



High-Speed/Radiation-Hard Optical Links

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

September 8, 2016

Outline



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

Use of VCSEL Arrays in HEP



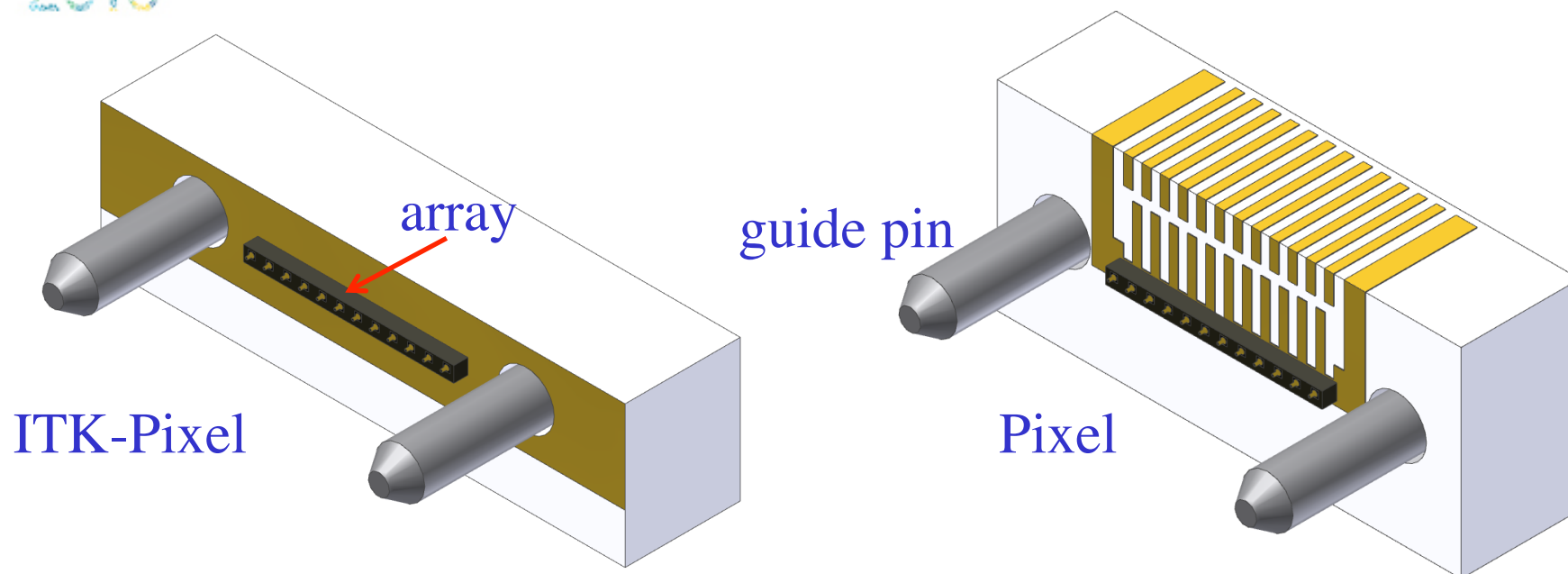
- Widely used in off-detector (no radiation) data transmission
- First on-detector implementation in pixel detector of ATLAS
 - ◆ experience has been positive
 - ⇒ use arrays for the second generation opto-links
 - ⇒ logical for HL-LHC ATLAS pixel detector to use 12-channel arrays as in the 1st and 2nd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

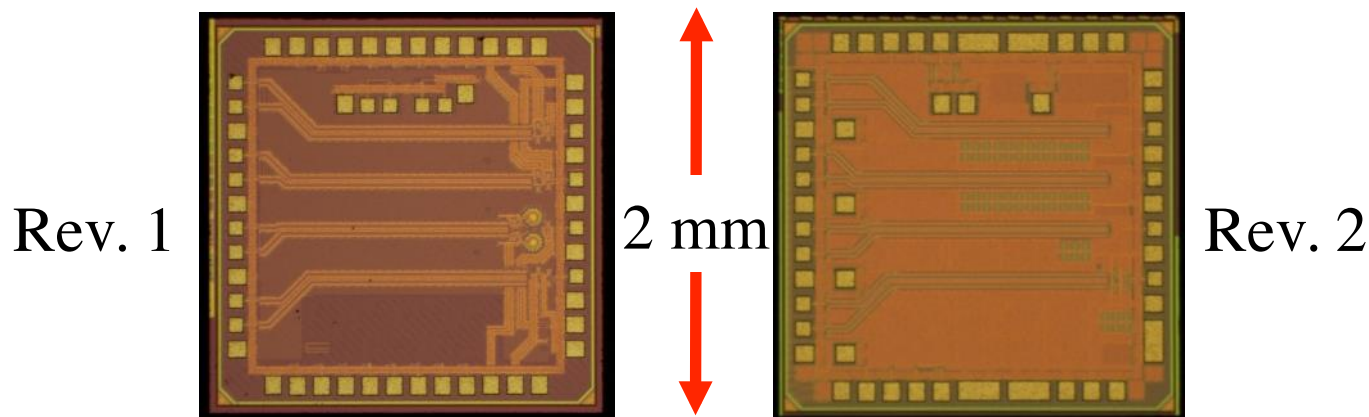


- Proposed opto-pack for ITK-Pixel has simpler design
 - ◆ continue to use BeO as substrate for heat management
- experience in building large quantity of opto-packs
 - ◆ fabricated 1,200 opto-packs for pixel opto-boards
 - ◆ fabricating 300 PIN opto-packs for off-detector opto-receivers
 - ◆ equivalent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

10 Gb/s VCSEL Array Driver



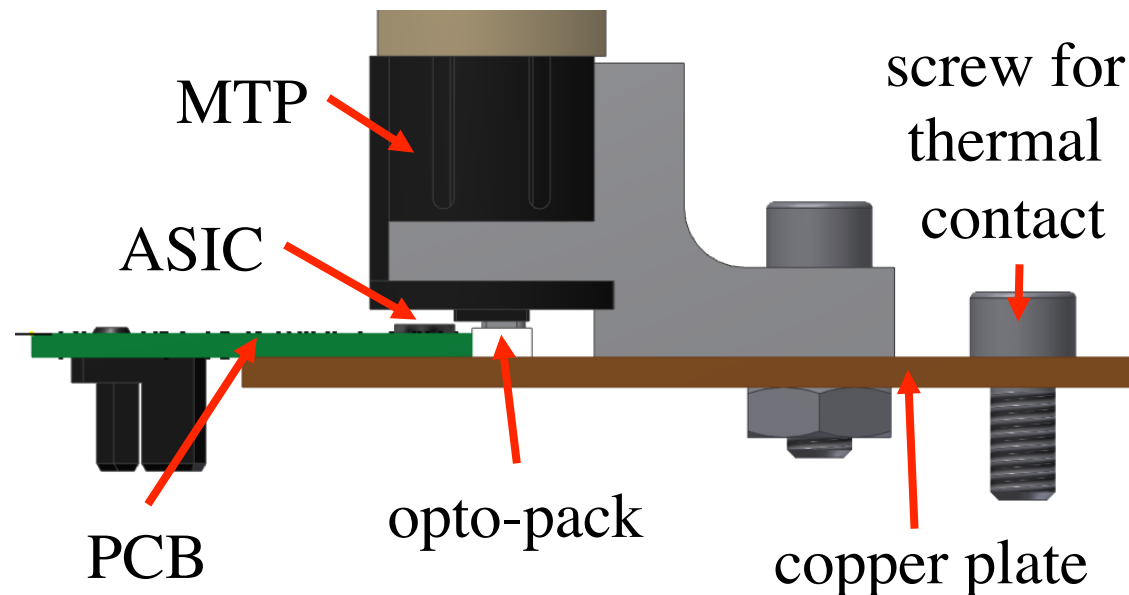
- R&D funded via CDRD program (FY13-15) of DOE (USA)
- Fabricated 4-channel test chips in 65 nm CMOS
 - ◆ 2 mm x 2 mm
 - ◆ 1st prototype submission: October 2014
 - ◆ 2nd prototype submission: March 2016
- Uses only core transistors to achieve maximum radiation-hardness
- 8-bit DACs to set the VCSEL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



ITK-Pixel Opto-Board Concept



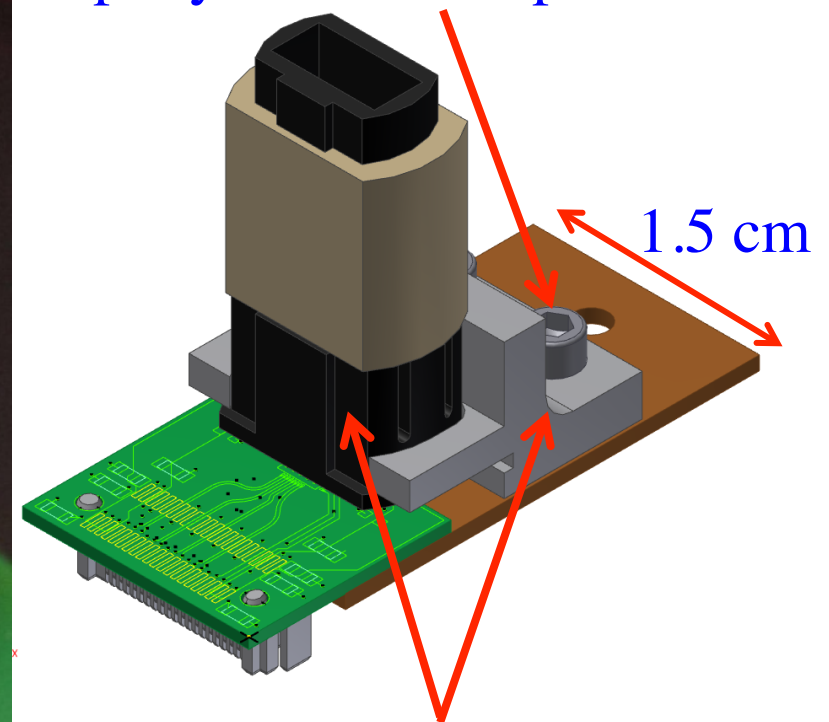
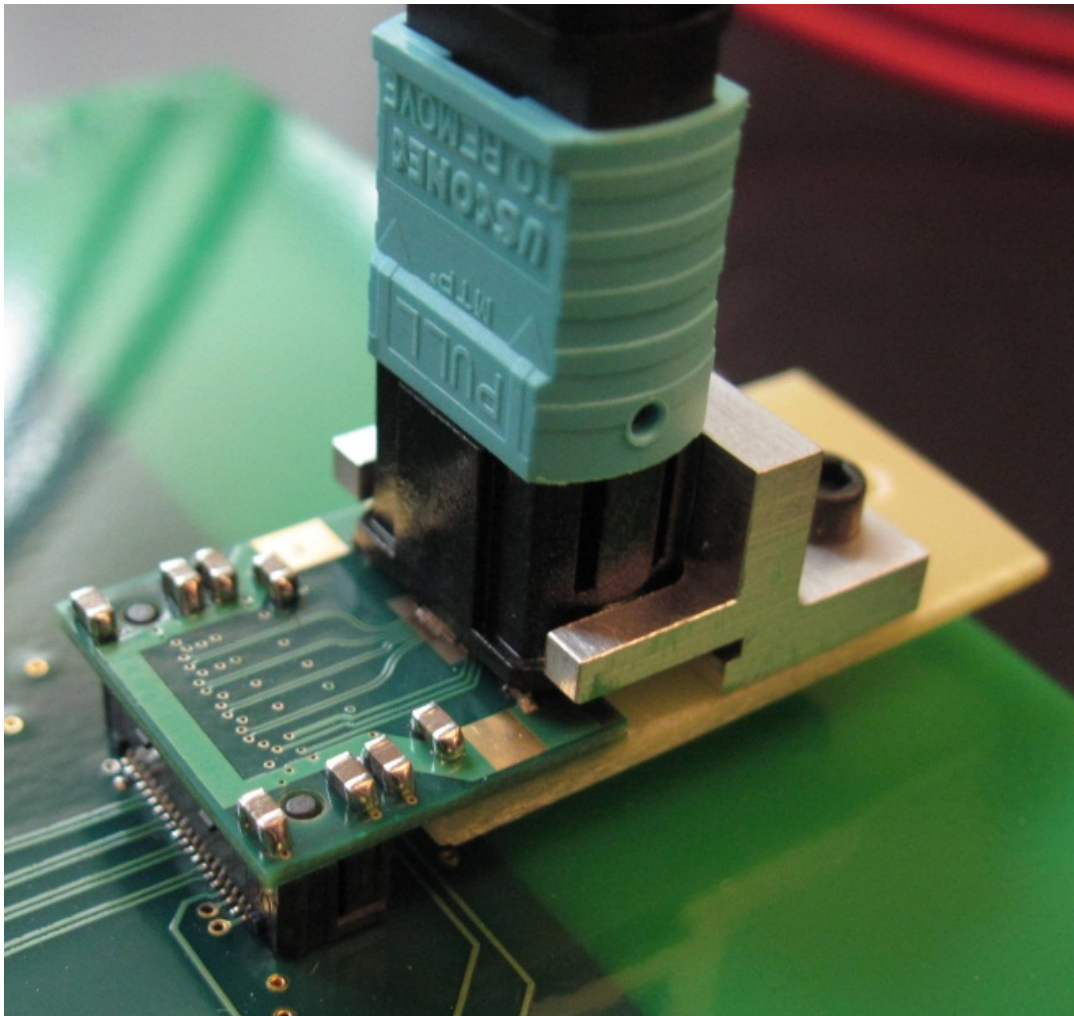
- Keep opto-pack
- Keep copper backed PCB
- Keep MTP connector
- Compatible with an opto-box (opto crate) concept
- No lenses/mirrors used to turn the light



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

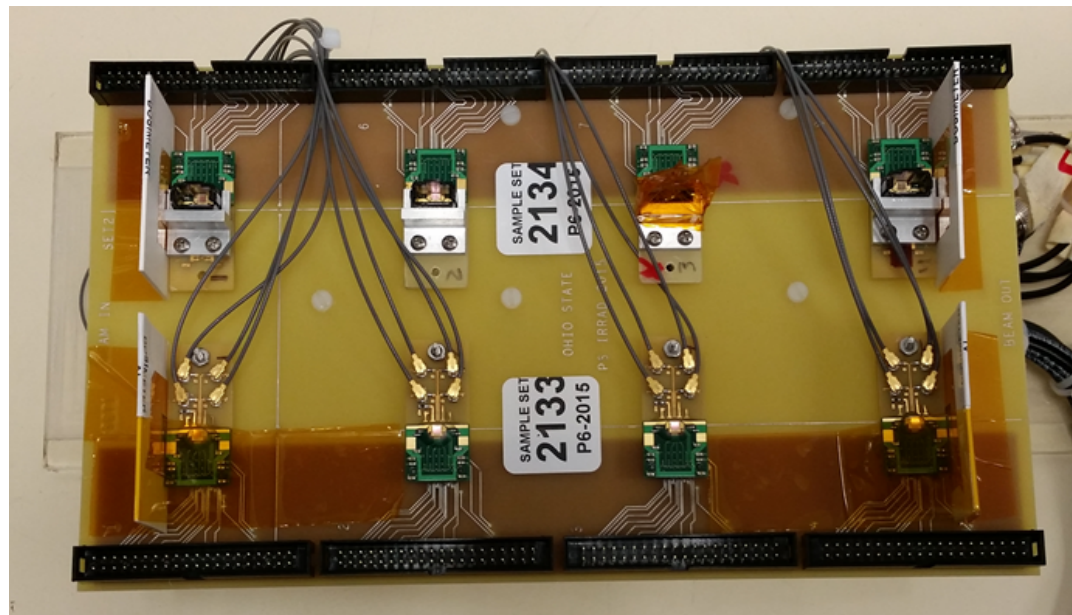
New Opto-Board Irradiation



- 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

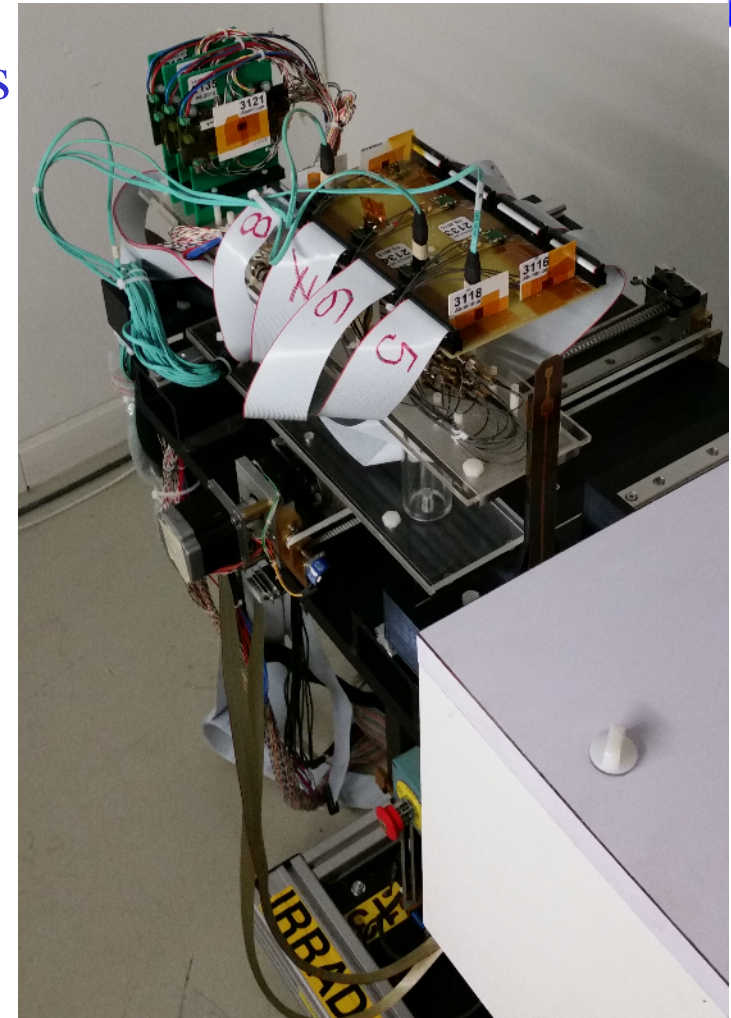
electrical



New Opto-Board Irradiation



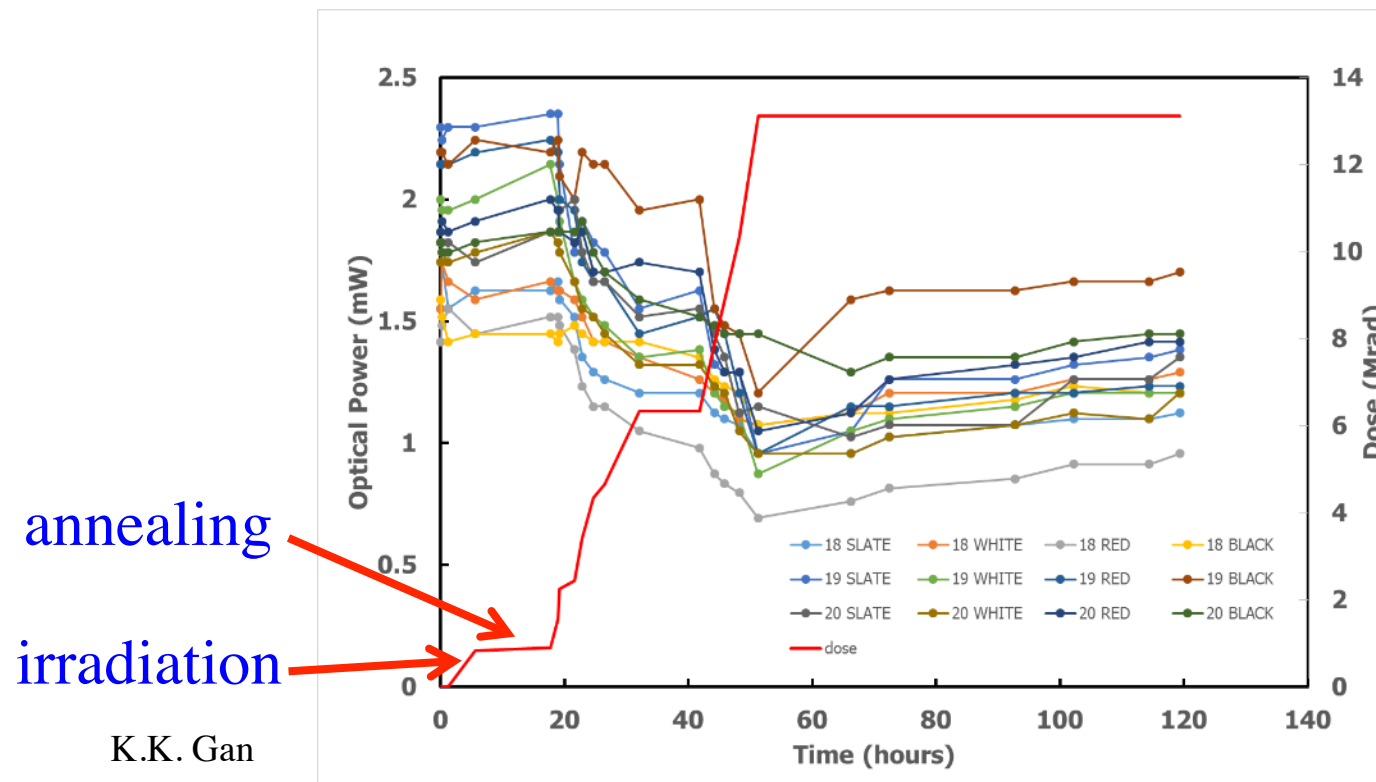
- Chips were powered and monitored during the irradiation at reduced speeds due to the irradiation facility cabling infrastructure
- All channels survived the irradiation and the cooled down chips have been returned to our lab for a study of their performance at high bit rates



VCSEL Optical Power vs. Dose



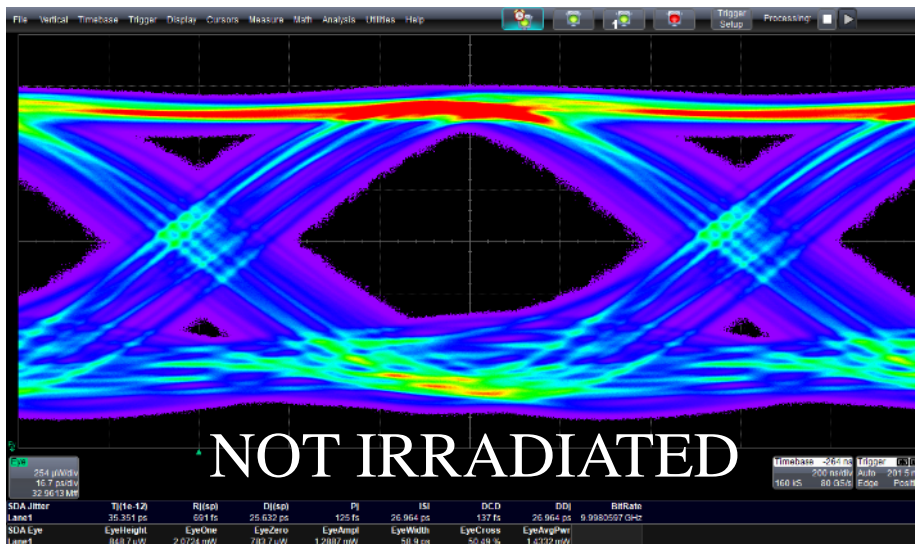
- Optical power of irradiated VCSELs decreased with dose as expected
- Annealing occurred (slowly) during times when the VCSELs were removed from the beam
- Monitored 12 out of the 16 VCSEL channels during irradiation due to limited number of fiber connections



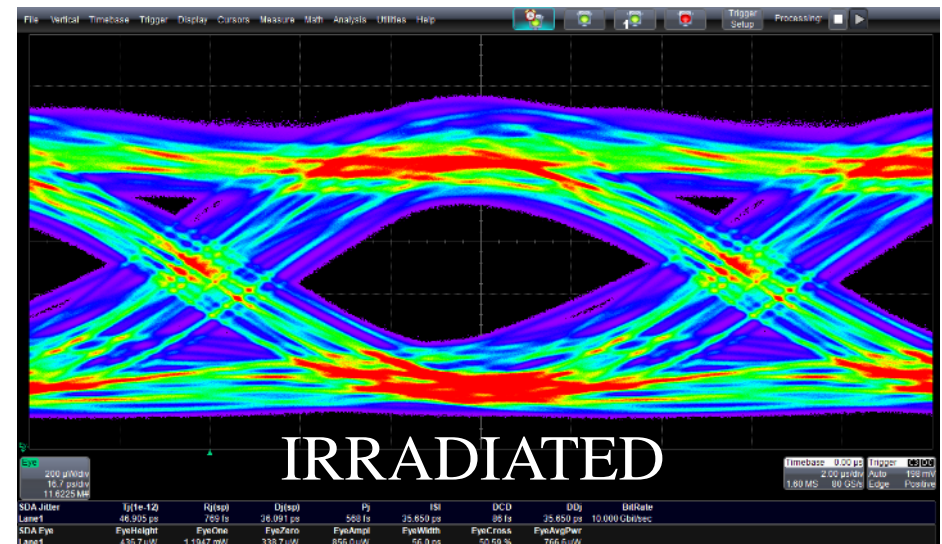
Post Irradiation Results – 10 Gb/s



- 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!

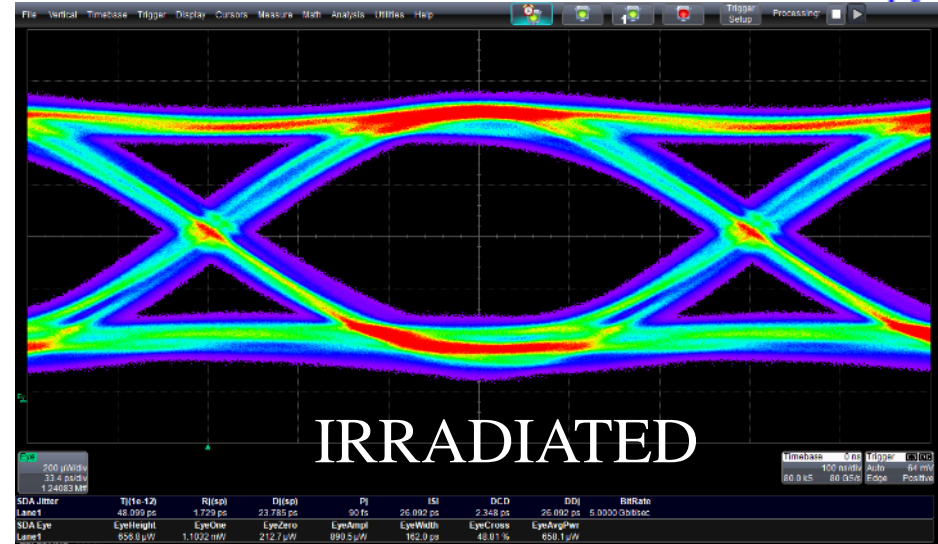
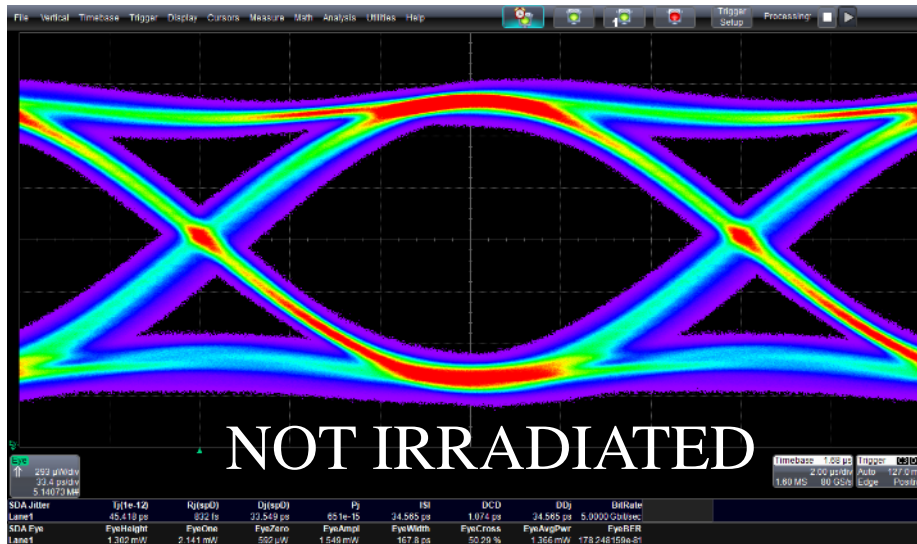


K.K. Gan



Pixel2016

Post Irradiation Results – 5 Gb/s

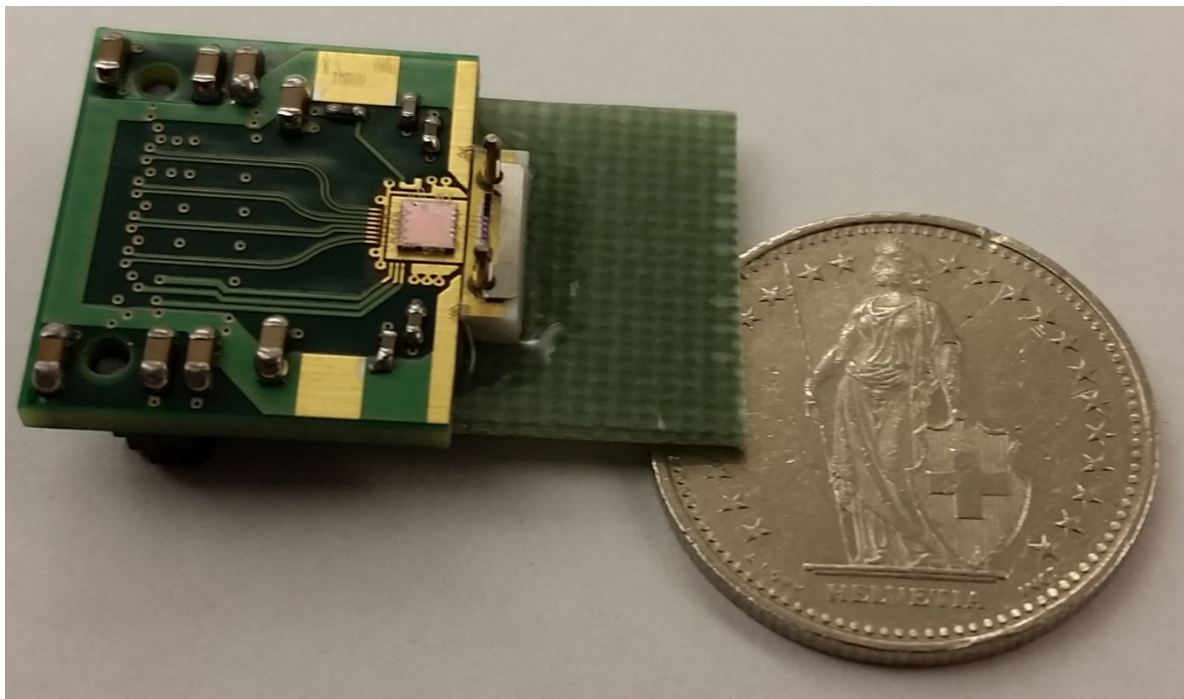


- performance of the array driver/VCSEL combination at 5 Gb/s is acceptable after irradiation

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

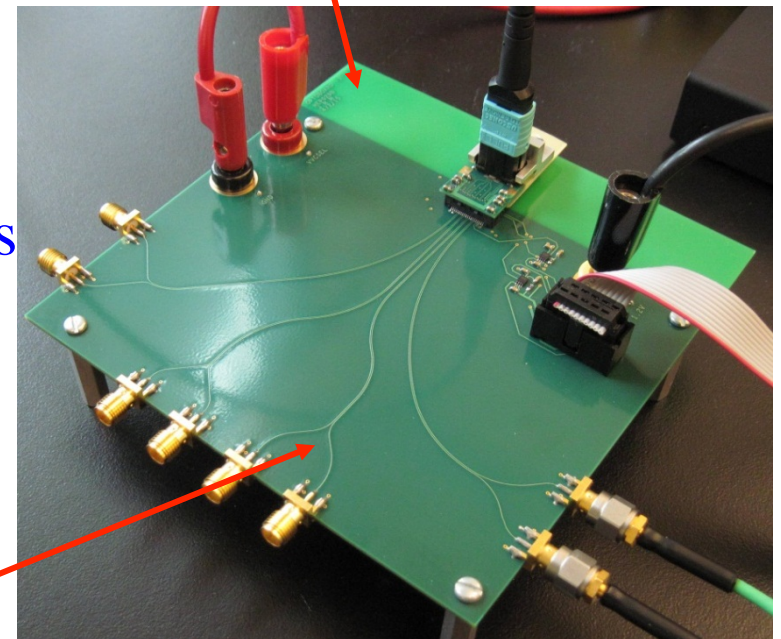
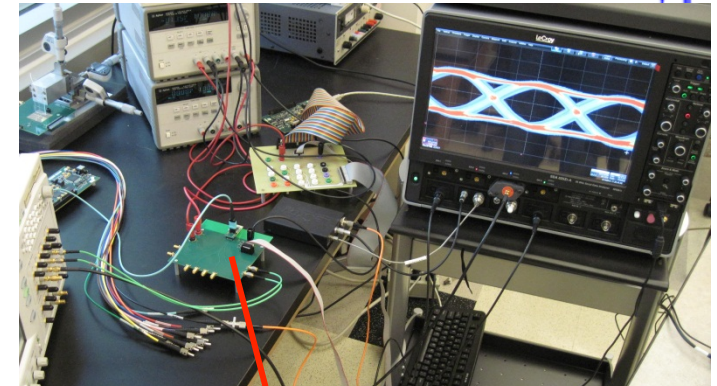


10-Gb/s Array Driver ASIC Rev. 2

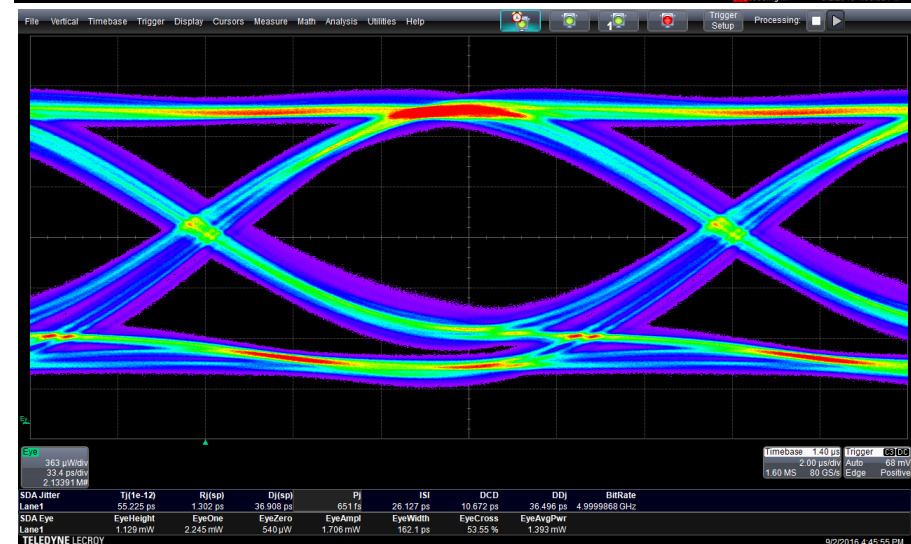
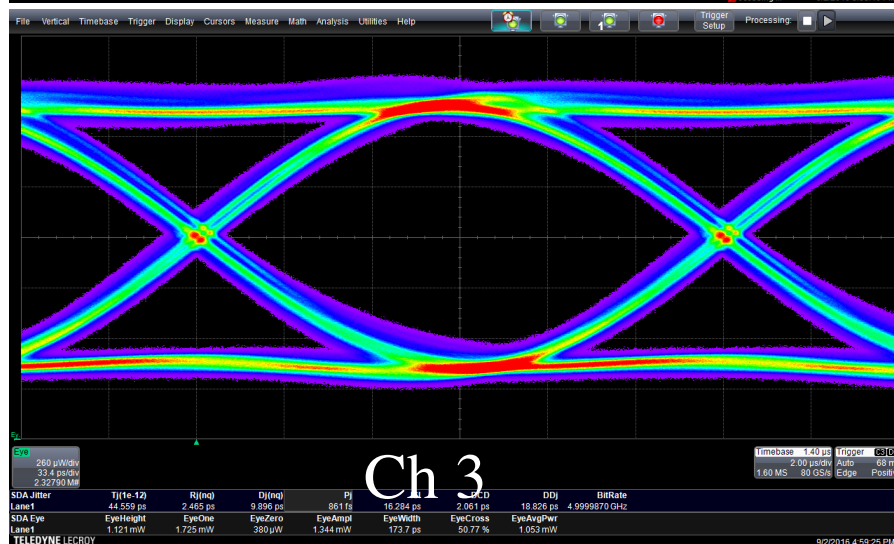
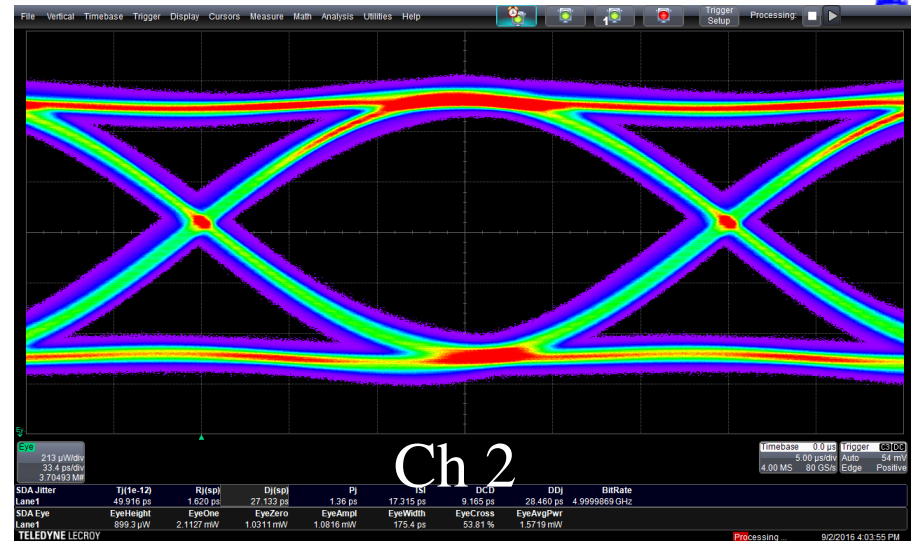
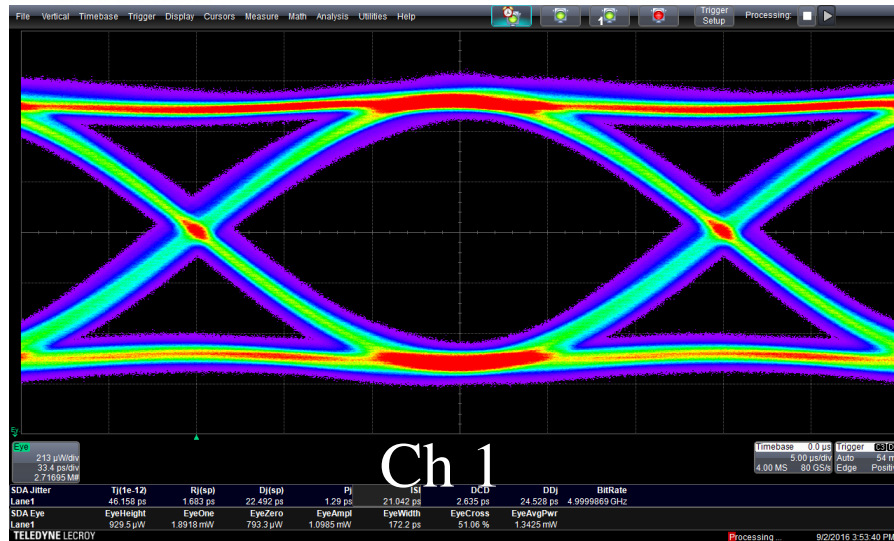


- runs at 1.2 V
 - ◆ consumes ~ 150 mA at 10 Gb/s with all four channels operating
- cathode set to -1.3 V to provide enough headroom to drive the VCSEL
- optical power > 2 mW on all channels
- BER $< 5 \times 10^{-14}$ on all channels at 10 Gb/s with every channel active

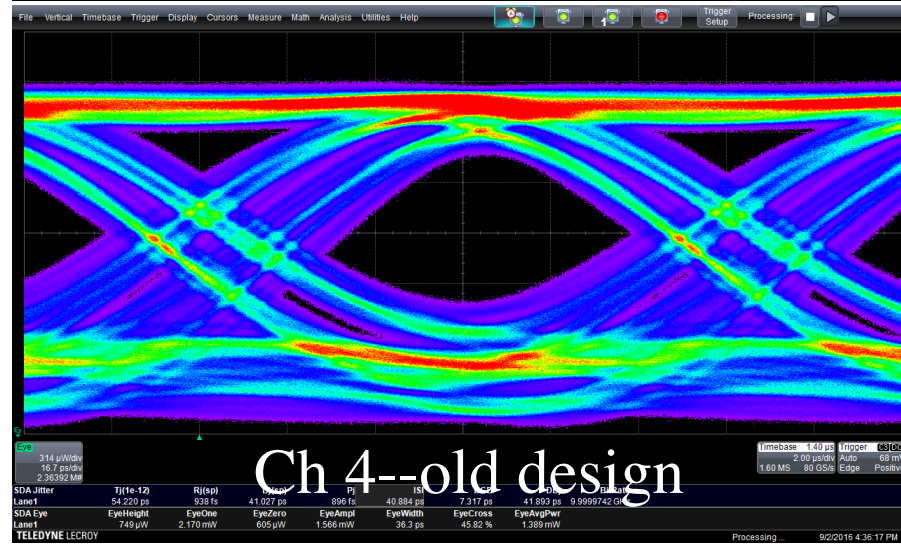
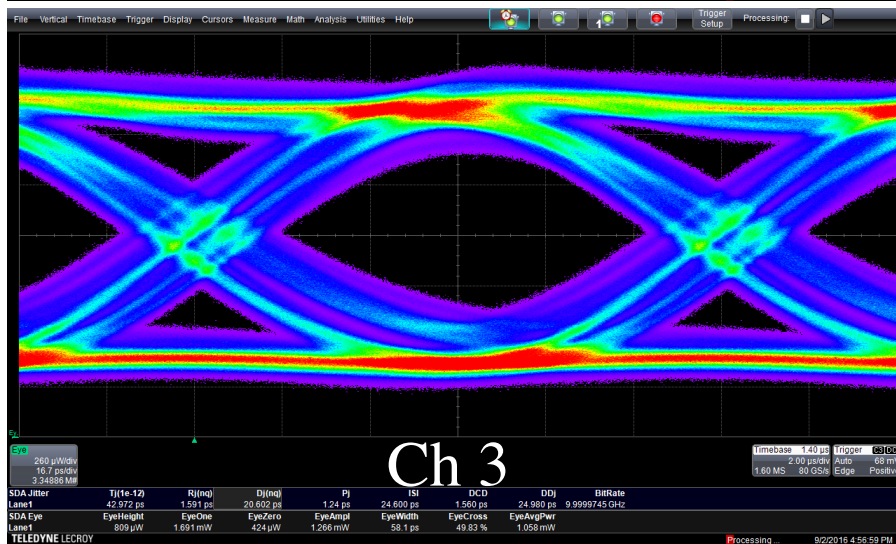
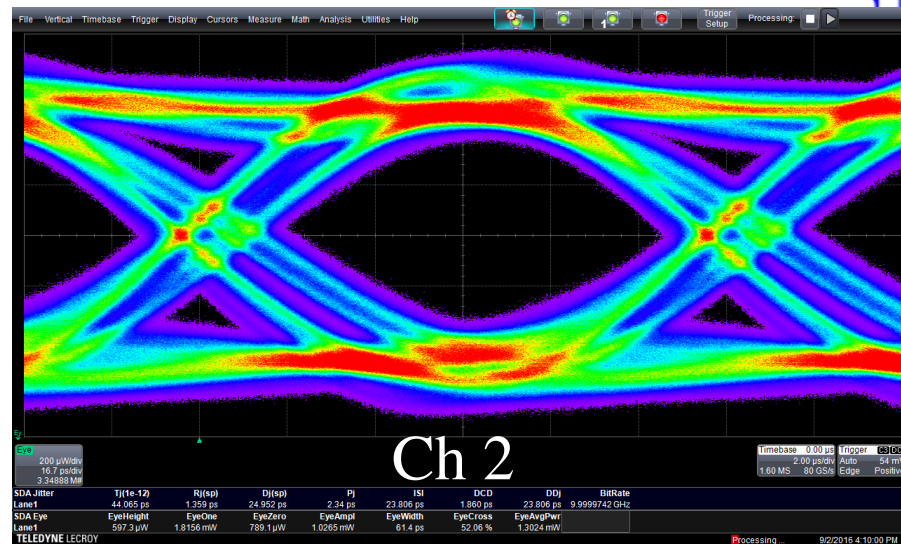
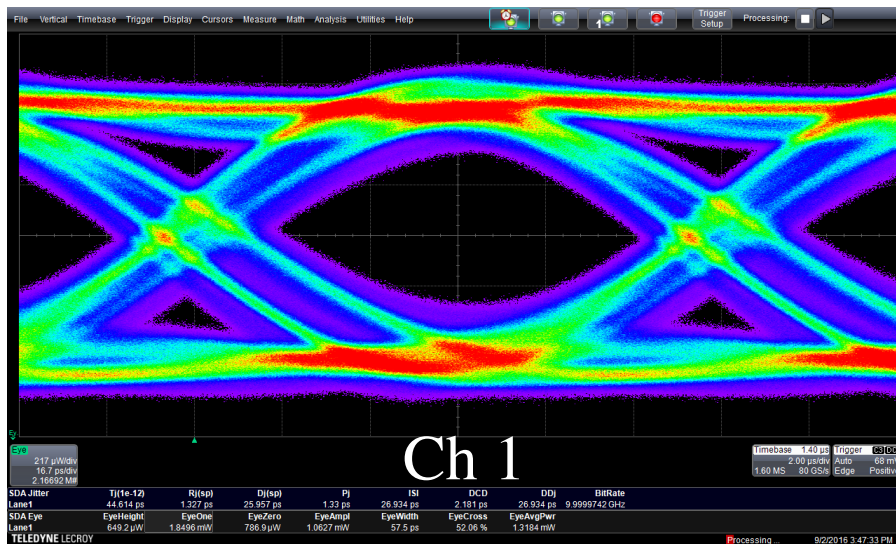
175 μm space/trace controlled impedance transmission lines



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