Radiation-Hard Optical Link in the ATLAS Pixel Detector

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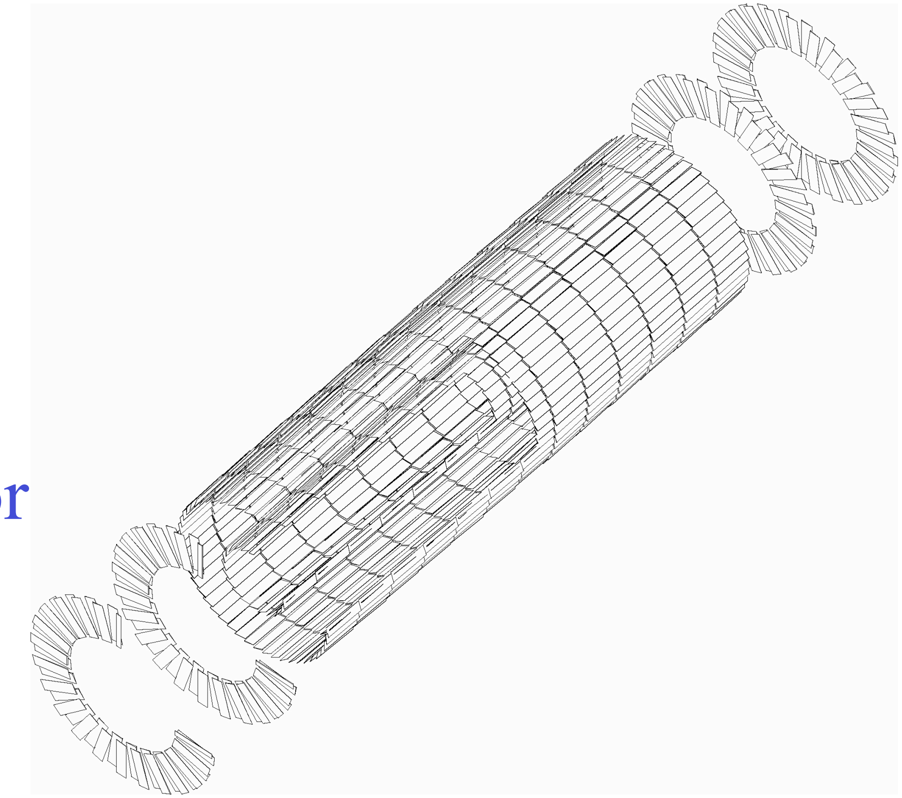
Outline

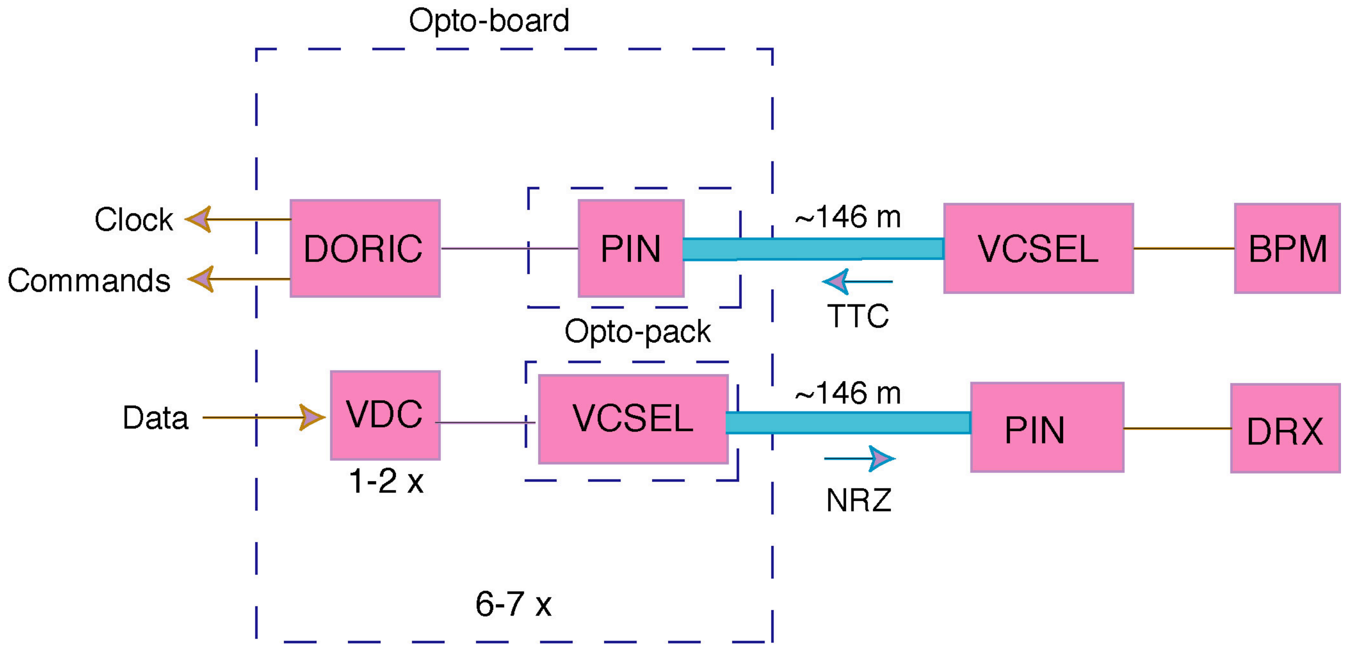
- Introduction
- Results on IBM 0.25 μm Chips
- Results on Proton Irradiations
- Summary

ATLAS Pixel Detector



- Inner most tracking detector
- Pixel size: 50 μm x 400 μm
- 100 million channels
- Barrel layers at r = 5.1, 12.3 cm
- Disks at z = 50, 65 cm
- Dosage after 10 years:
  - optical link: 30 Mrad or 6 x 10^{14} 1-MeV n_{eq}/cm^2

ATLAS Pixel Opto-link



VCSEL: Vertical Cavity Surface Emitting Laser diode

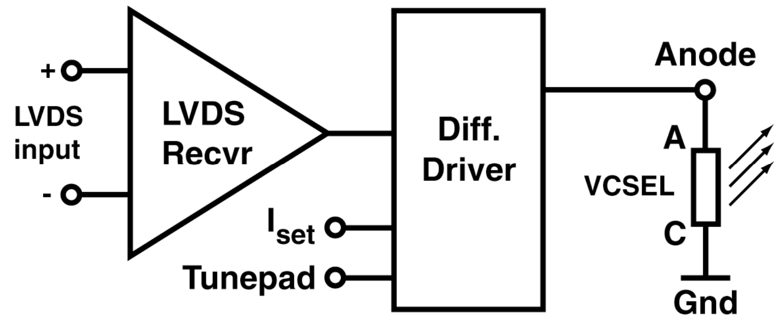
VDC: VCSEL Driver Circuit

PIN: PiN diode

DORIC: Digital Optical Receiver Integrated Circuit

VDC: VCSEL Driver Circuit

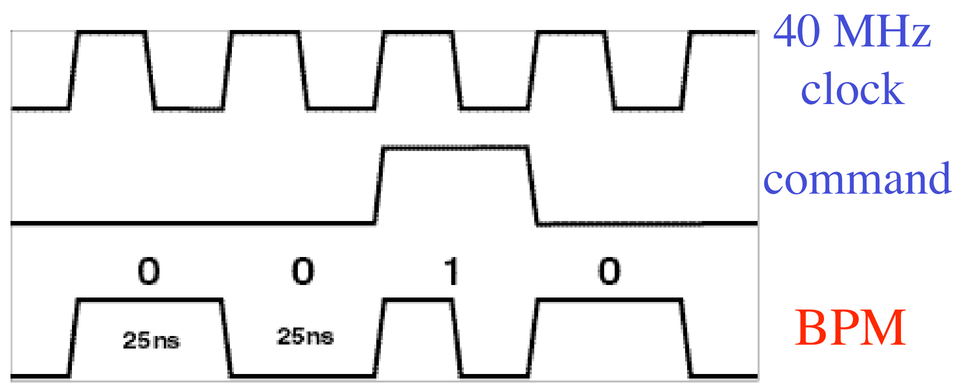
- Convert LVDS input signal into single-ended signal appropriate to drive VCSEL diode
- Output (bright) current: 0 to 20 mA
  - controlled by external current I_{set}
- Standing (dim) current: ~ 1 mA
  - improve switching speed

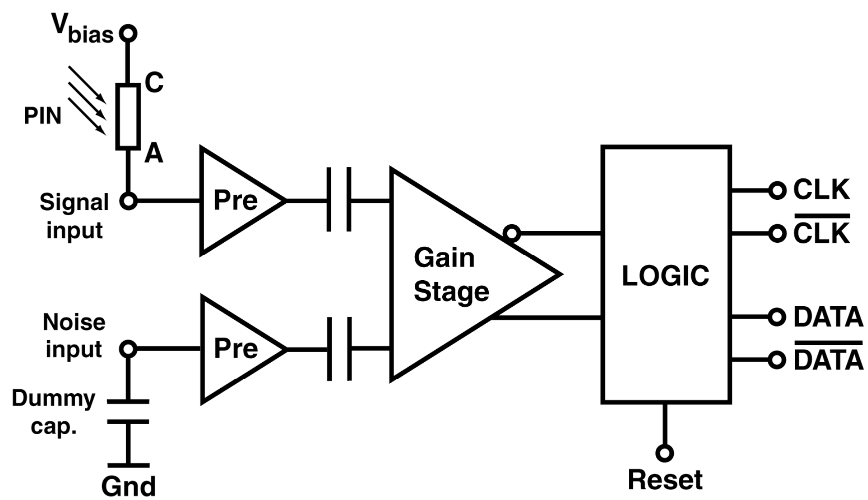


- Rise & fall times: 1 ns nominal for 80 MHz signals
- "On" voltage of VCSEL: up to 2.3 V at 20 mA for 2.5 V supply
- Constant current consumption!
- use Truelight high-power oxide common cathode VCSEL array

DORIC: Digital Optical Receiver IC

- Decode Bi-Phase Mark encoded (BPM) clock and command signals from PIN diode
- Input signal: 40-600 μA
- Extract: 40 MHz clock
- Duty cycle: (50 ± 4)%
- Total timing error: < 1 ns
- Bit Error Rate (BER): $< 10^{-11}$ at end of life
- use Truelight common cathode PIN array

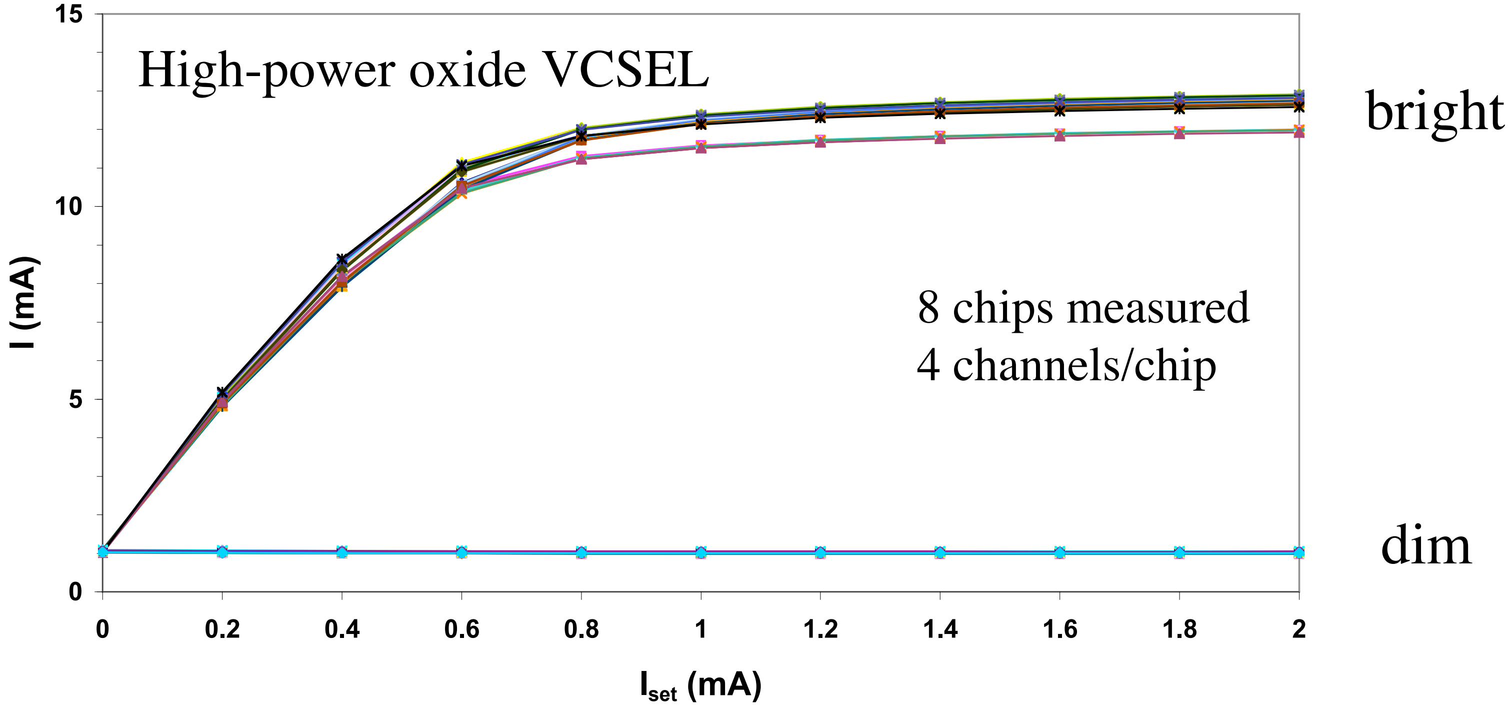




Status of VDC & DORIC

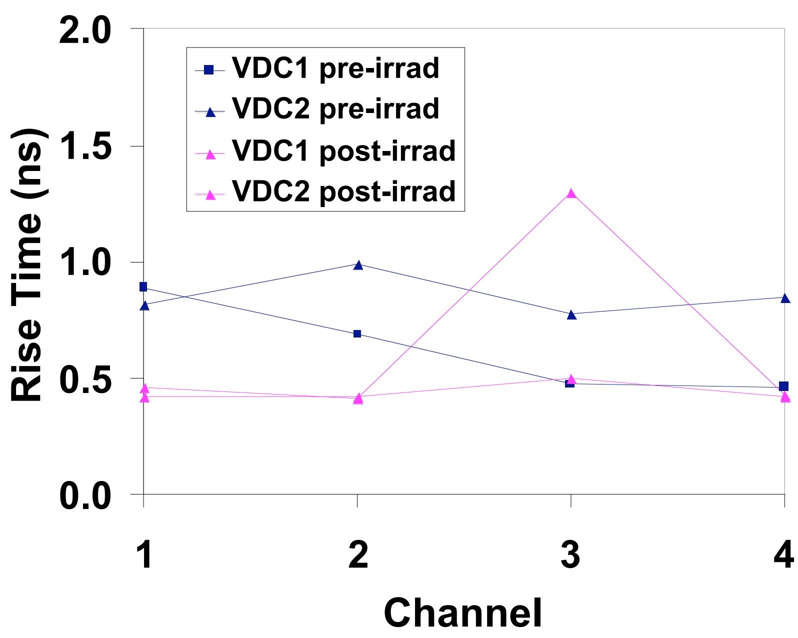
- Original design for ATLAS SemiConductor Tracker (SCT)
  - AMS 0.8 μm BiPolar in radiation tolerant process (4 V)
- DMILL #1-3: Summer 1999 - May 2001
  - 0.8 μm CMOS rad-hard process (3.2 V)
  - VDC & DORIC #3: meet specs
  - severe degradation of circuit performance in April 2001 proton irradiation
- IBM #1-5: Summer 2001 - Dec 2002
  - 0.25 μm CMOS rad-hard process (2.5 V)
  - enclosed layout transistors and guard rings for improved radiation hardness
- IBM 5e: April 2003 engineering run
  - convert 3-layer to 5-layer layout for submission with pixel Module Control Chip (MCC) for cost saving
  - ⇨ this is the production run since chips meet specs and sufficient quantity of chips were produced

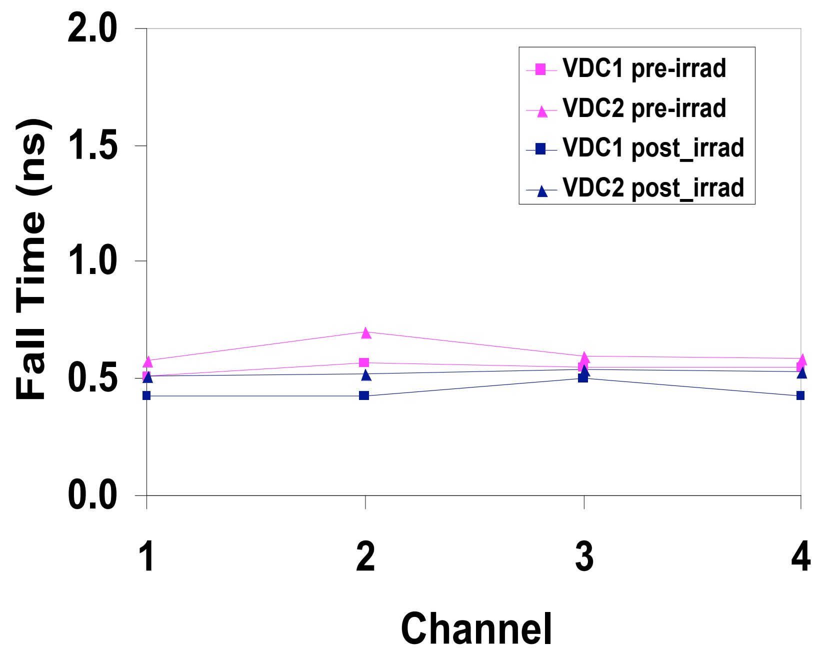
VDC-I5e: Bright and Dim Currents vs. I_{set}



- dim current is ~ 1 mA as expected
- bright current measured with 1 Ω in series
- maximum bright current is ~ 13 mA
  - oxide VCSEL has larger effective resistance than p^+ implanted VCSEL
  - target is 20 mA but 13 mA is adequate for annealing from irradiation damage

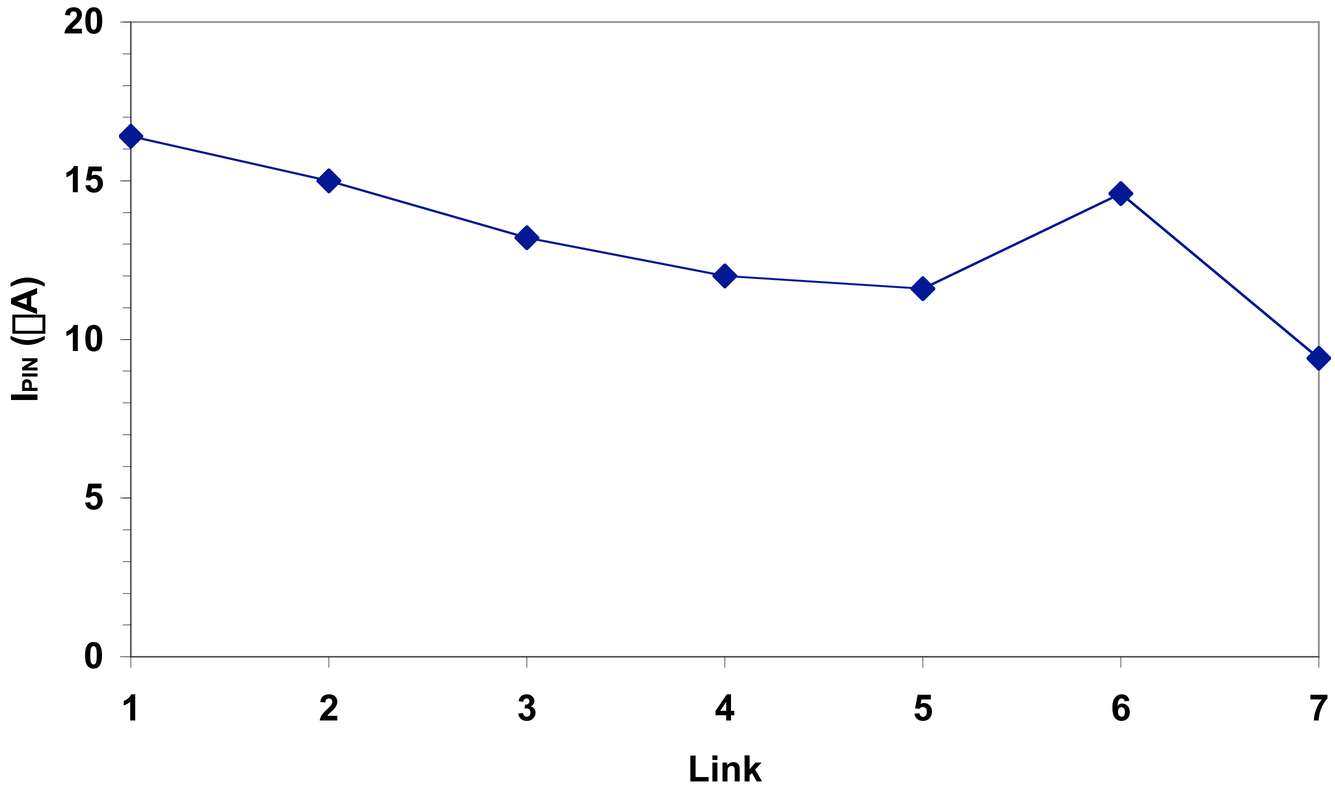
VDC-I5e: Clock Rise/Fall Time





- ✔ fall time < 1 ns
- × rise time > 1 ns
  - ◆ measured with 44-pin package
  - ◆ faster rise time on opto-board
- ✔ no degradation up to 62 Mrad

DORIC: PIN Current Thresholds with No Bit Errors

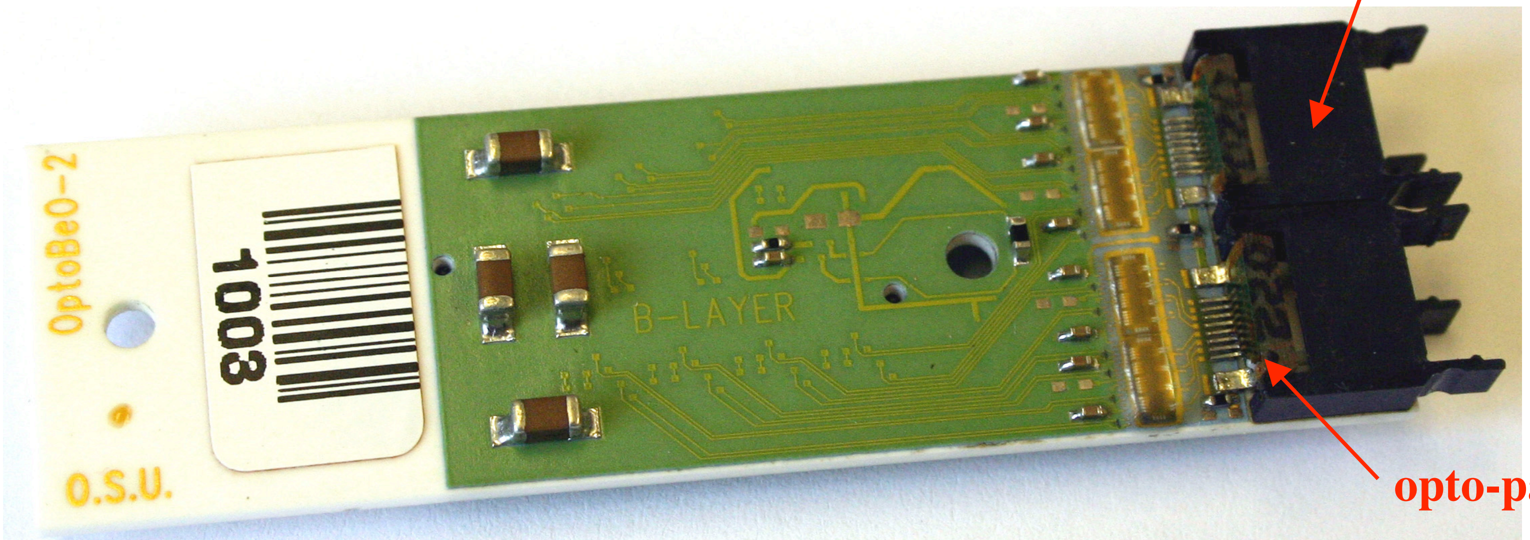


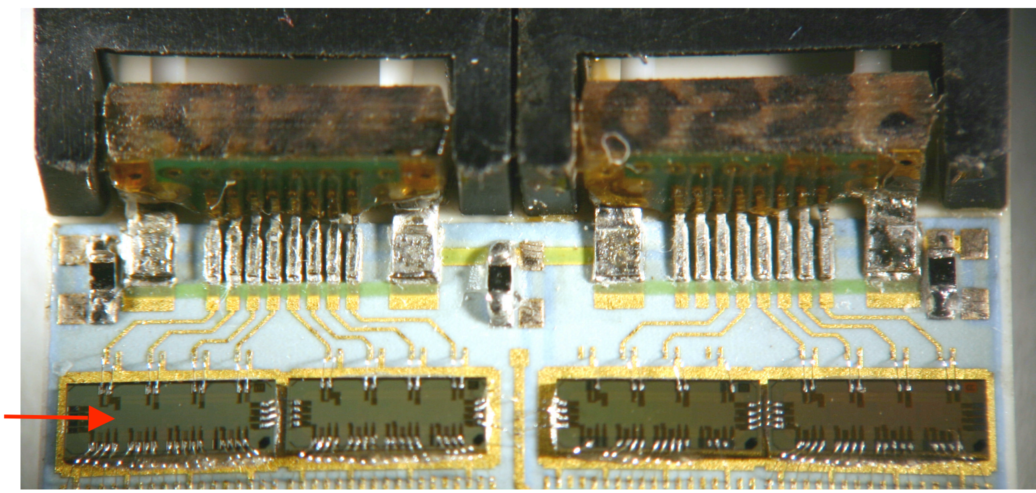
- thresholds significantly better than spec: 40 μA

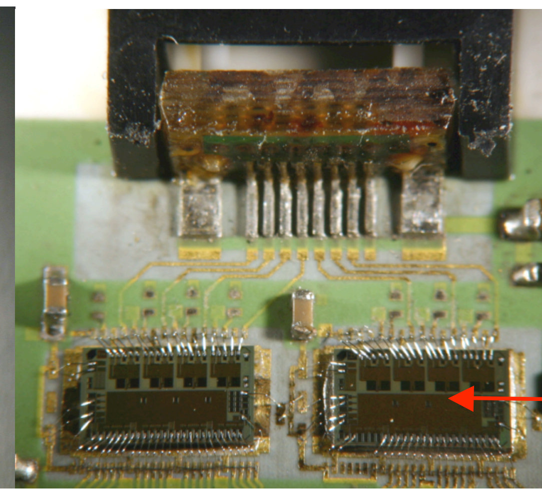
Status of BeO Opto-board

- converts: optical signal ↔ electrical signal
- contains 7 optical links
- use BeO for heat management but prototype initially in FR-4 for fast turnaround and cost saving
- 1st BeO prototype:
  - many open vias due to insufficient gold filling
  - ✔ opto-links works after via repairs!
- 2nd BeO prototype:
  - recycled BeO boards
  - many shorts due to over filling
  - ⇨ use more experienced/expensive vendor
  - ⇨ produced opto-boards of high quality

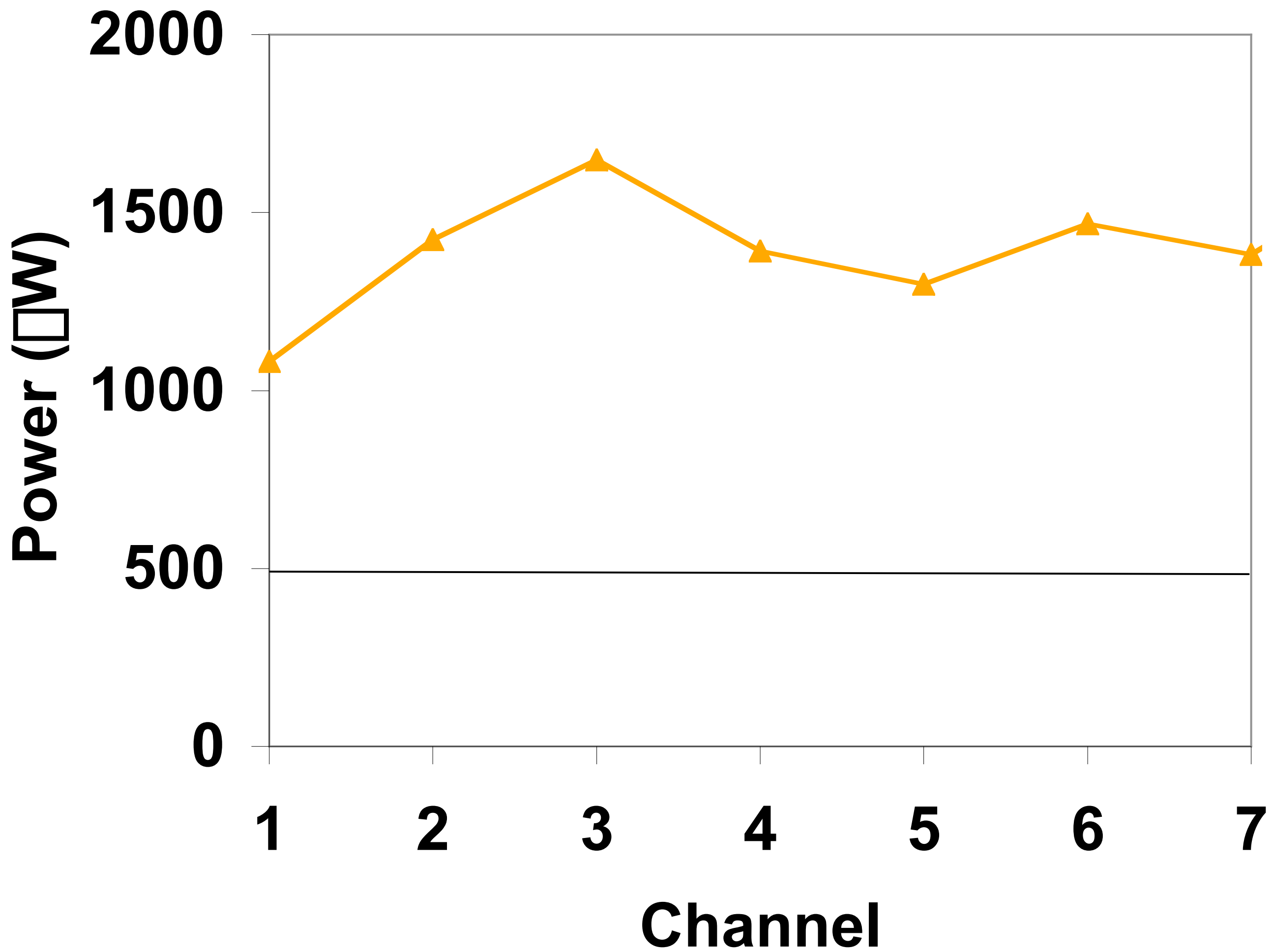
BeO Opto-board







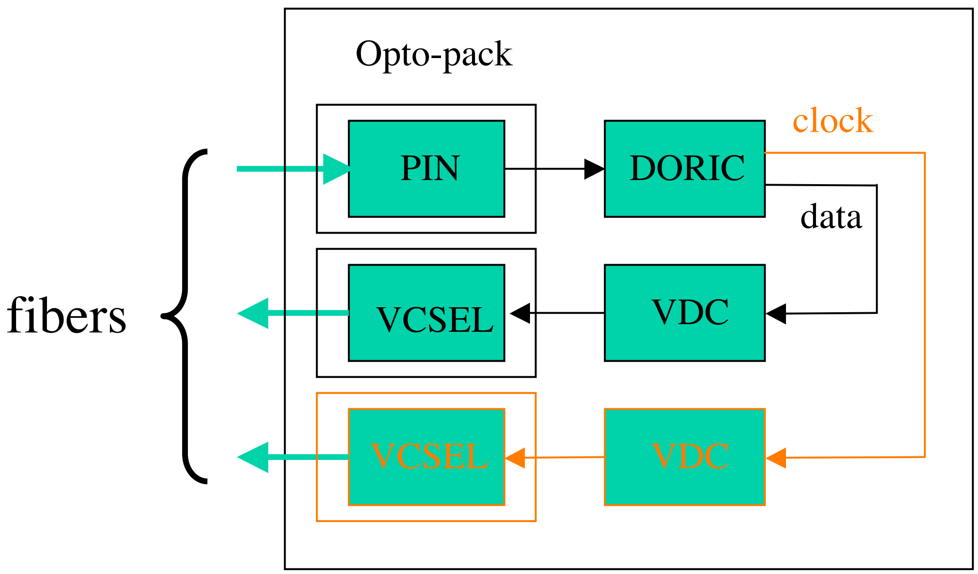
Optical Power



- optical power at 10 mA significantly above spec: 500 W

Proton Irradiation at CERN

- use 24 GeV protons at T7 to verify radiation hardness of opto-links
- monitor performance of opto-links in real time
- cold box: irradiate 4 VDC-I5e and 4 DORIC-I5e with no optical components
- shuttle: irradiate 4 opto-boards
  - opto-boards can be moved in and out of beam remotely for VCSEL annealing



Shuttle Test System

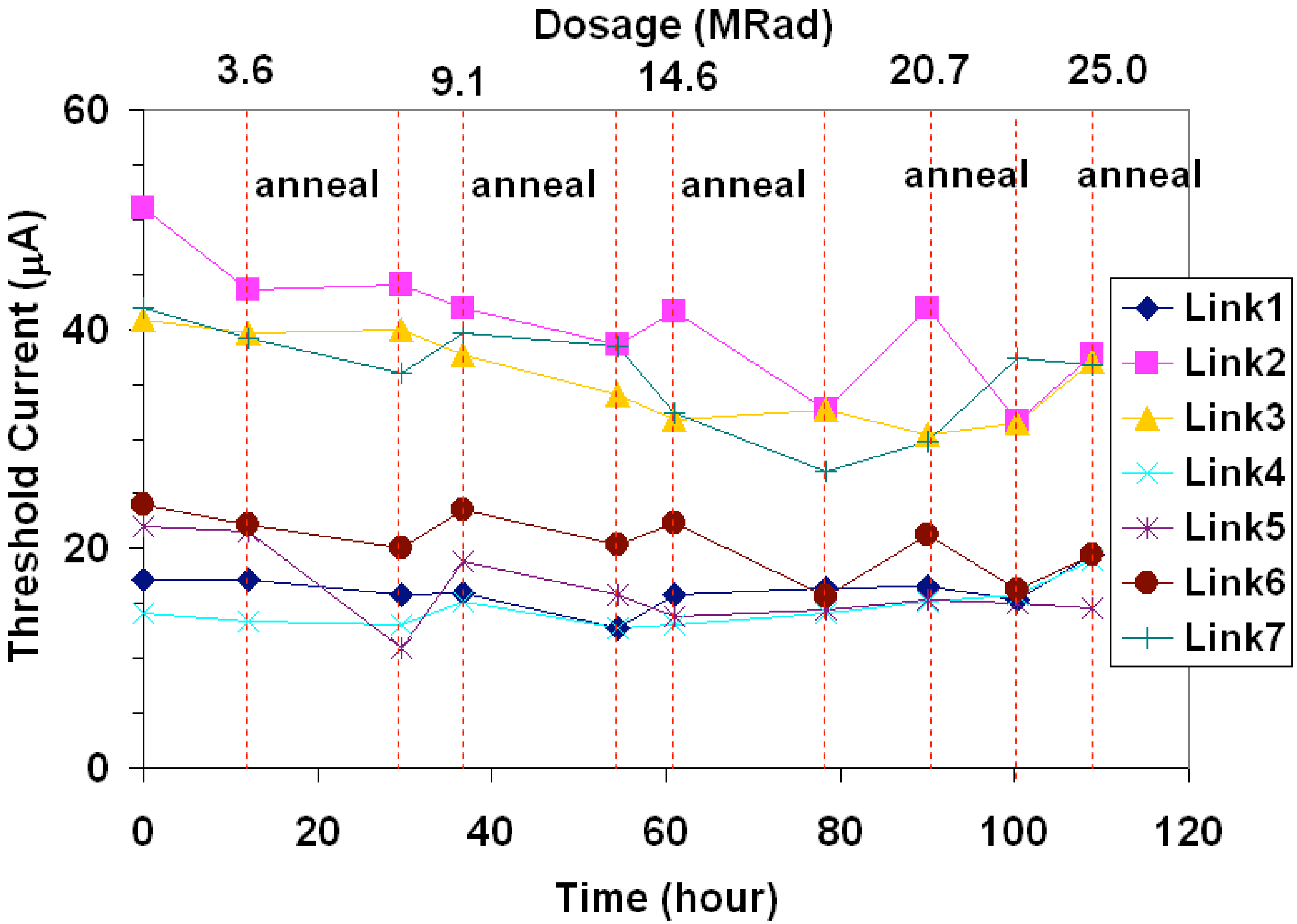
shuttle test electronics at OSU prior to shipping to CERN

opto-board test system

20 m fibers/wires spool

opto-boards

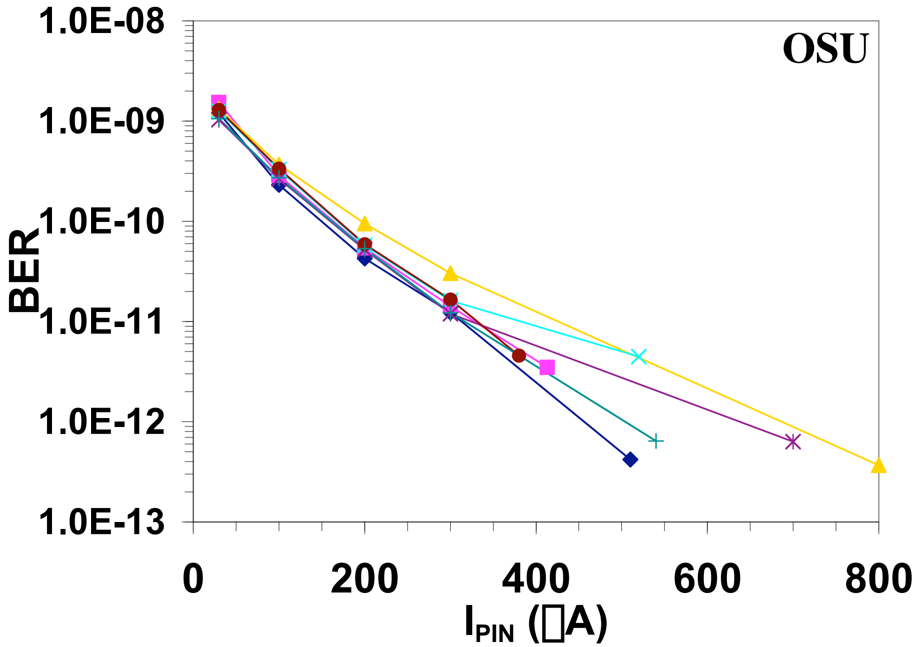
PIN Current Threshold vs Dosage

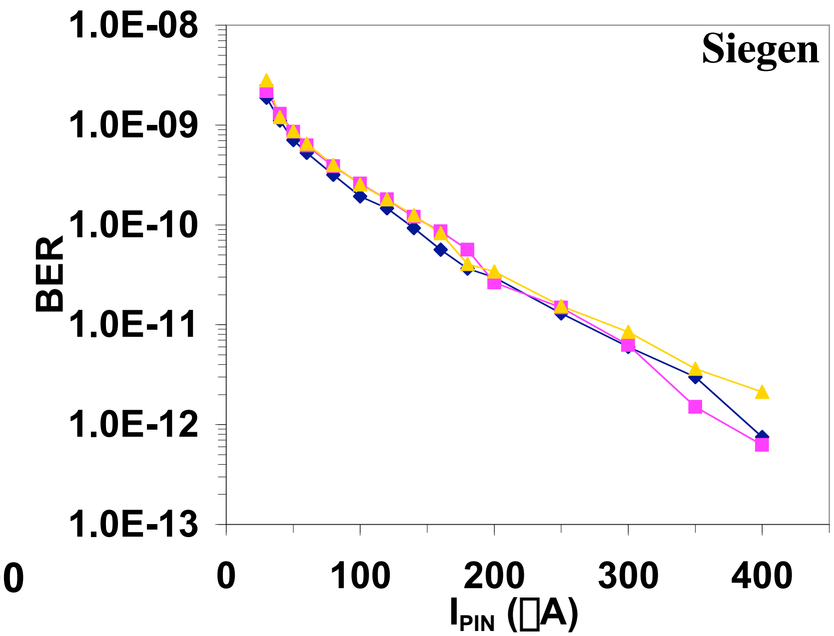


- PIN current thresholds for no bit errors remain constant

Proton Induced Bit Errors in PIN

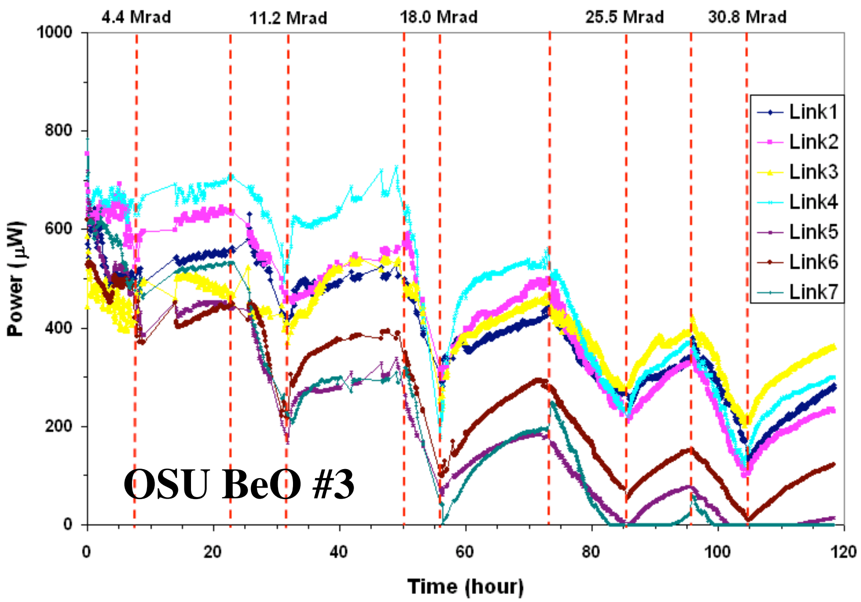
- convert observed bit errors into bit error rate at opto-link location:

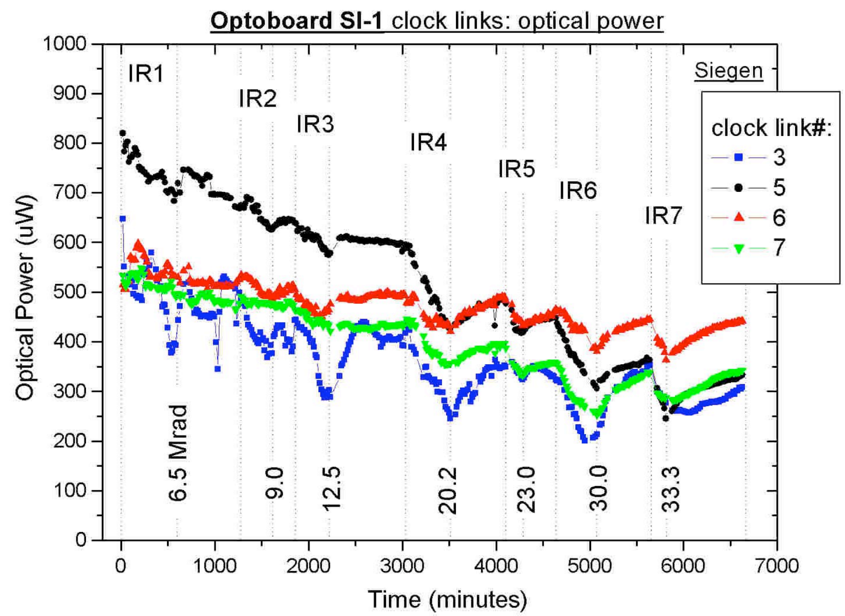




- bit error rate decreases with increasing PIN current as expected
- bit error rate ~ 3 x 10^{-10} at 100 μA (1.4 errors/minute)
  - DORIC spec: 10^{-11}

Optical Power vs Dosage





- irradiation procedure: ~ 5 Mrad/day (6 hours) with the rest of day annealing
- optical power decreases with dosage as expected
- annealing at ~ 13 mA recovers some lost power
- optical power satisfies spec after extended annealing at home institutions

Summary

- VDC-I5e & DORIC-I5e (IBM 0.25 μm):
  - ✔ radiation hard to 62 Mrad
  - ✔ meet ATLAS pixel specs
  - ✔ production is completed
- BeO opto-board:
  - ✔ several pre-production opto-boards have been fabricated
    - ❑ low PIN current thresholds for no bit errors
    - ❑ excellent optical power
- VCSEL lost significant fraction of optical power after irradiation
  - ❑ power satisfies spec after extended annealing at home institutions
- start opto-link production in July 2004