

High-Speed/Radiation-Hard Optical Engine for HL-LHC

K.K. Gan, H. Kagan, R. Kass, J. Moore, D.S. Smith
The Ohio State University

P. Buchholz, S. Heidbrink, M. Vogt, M. Ziolkowski
Universität Siegen

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Outline



- Introduction
- Results from 1st Prototype ASIC
- Results from 2nd Prototype ASIC
- Summary



Use of VCSEL Arrays in HEP



- Widely used in off-detector (no radiation) data transmission
- First on-detector implementation is in pixel detector of ATLAS
 - ◆ experience has been positive
 - ⇒ use arrays for the second generation opto-links
 - ⇒ logical for HL-LHC ATLAS pixel detector to use 12-channel arrays as in the 1st and 2nd generation optical modules (opto-boards)



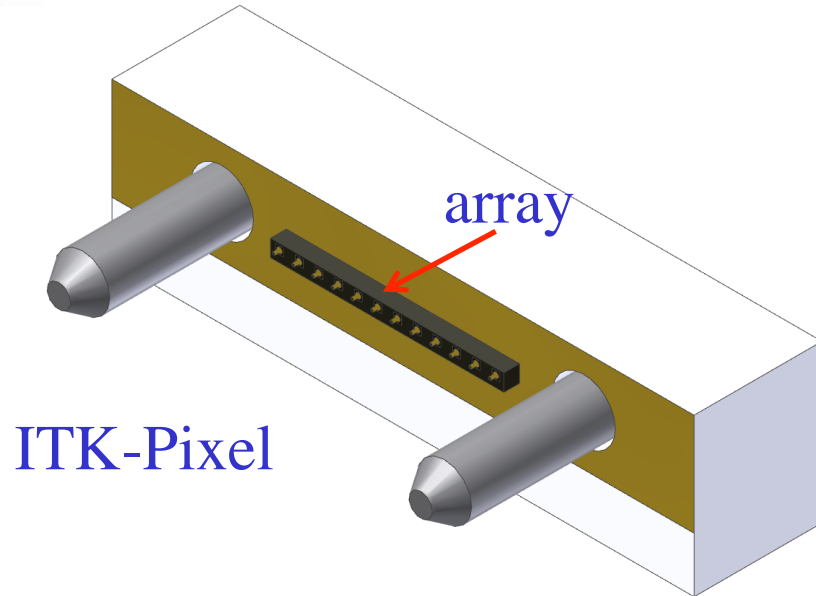
Opto-Board for HL-LHC ATLAS Pixel Detector



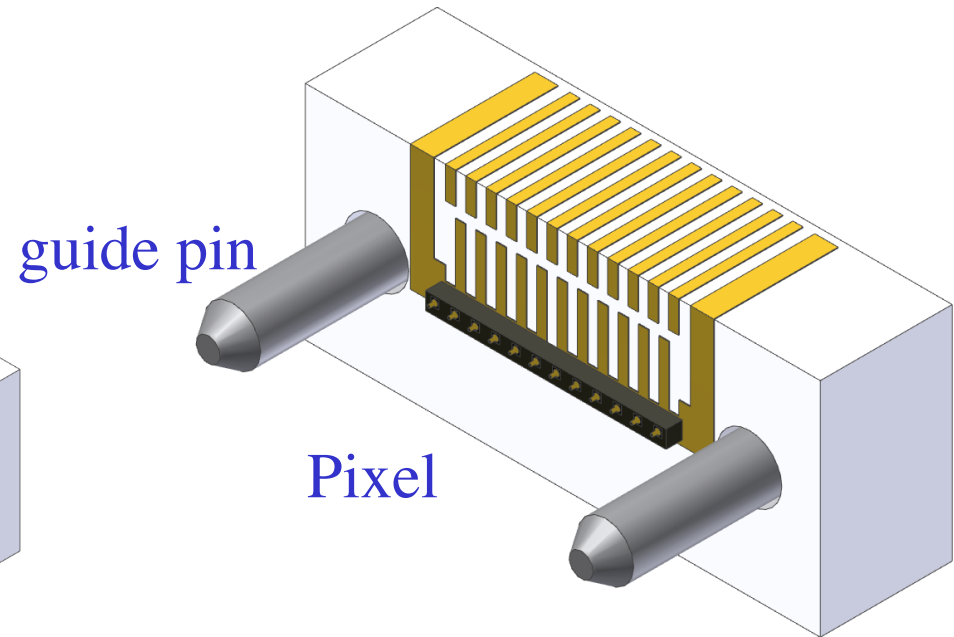
- Use experience from building two generations of opto-boards to develop an opto-board capable of operation at 5 Gb/s or higher for HL-LHC ATLAS pixel detector (ITK-Pixel)
- What is required to demonstrate that the opto-board concept is a logical solution?
 - 5 Gb/s per channel VCSEL arrays
 - radiation-hard VCSEL array driver
 - robust high speed array based packaging with thermal management
- A working prototype has been constructed



Opto-Pack for ITK-Pixel



ITK-Pixel



Pixel

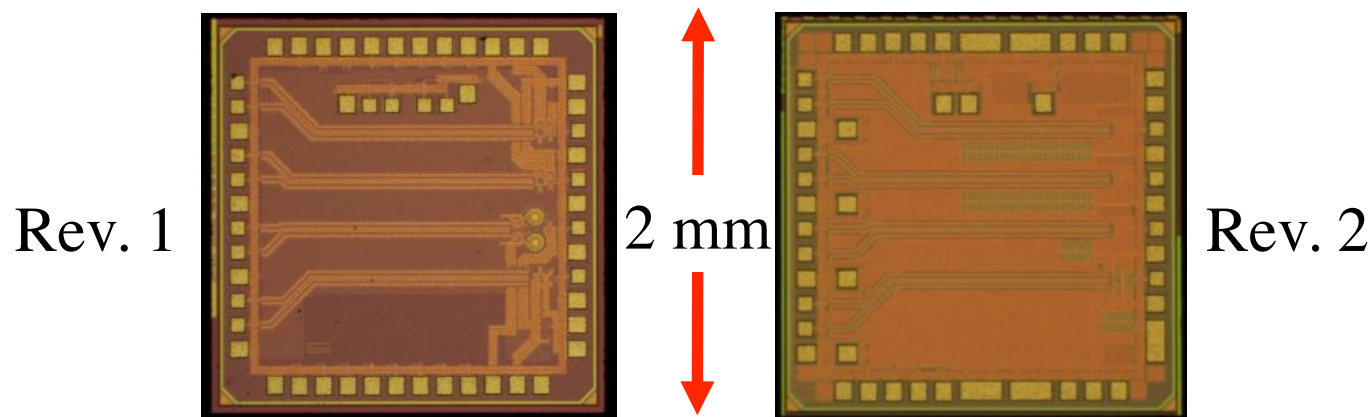
- Proposed opto-pack for ITK-Pixel has simpler design
 - ◆ continue to use BeO as substrate for heat management
- experience in building large quantity of opto-packs
 - ◆ fabricated 1,200 opto-packs for pixel opto-boards
 - ◆ fabricating 300 PIN opto-packs for off-detector opto-receivers
 - ◆ equivalent to 18,000 channels



10 Gb/s VCSEL Array Driver



- R&D funded via CDRD program (FY13-15) of DOE (USA)
- Fabricated 4-channel test chips in 65 nm CMOS
 - ◆ 2 mm x 2 mm
 - ◆ 1st prototype submission: October 2014
 - ◆ 2nd prototype submission: March 2016
- Uses only core transistors to achieve maximum radiation-hardness
- 8-bit DACs to set the VCSEL modulation and bias currents
 - ◆ DAC settings stored in SEU tolerant registers

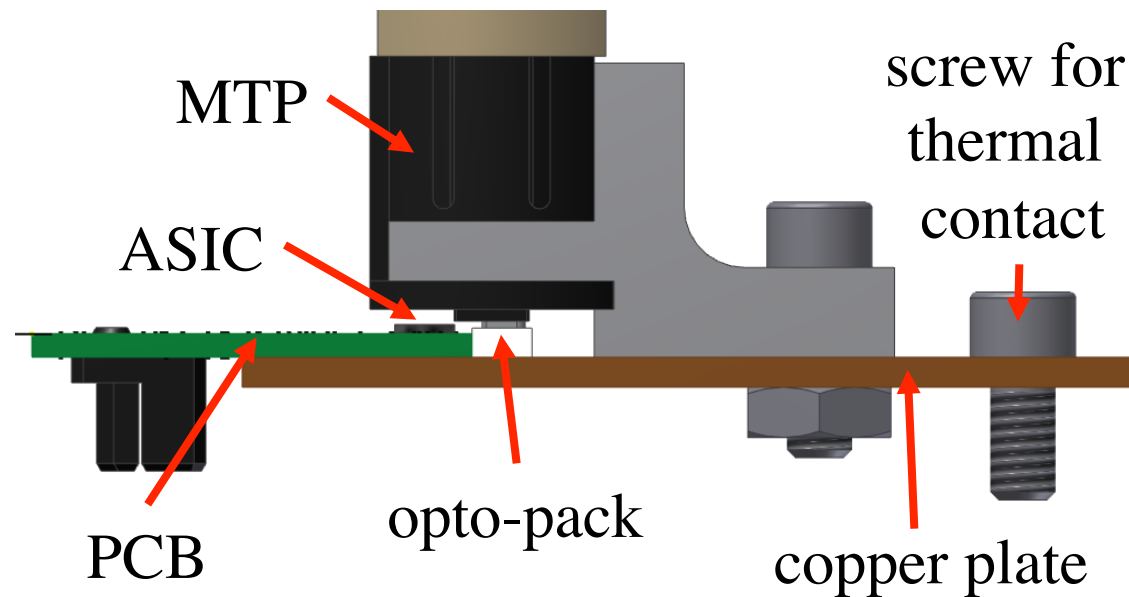




ITK-Pixel Opto-Board Concept



- Keep opto-pack
- Keep copper backed PCB
- Keep MTP connector
- Compatible with an opto-box (opto crate) concept
- No lenses/mirrors used to turn the light

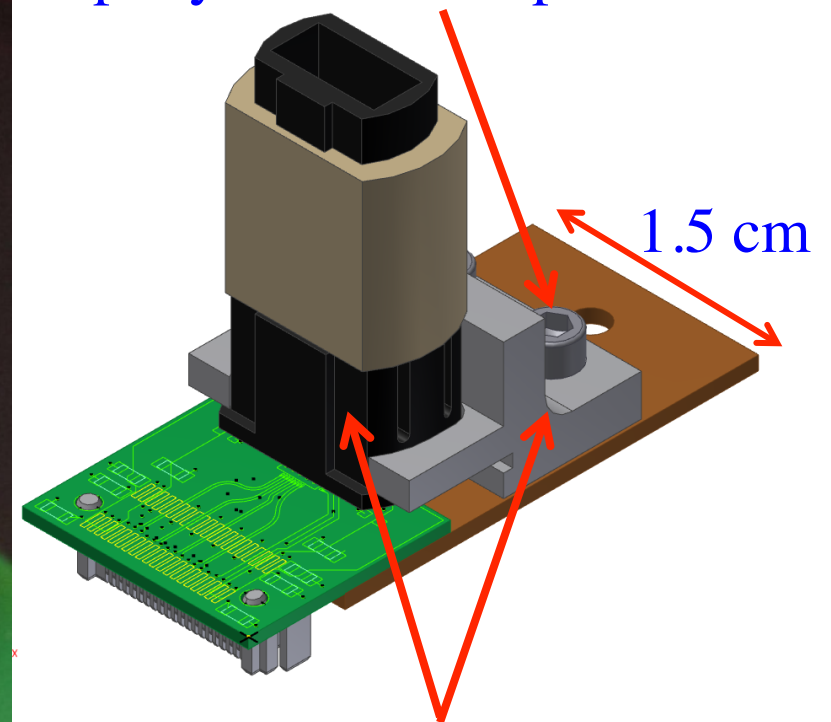
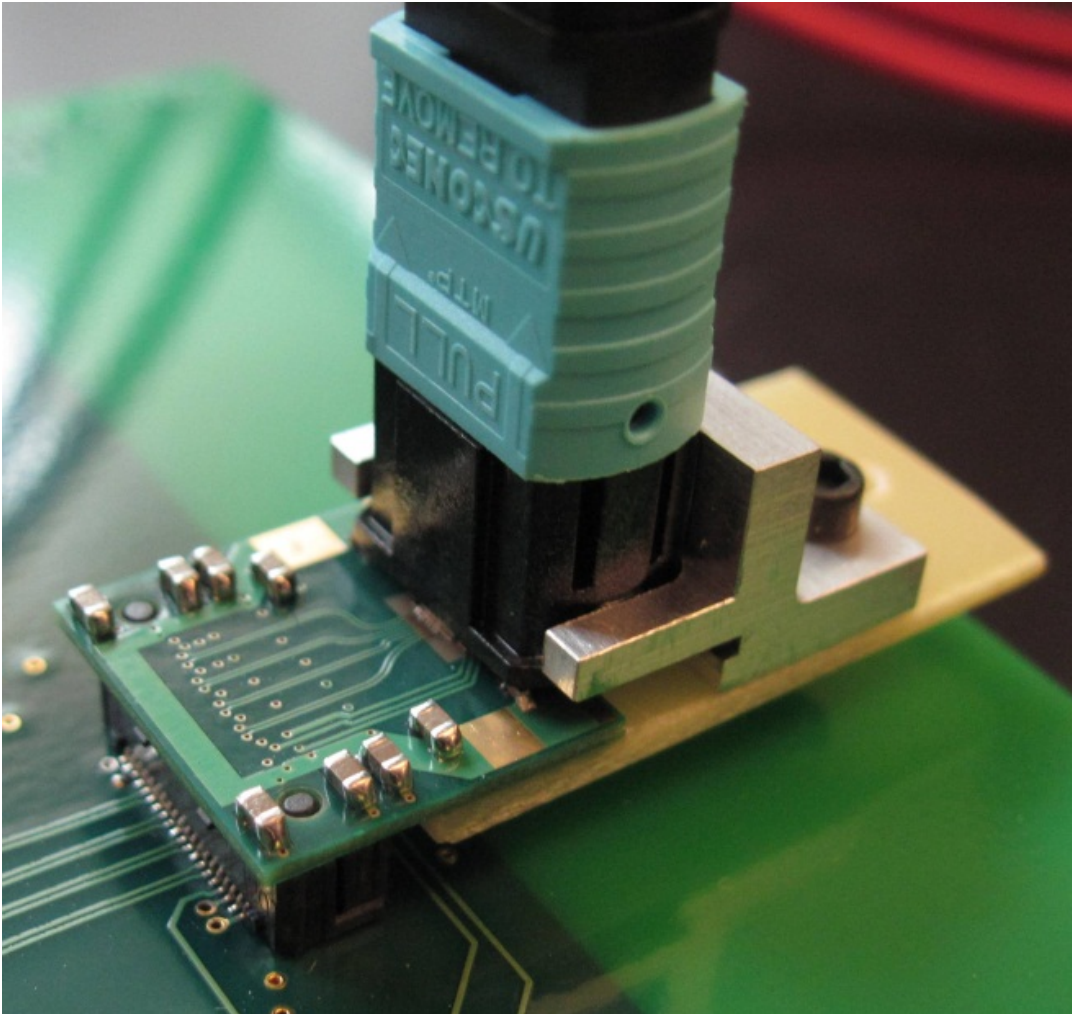




ITK-Pixel Opto-Board



Connector secured to opto-board with screws instead of epoxy in current opto-board



Could be fabricated as one piece with mold injection



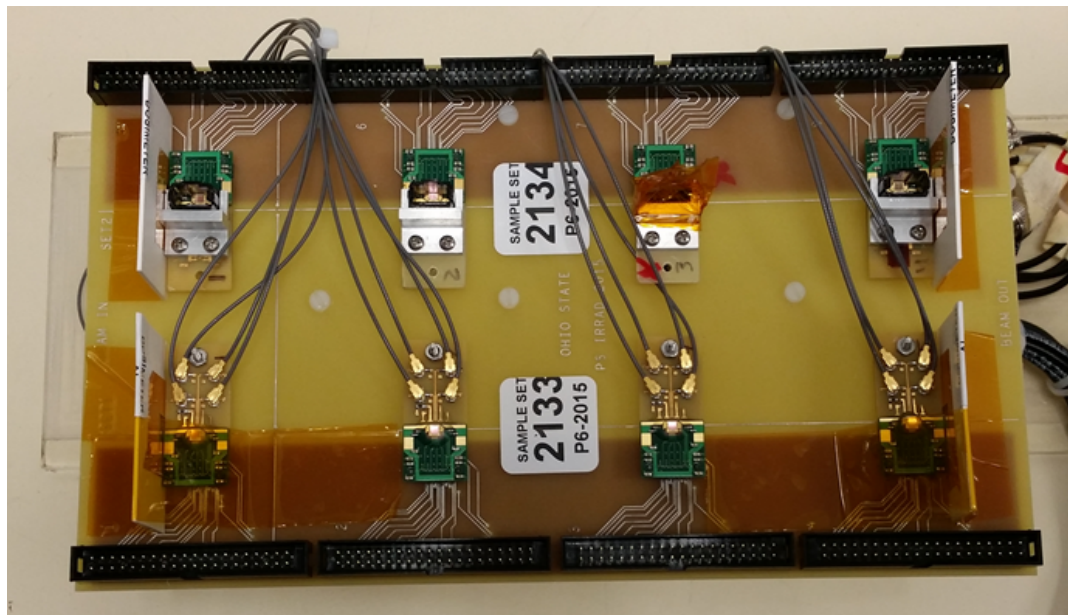
New Opto-Board Irradiation



- October 2015: irradiated 8 opto-boards with Rev. 1 array driver using 24 GeV protons at the CERN PS Irradiation facility
- 4 pcs. optical: driving Finisar VCSEL arrays (V850-2174-002)
 - ◆ dose: 13 Mrad
- 4 pcs. electrical: driving resistive load
 - ◆ dose: 111 Mrad

optical

electrical

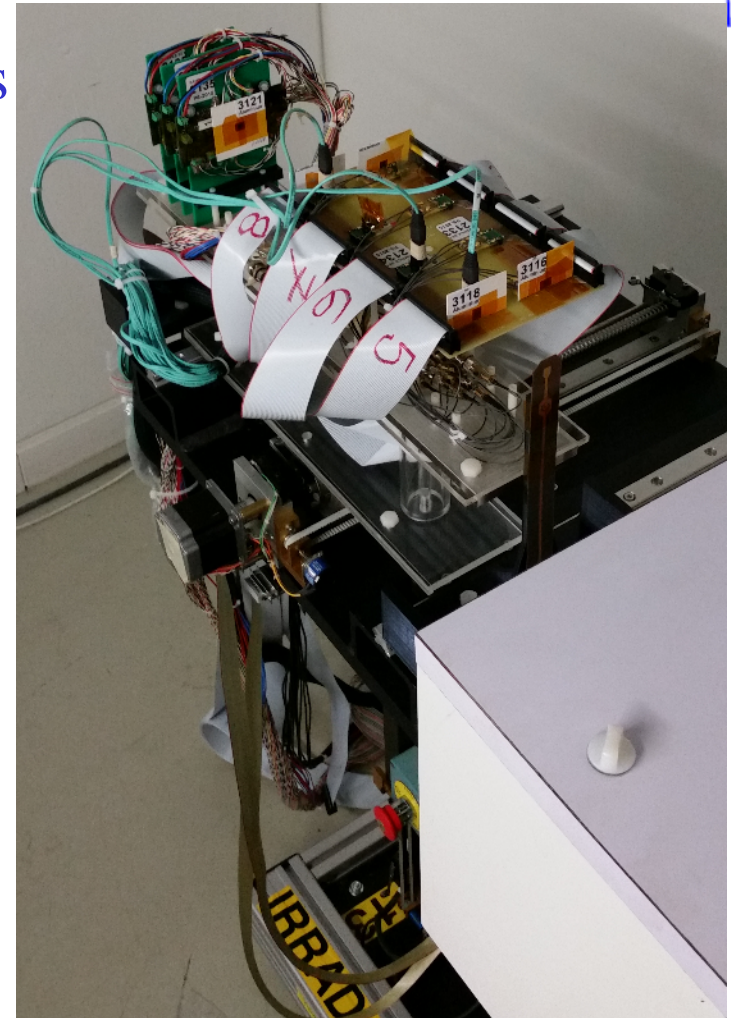




New Opto-Board Irradiation



- Chips were powered and monitored during the irradiation at reduced speeds due to the irradiation facility cabling infrastructure
- All channels survived the irradiation and the cooled down chips have been returned to our lab for a study of their performance at high bit rates

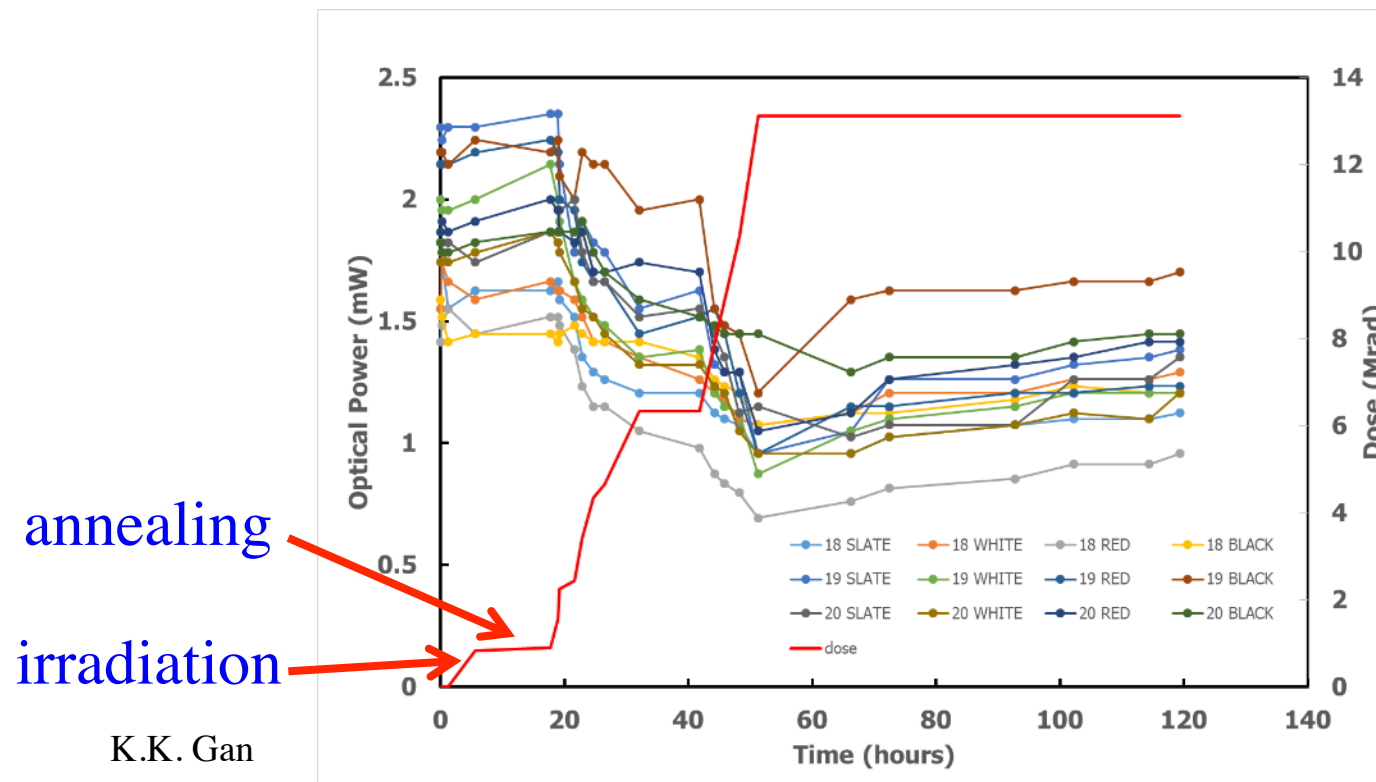




VCSEL Optical Power vs. Dose



- Optical power of irradiated VCSELs decreased with dose as expected
- Annealing occurred (slowly) during times when the VCSELs were removed from the beam
- Monitored 12 out of the 16 VCSEL channels during irradiation due to limited number of fiber connections

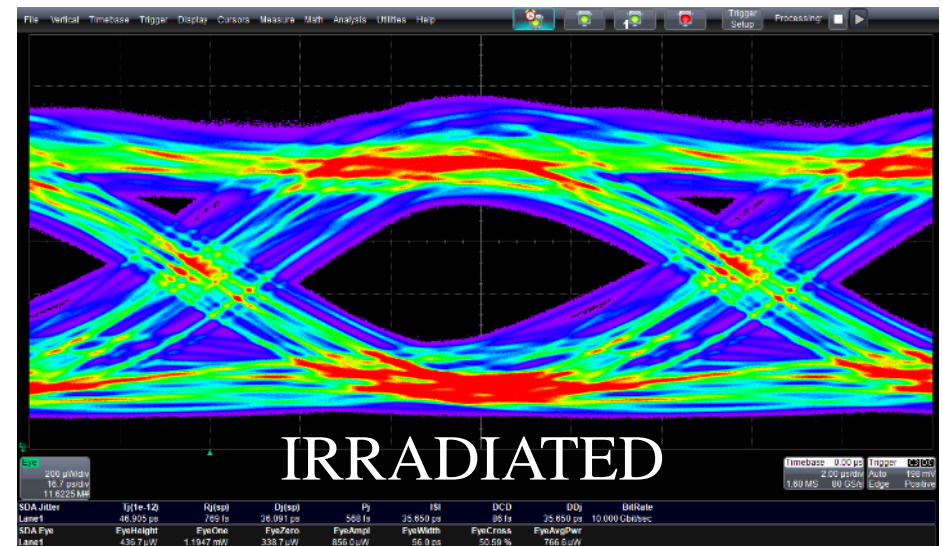
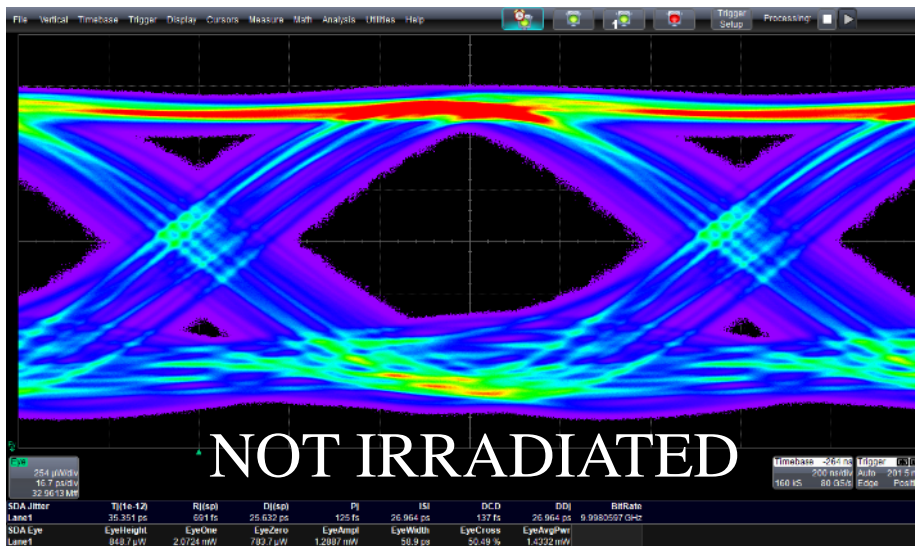




Post Irradiation Results – 10 Gb/s

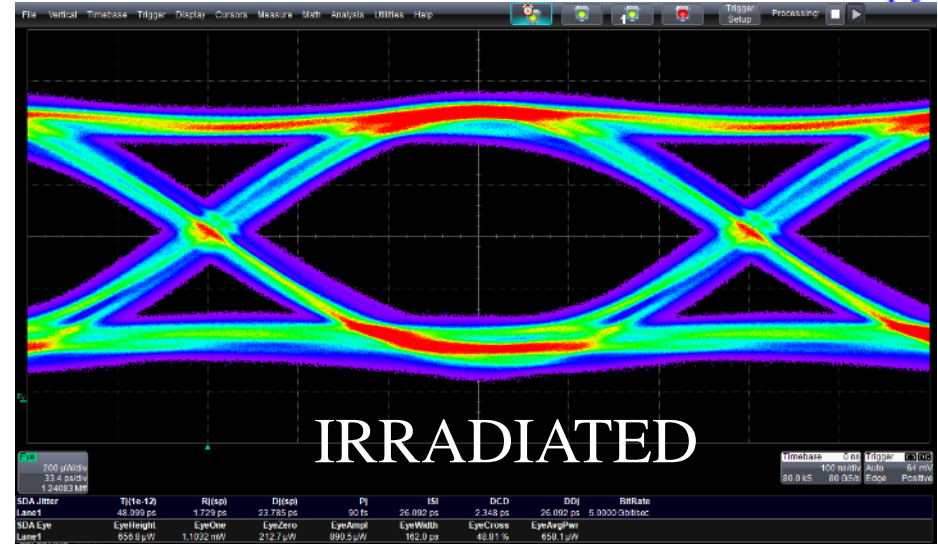
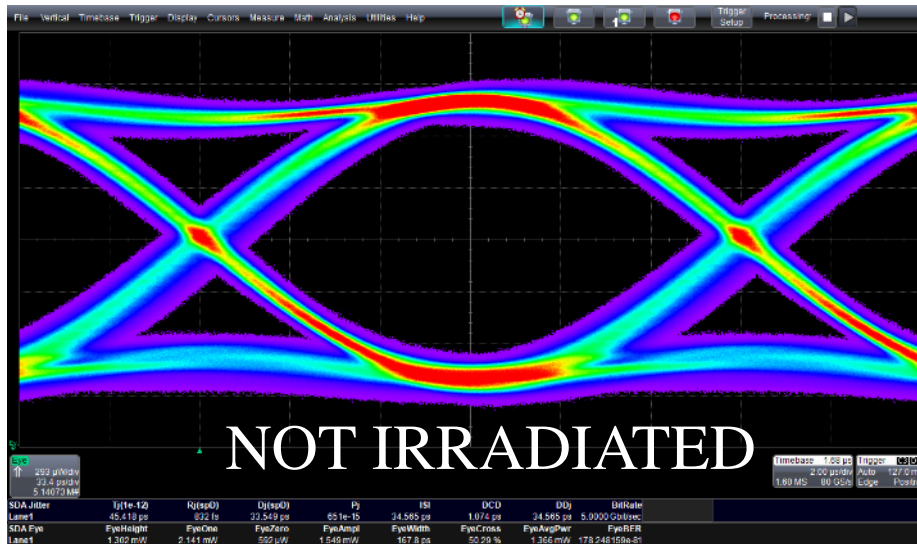


- All channels operational after irradiation
- Optical amplitude reduced from 2.07 mW to 1.19 mW
 - ◆ consistent with power loss seen during irradiation
- $BER < 5 \times 10^{-14}$ (run error free for more than 30 minutes)
- First demonstration of radiation hardness of an array driver/VCSEL combination at 10 Gb/s with a dose greater than 10 Mrads!





Post Irradiation Results – 5 Gb/s



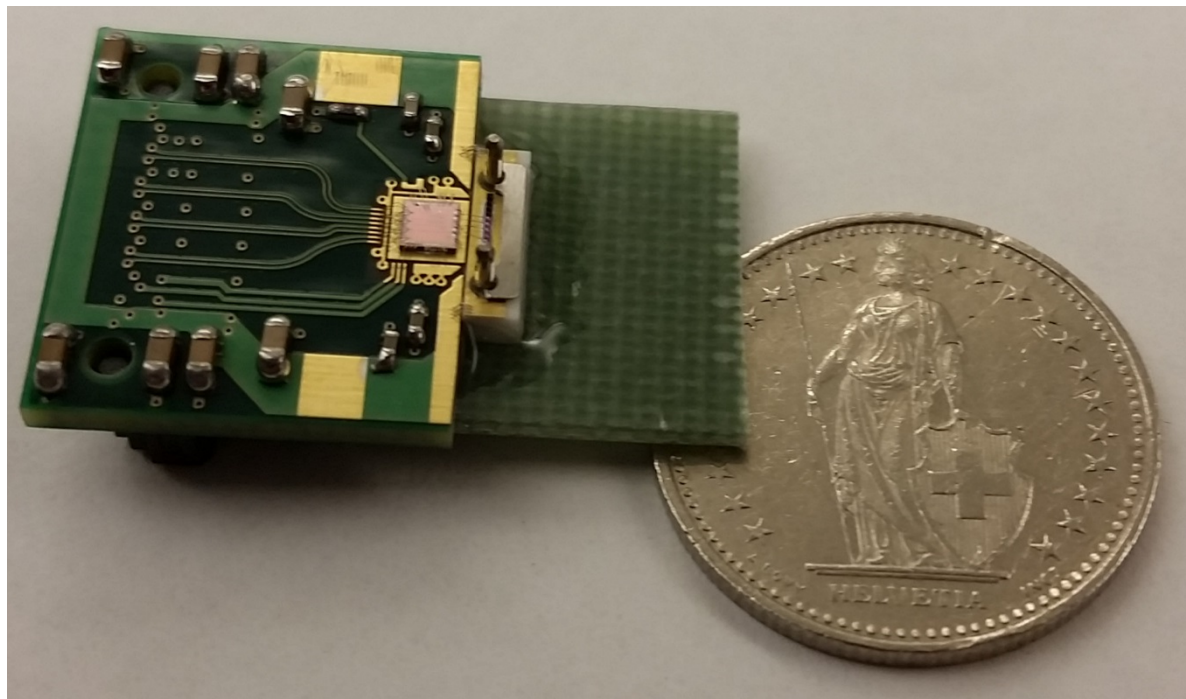
- performance of the array driver/VCSEL combination at 5 Gb/s is acceptable after irradiation



10 Gb/s Array Driver ASIC Rev. 2



- Rev. 2 has improved architecture for the first three channels, including programmable pre-emphasis current and delay
- One channel was simply a copy of the old design to check for consistency between the versions
- Rev. 2 ASIC is much easier to tune for operation at 10 Gb/s



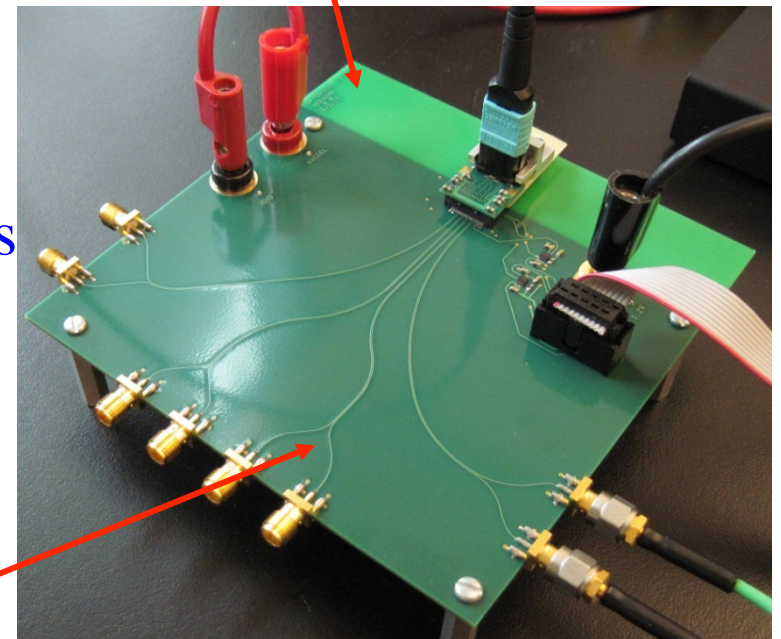
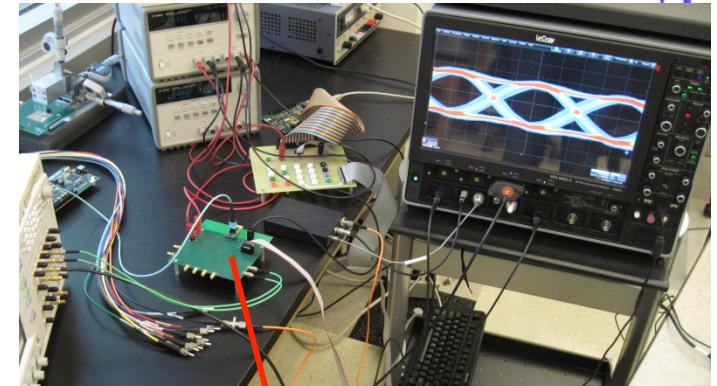


10 Gb/s Array Driver ASIC Rev. 2



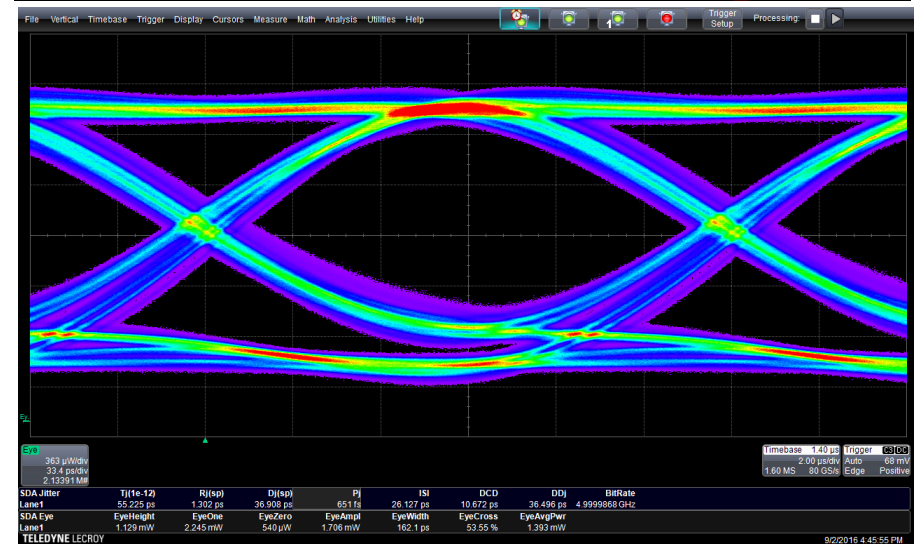
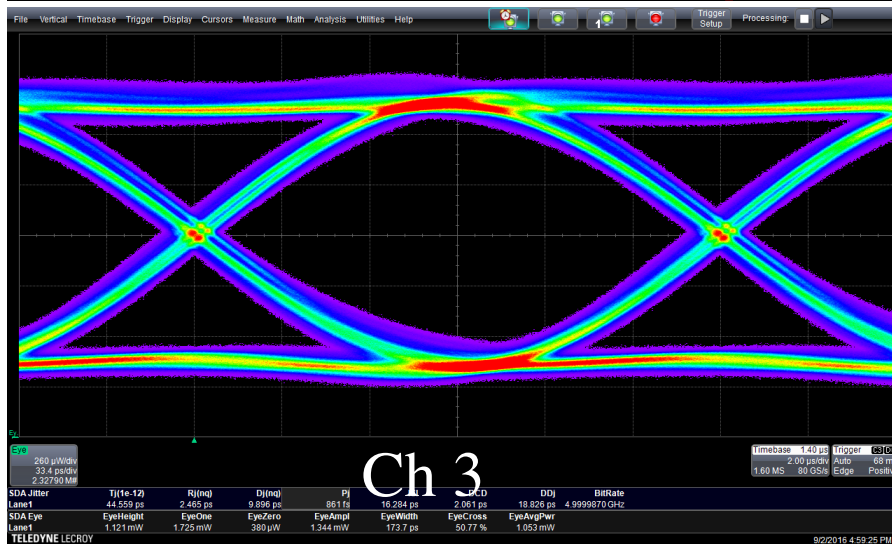
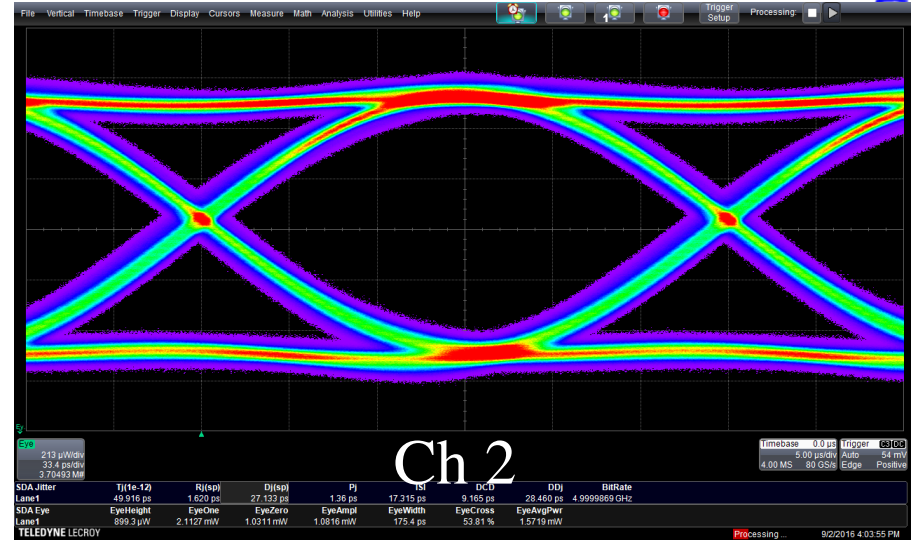
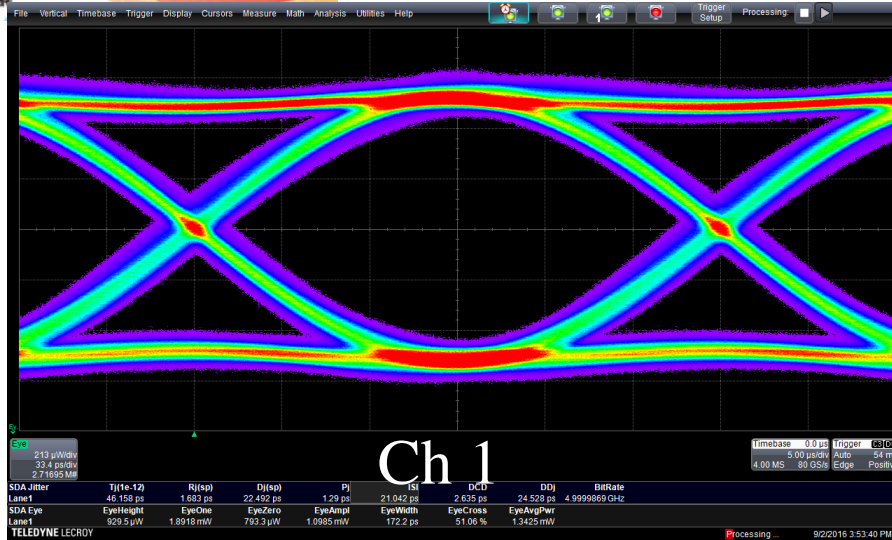
- runs at 1.2 V
 - ◆ consumes ~ 150 mA at 10 Gb/s with all four channels operating
- cathode set to -1.3 V to provide enough headroom to drive the VCSEL
- optical power > 2 mW on all channels
- BER $< 5 \times 10^{-14}$ on all channels at 10 Gb/s with every channel active

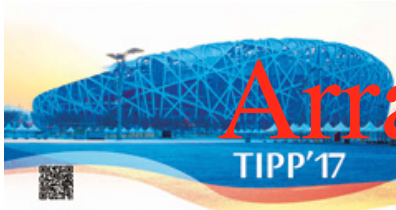
175 μm space/trace controlled impedance transmission lines



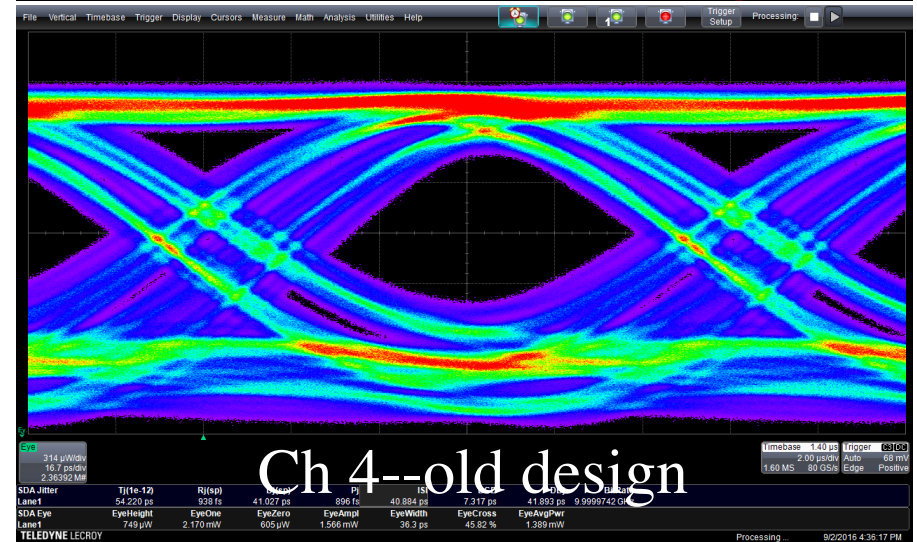
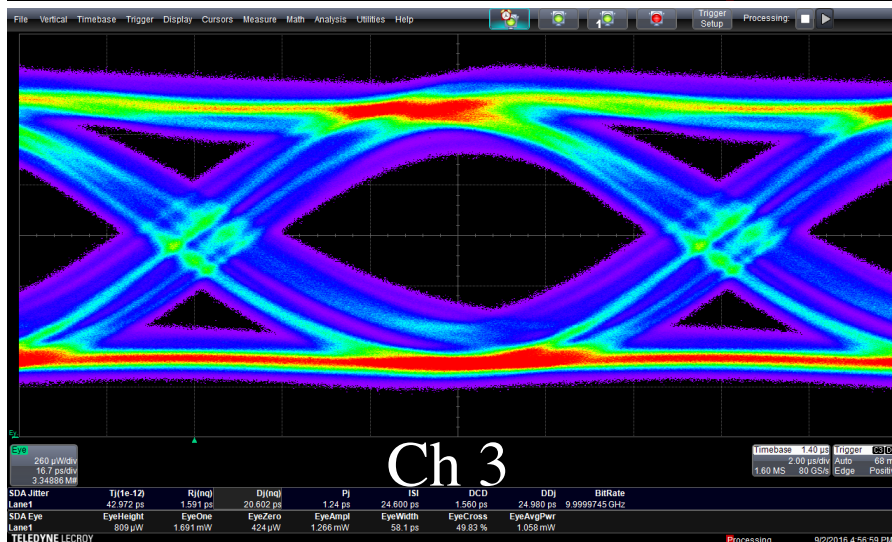
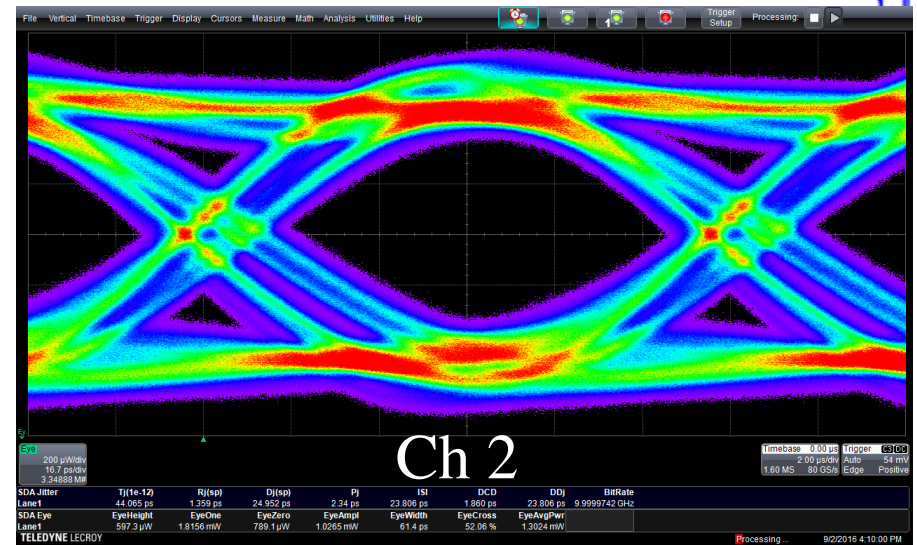
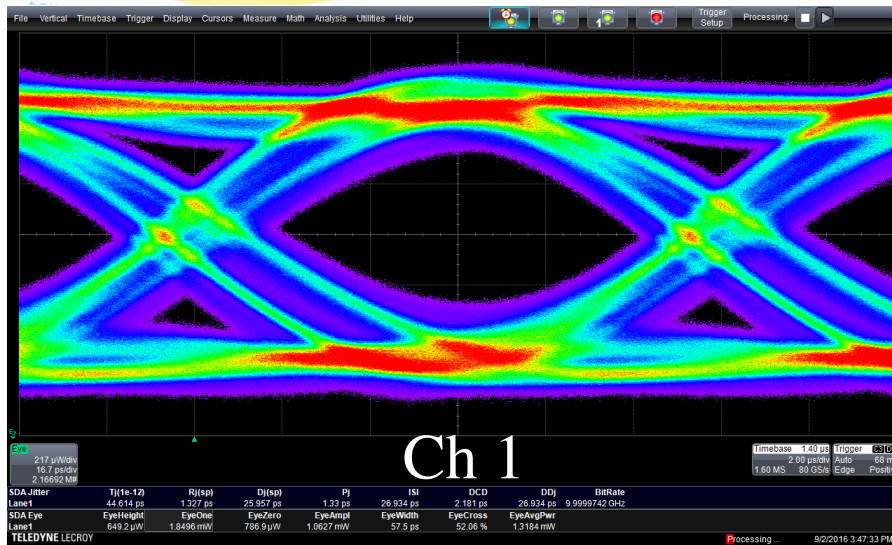


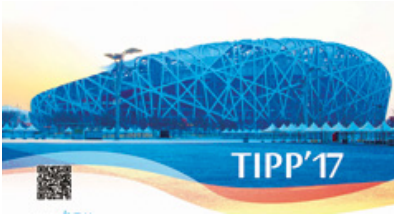
Array Driver ASIC Rev. 2: 5 Gb/s





Array Driver ASIC Rev. 2: 10 Gb/s





Summary



- designed and fabricated a new opto-board including an array driver ASIC and optical packaging to allow 10 Gb/s optical data transmission
- demonstrated the radiation hardness of the combination of a new VCSEL array and an array driver ASIC with successful 10 Gb/s operation after irradiation (> 10 Mrad)
- improved VCSEL array driver has been fabricated