Design and operation of radiation hard 65 nm drivers for Silicon Photonics based optical links

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Introduction

The increase of power in future accelerators for High Energy Physics experiments creates new harsh challenges for the front-end electronics in terms of data rates and radiation tolerance. The next upgrade of the CERN's LHC requires from 5 Gbps to 10 Gbps high-speed links, and a Total Ionizing Dose (TID) of about 1 Grad in the inner layers of the Silicon Trackers. The currently high-speed optical links are based on VCSEL, which have been qualified for lower TID. One of the most promising technologies currently investigated to face higher radiation levels is based on Silicon Photonics optical modulators. In particular, two devices are the target optical modulators for the next upgrade: Mach Zehnder Modulators (MZM) and Ring Resonators (RR)

Design & Implementation

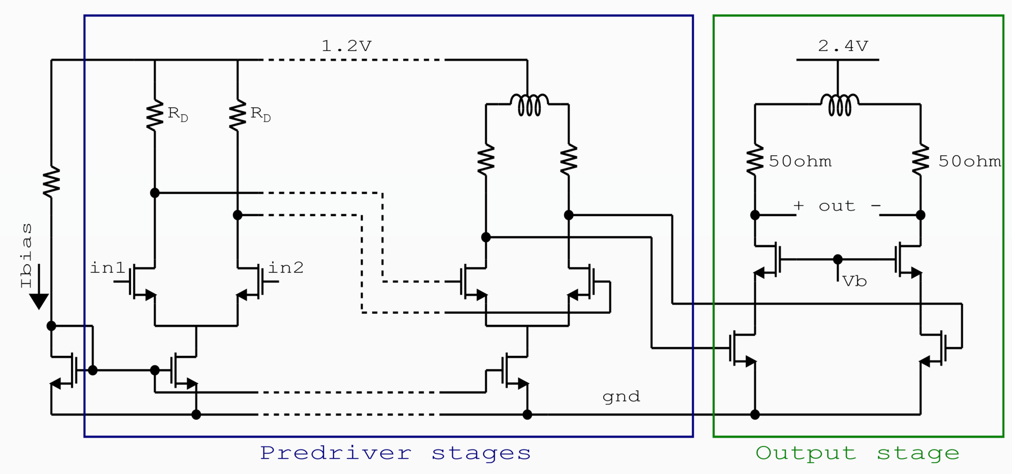
Requirements

- High-speed data rate up to 5 Gbps
- High-voltage swing of the driving signals:
    - Mach Zehnder Modulator: 2 Vp-p differential signal
    - Ring Resonator: 1.5 Vp-p differential signal
- Radiation tolerant up to 800 Mrad TID

Radiation Effects and RHBD Techniques

The high TID levels heavily affect the performances of P and N transistors. The current loss of a core transistors, connected as a diode, in the target 65 nm technology is -43% and -77% at 800 Mrad, for minimum length N-mosfets and P-mosfets respectively.
Therefore, for the design of the drivers three Radiation Hardening By Design (RHBD) techniques have been adopted:

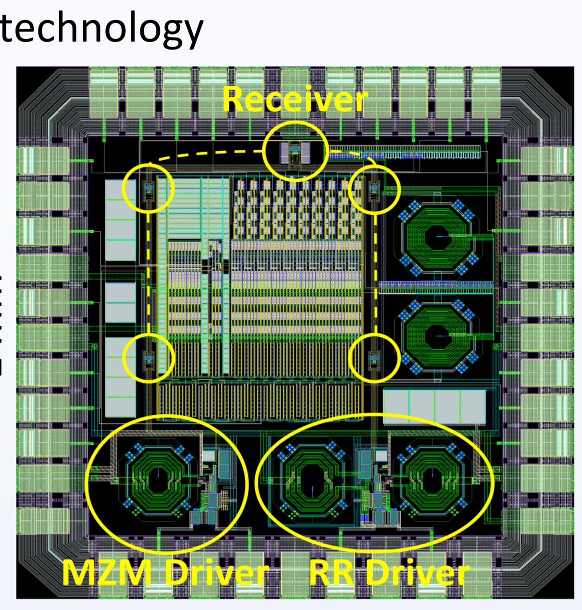
- The P-mosfets are avoided in all chip design for their performances losses.
- Only ELT (Enclosed Layout Transistors) mosfets, are used to face the effects of charge trapped in STI (Shallow Trench Insulation).
- The minimum mosfets length used in the design is 120 nm. This value is obtained by a trade-off between the maximum speed achievable by the drivers and the TID effects.



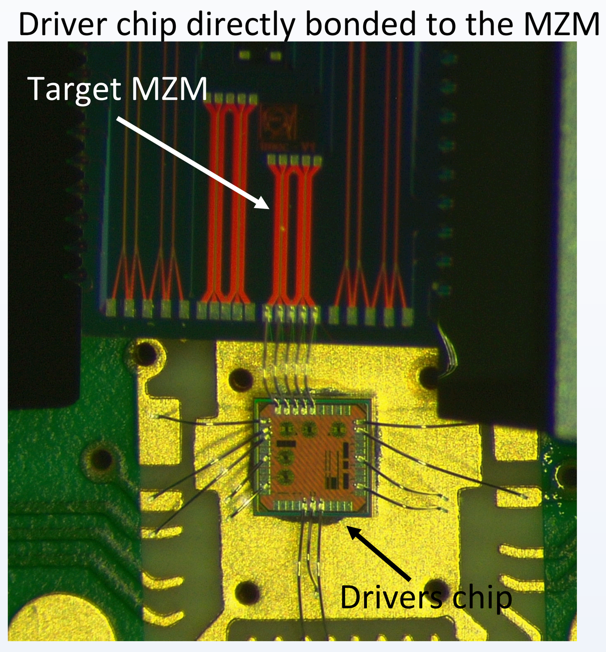
Design

The core mosfets used in the whole chip are able to sustain only 1.2 V, therefore the generation of the required driving voltage is managed using a cascode architecture and a 2.4 V supply voltage in the last stage. The two drivers have the same configuration but different output stages. The RR-driver has a 50 Ω internal termination connected to power supply plus a 800 pH series inductor for bandwidth extension. The MZM-driver uses an open drain configuration.
The output stage is sized with wide mosfets width to face high-TID so a predriver is used to drive it. The predriver is a cascade of CML (Current Mode Logic) stages with increasing size. Moreover, an inductive peaking technique is used in the last predriver stage to increase the driver bandwidth.

In the test chip only a distributed receiver is used to reduce the number of pads required by the input signals.
The 1 mm x 1 mm chip is fabricated in 65 nm TSMC technology



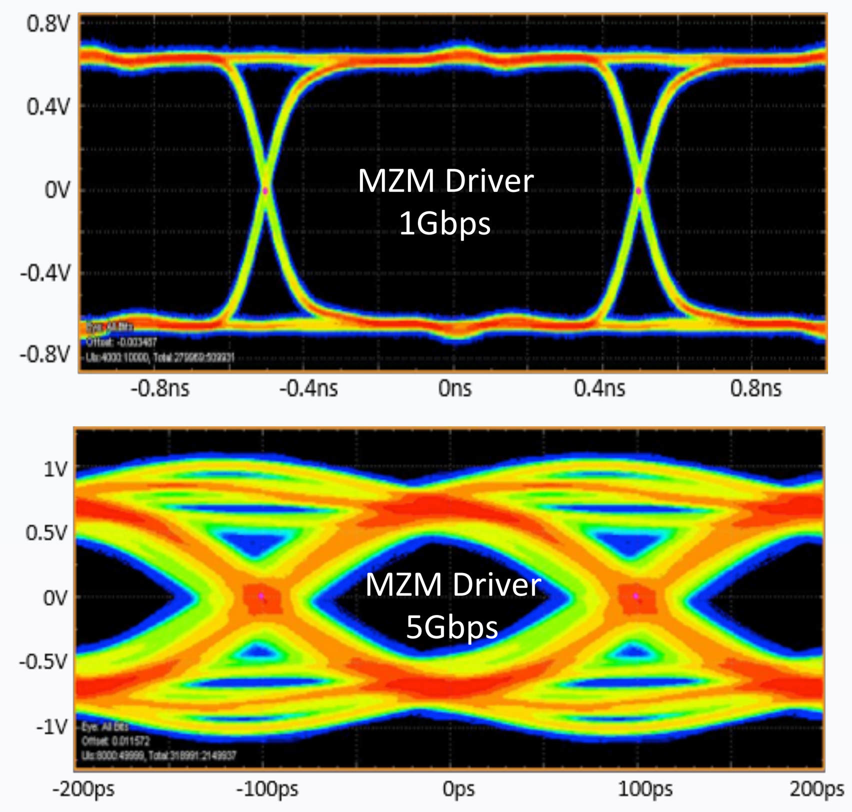
Driver chip directly bonded to the MZM

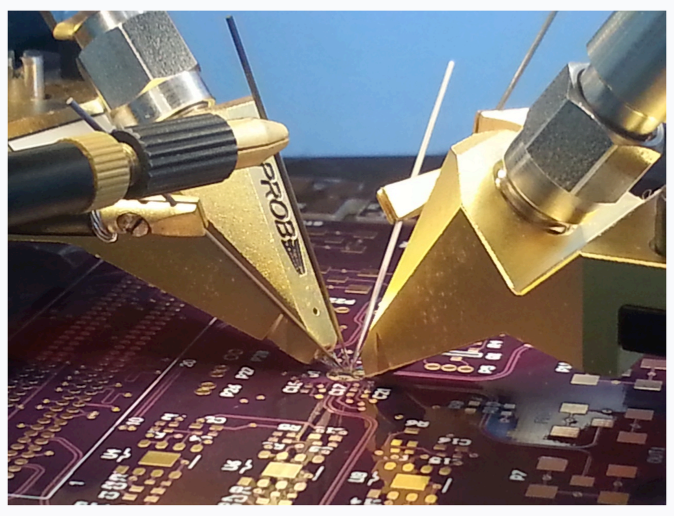


Measurement Results

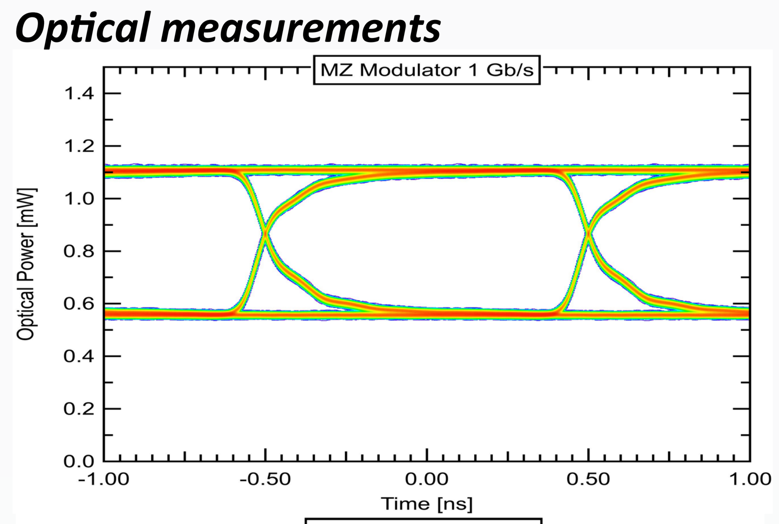
Electrical and optical measurements of the system are done in typical and irradiated conditions for the drivers characterization. We used a MZM and RR fabricated by IMEC under CERN's design in ISIPP25G technology.

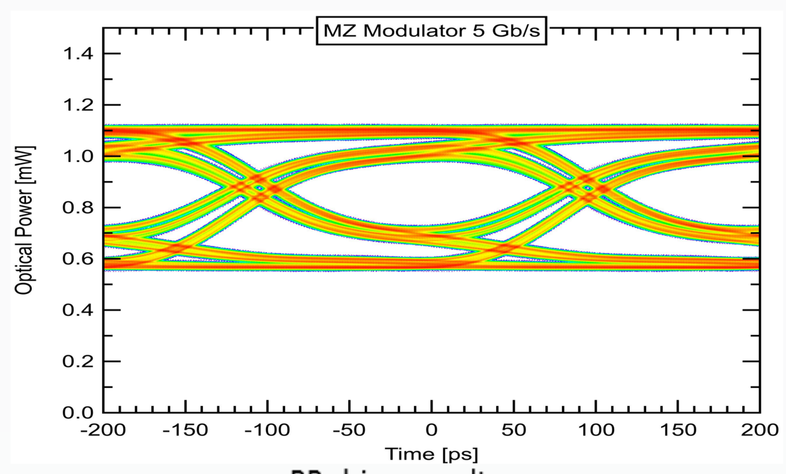
Electrical measurements

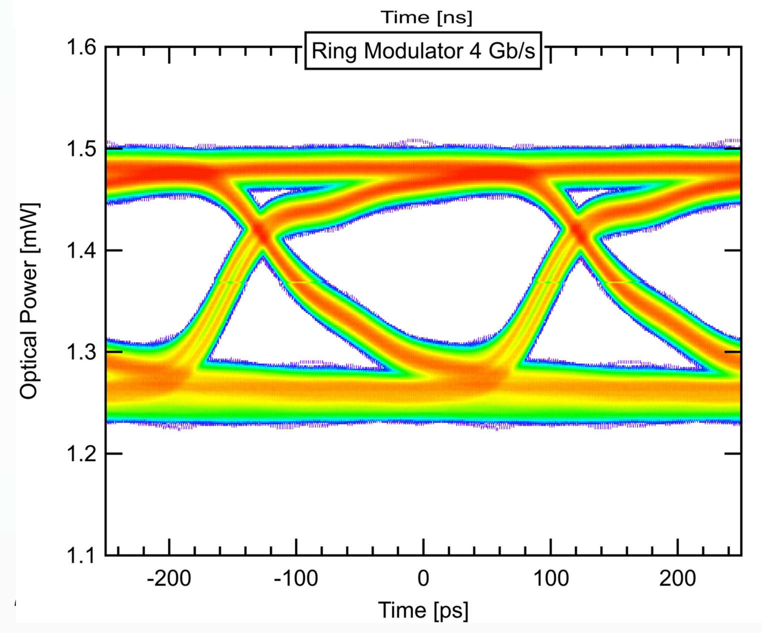


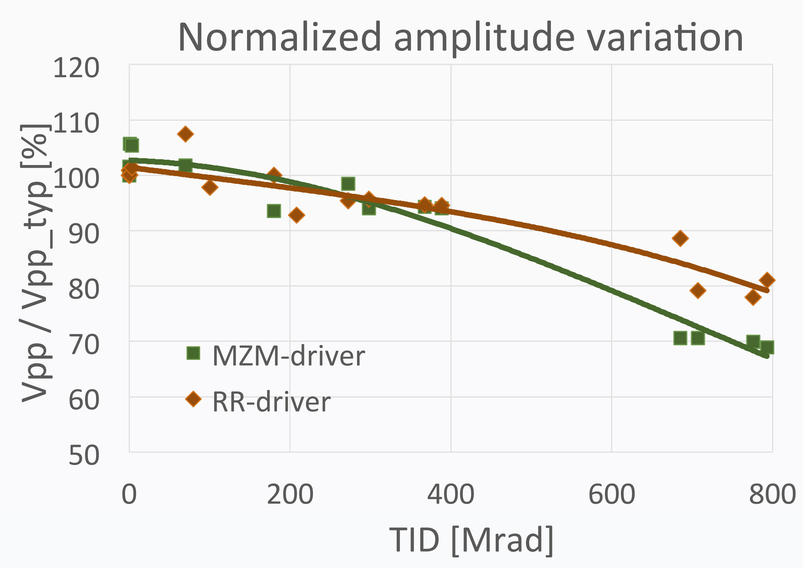


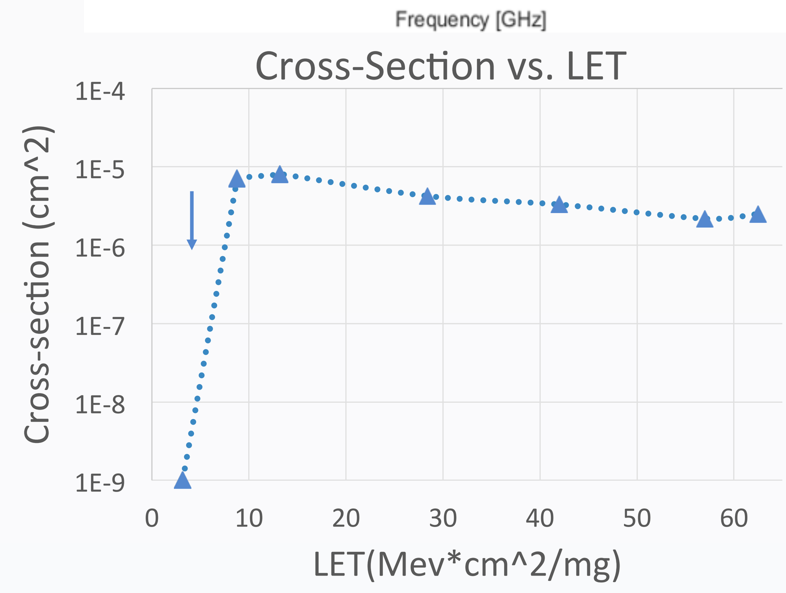
Optical measurements











Conclusions

The measurements performed on the two drivers verify the results predicted by simulations. The measurement results at 5 Gbps show a differential signal amplitude of about 2.75 Vp-p for the MZM-driver and 2.08 V for the RR-driver. Those values allow the MZM and RR to operate adequately also considering an amplitude reduction of 30% for MZM-driver and 25% for RR-driver at 800 Mrad.

References:
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[2] S. Saponara, G. Magazzù, G. Ciarpi: "A high-speed driver for silicon photonics Mach-Zehnder modulator for high data-rate transfer of particle collision images in high-energy physics and in medical physics", SPIE Real-Time Image and Video Processing 2018, May 2018.
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