3	232	24	$<10^{-13}$
6	114,5	120	$<10^{-14}$
9	57,6	24	$<10^{-13}$
12	27,34	24	$<10^{-13}$
14	18,29	24	Errors Observed

The optical attenuator used in our test is the Amphenol AFO 46946. It is an adjustable attenuator without pre-definite steps. The attenuation level can be varied by rotating a milled ring.



Figure 9: Optical Attenuator, Amphenol AFO 46946

V. CONCLUSION

The power consumption of the single-channel mezzanine is of about 150mA at 2.5V while is of about 8.9mA at 3.3V.

The power consumption of the multi-channel mezzanine has been measured to be of 150mA per channel at 2.5V and 1.07A at 3.3V due to the laser and to the clock distributor power consumptions.

We heated the boards up to 60°C to test their behaviour. We didn't observe any transmission problems on runs lasting several hours.

The I2C bus and the JTAG bus of the mezzanine has been connected to Credit Card PC through the LHCb Glue-Card bus converter named the Glue Card. Thanks to a dedicated control program, running on the Credit Card PC, one can set and control the status of each GOL of the boards.

VI. REFERENCES

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