The 120Gbps VCSEL array based optical transmitter (ATx) development for the High-Luminosity LHC (HL-LHC) experiments

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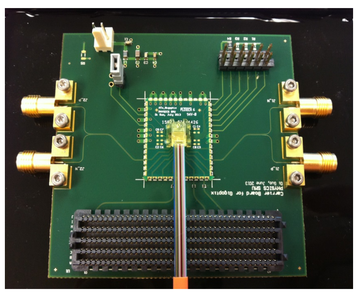
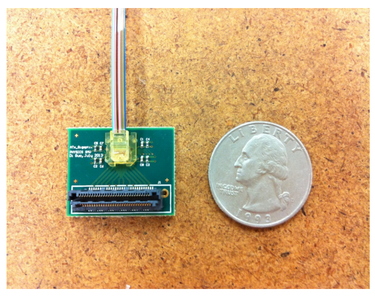
Abstract

The integration of VCSEL array and driving ASICs in a custom optical transmitter module (ATx) for operation in the detector front-end is demonstrated.

The ATx provides 12 parallel channels with each channel operating at 10 Gbps. The first demonstrator comprises an FR4 substrate with high-density wiring for electrical interface, OE components, and a micro-lens array mating with 90 optical turn structure for fiber ribbon interface.

10 Gbps optical eye diagram passes the transmitter mask test, and BER better than 1E-12 transmission with parallel receiver is achieved. Commercial driver is currently used in the demonstrator and will be replaced by a radiation tolerant driver.

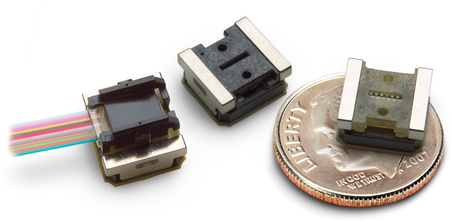




Introduction

The development of high-speed, low power, radiation-tolerant optical data links is critical for the LHC upgrade and other collider detector developments. A general trend is to leverage the rapid advancement in commercial optical transceivers, qualify a suitable form factor, maintain the optical/electrical interfaces and fabrication/assembly platform, and customize the components and materials to ensure radiation tolerance.

VCSEL-based technology has been widely adopted by short-range data transmission links and parallel modules. Utilizing an array of VCSELs has also been commercialized, such as Micro Pod and QSFP transceivers. The first Atx prototype adopts the POD packaging approach with collimating optics, ribbon terminals and FR4/ceramic ASIC carriers. The integrated modules offer pluggable or low temperature re-flow options.

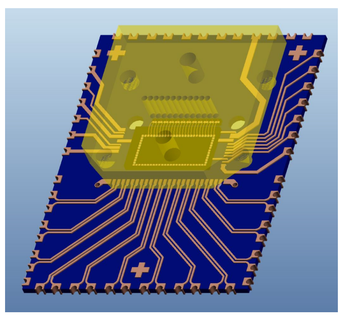


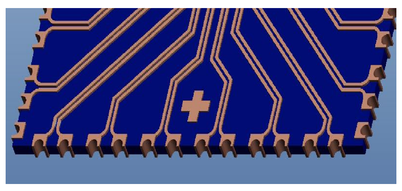
ATx Designs: Electrical Interface

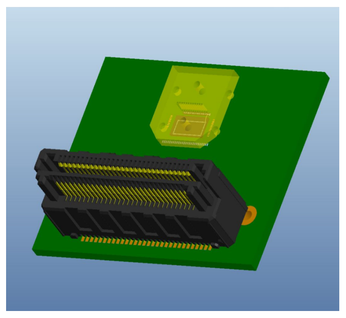
We have designed two different electrical interfaces for the module to provide 12 pairs of high speed differential signals, IOs and power sources: EdgeWrap for solder/reflow and dense high speed connector for pluggable.

EdgeWrap version has a size of 1.9 cm x 2.2 cm with an 0.7 mm half via.

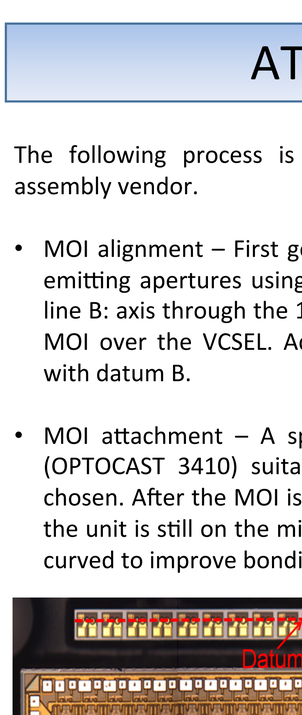
Connector version has a size of 2.5 cm x 2 cm implemented with SamTec LSHM 60 pins connector.







ATx Designs: Electrical Interface



0.98 cm x 1.30 cm

Another electrical interface variation uses a ceramic thick film as IC-OE substrate to form the transmitter module.

The ceramic substrate serves as a good heat spreader for stable laser operation.

Low thermal coefficients of linear expansion of ceramic and optical connector resin, are also beneficial to the reliability of the modules.

The ceramic assembly provides a high-reliability for the optoelectronics and a more flat surface for the subsequent MOI assembly.

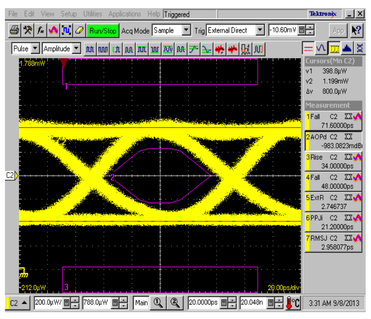
The ceramic substrate also offers the advantage of accommodating small linewidth and spacing to perform the layout of 12 pairs high speed differential lines in a more compact area.

Test Results

Eye diagrams of two channels on separate ends (ch2 & ch11) are captured by an oscilloscope. Both channels showed widely-opened eyes for the 10Gbps PRBS-7 pattern.

At modulation current of 6.7 mA, the obtained OMA is 800 µW, which result in a coupling loss of less than 5.5 dB.

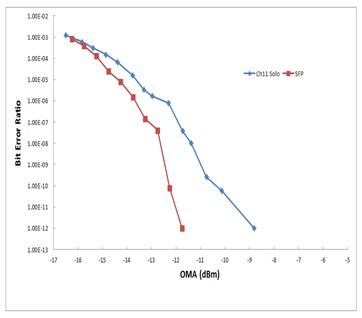
ATx optical output, 10G PRBS



The sensitivities of Atx_ch11, at a BER = 1E-12 and at 10 Gbps are compared to that of a single SFP+ Tx, showing a system penalty of less than 3 dB.

The cross talk from optical coupling has proved to be very small.

ATx to SFP+_Rx, 10G PRBS

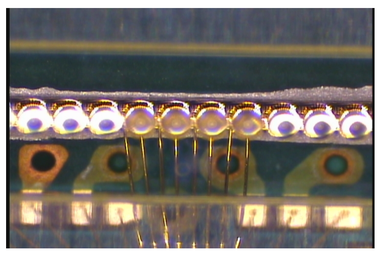


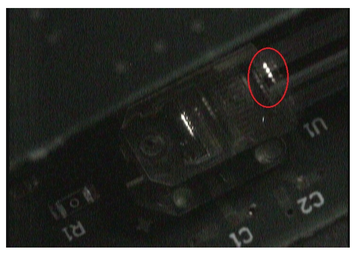
Test Results

Precise alignment between micro-lens (MOI) and VCSEL is challenging and critical for the efficient optical coupling.

Misalignment was found from one module, where curing shift is the possible cause. Poor coupling into the Prizm fiber was found on another, where VCSEL tilt is the possible cause.

Both misalignment modes can be eliminated by tight process control.

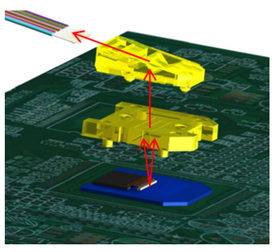




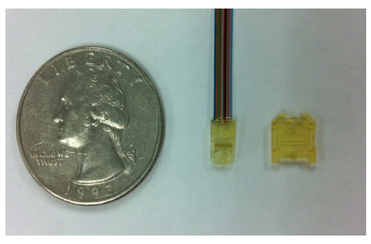
ATx Designs: Optical Interface

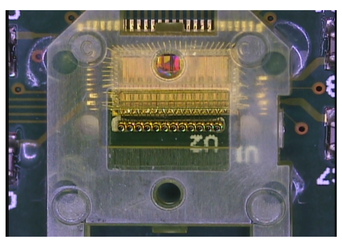
Outputs of the VCSEL are collimated by micro-lens (MOI) and deflected by 90 degree using Prizm connector, both of which are COTs.

MOI is first aligned to the VCSEL and permanently attached to the substrate allowing for passive alignment of Prizm connector.



The 2 parts collimating and deflection design greatly relaxed alignment tolerances and sufficient coupling efficiency is provided. The relaxed tolerances can provide greater compatibility with typical board-level package manufacturing tooling.

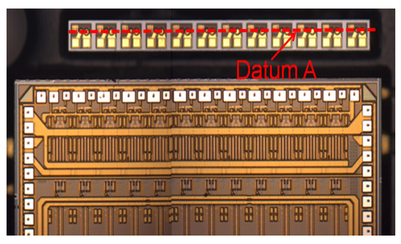


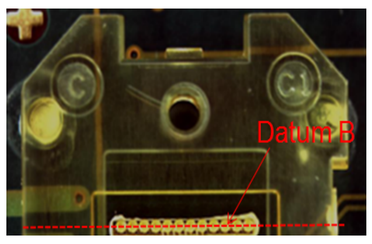


ATx Assembly

The following process is our present choice after discussing with assembly vendor.

- MOI alignment – First get datum line A: axis through 12 VCSEL light emitting apertures using microscope reticles. Second get the datum line B: axis through the 12 center points of MOI lens after placing the MOI over the VCSEL. Adjust the MOI to make datum A coincident with datum B.
- MOI attachment – A specific UV light and/or heat curable epoxy (OPTOCAST 3410) suitable for opto-electronic assembly has been chosen. After the MOI is aligned, perform a short time UV cure while the unit is still on the microscope. Then the whole module is thermal curved to improve bonding strength.





System Consideration

The ATx is designed to work with commercial parallel receivers at the back-end, which comply with 100GBASE-SR10 specifications.

SR10 links require both jitter budgeting ad power budgeting --- 9.3 dB power budget with allocation for jitter reduction seems adequate.

For the ATx transmission to stretch from 100~150meter over OM3/OM4 fibers, link penalty will increase by another 1dB. Link budget is to be supported by increased optical power at the transmitter -- efficient optical coupling is the key.

Tx over Rx	9.30	dB
Attenuation	0.40	dB
Insertion Loss	1.50	dB
ISI	2.80	dB
MPN, MN	0.70	dB
Jitter allocation	3.90	dB
Link margin	0.00	dB

Future Work

- The complete module with ASIC shielded is to be irradiated under X-ray with total dose over 10Mrad.
- The electrical cross talk of the commercial driver used in the module will be further evaluated.

Summary

We report here on the design and fabrication of a parallel optical transmitter with twelve transmitters for a 120 Gbps aggregate data rate. The first prototype demonstrates 10Gbps eye diagram and >1E-12 BER transmission.

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