VCSEL Failures in ATLAS

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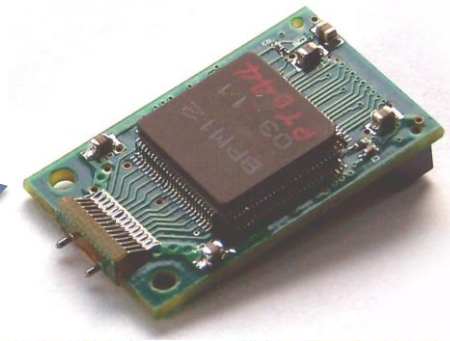
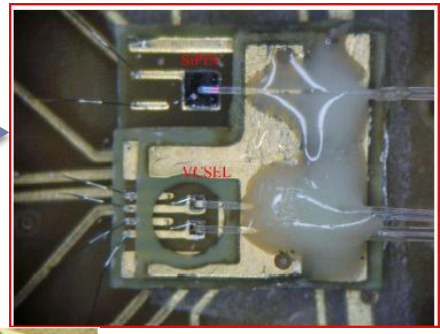
Overview

- Problematic VCSELs in ATLAS
  - Which are the VCSELs we use?
  - What failures do we see?
  - Investigations on understanding the reasons
- What keeps us alive?
  - How to keep the detectors running and taking data?
- The way out…
  - How to solve the situation reliably?

VCSELs used in ATLAS which failed so far

- Pixel and SCT have a very similar optical link. Off-detector components are the same, on-detector differ.
- The off-detector components (Tx Plugins) are equipped with a VCSEL array (12 channels) and a driving chip
- The Pixel on-detector components (optoboards) are also array based (8 channels / 2* 8 channels)
- SCT on-detector components are single laser based, realized as redundant links.
- LArg calorimeter has single channel VCSELs for the optical link on both ends.





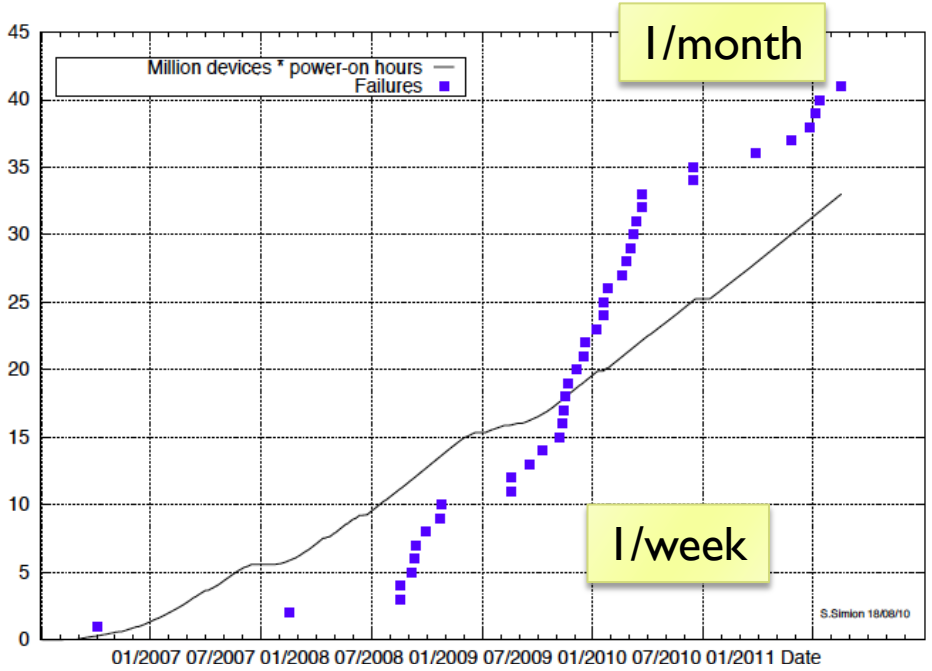
VCSELs in ATLAS not failing

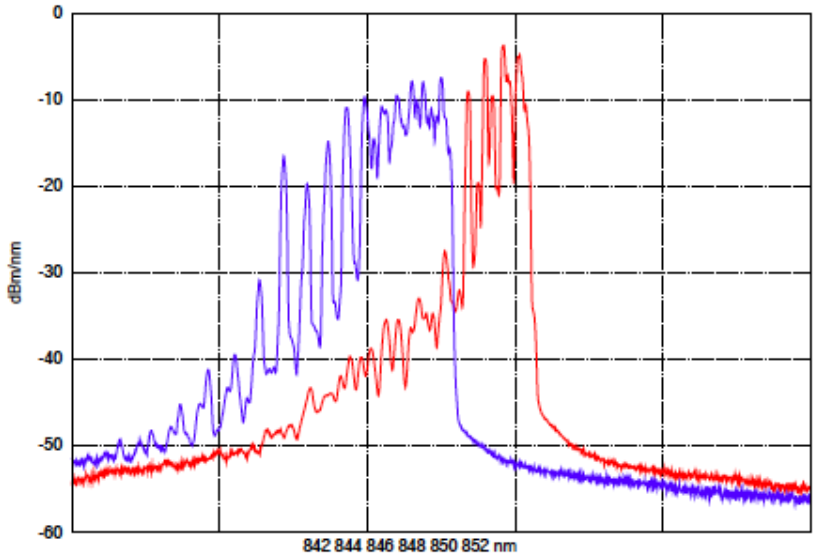
- TRT uses VCSELs (~1500) which have not shown any failure
- RPC had 3 failures which the company believes were due to ESD

- I will not discuss these two in the talk.

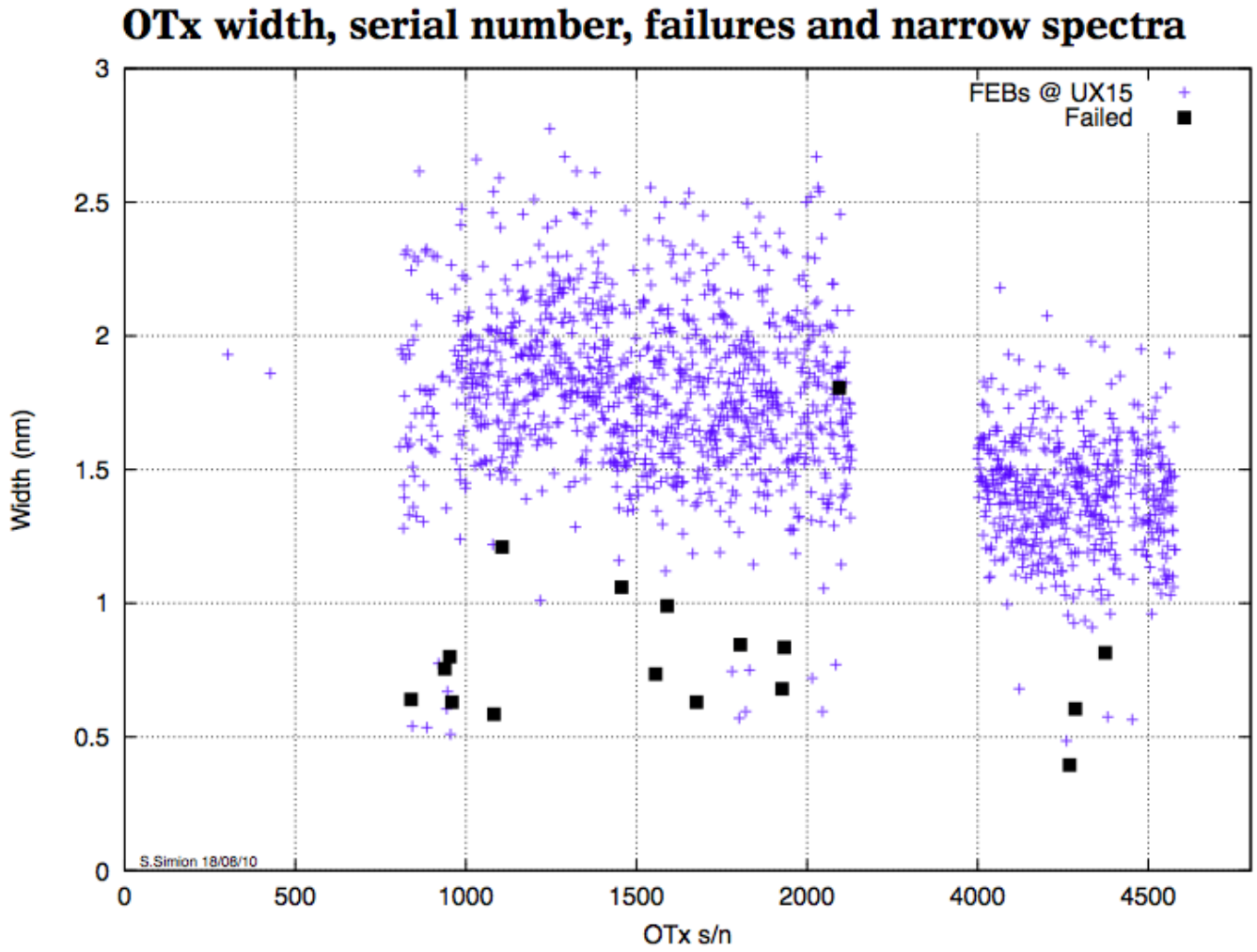
LArg VCSEL failures

- Failure rising started in 2008.
- Changed I-V curve for death lasers has been observed.
- Used optical spectrum measurements for indicating damaged lasers → Exchange them.
- From investigation of the VCSEL surfaces (EL, TEM, …):
  - Hint that the failed VCSELs had a processing defect (irregular growth of oxide aperture → stress in the active region?).
  - Attempts to trace the propagation of the defect from the oxide aperture down to the active region were not successful until now.





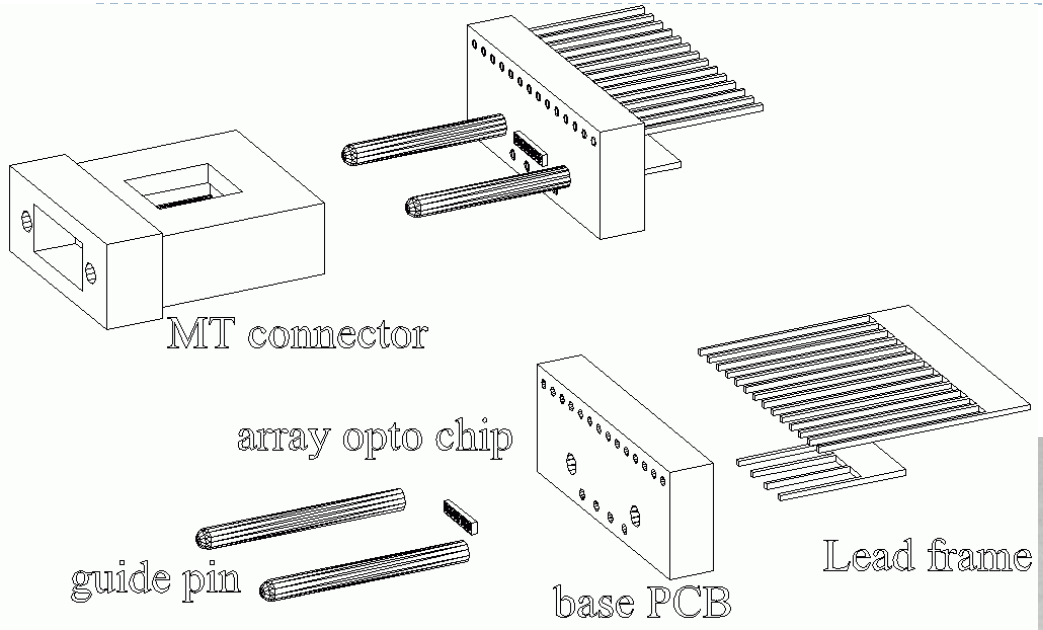
Spectrum Width contra Death



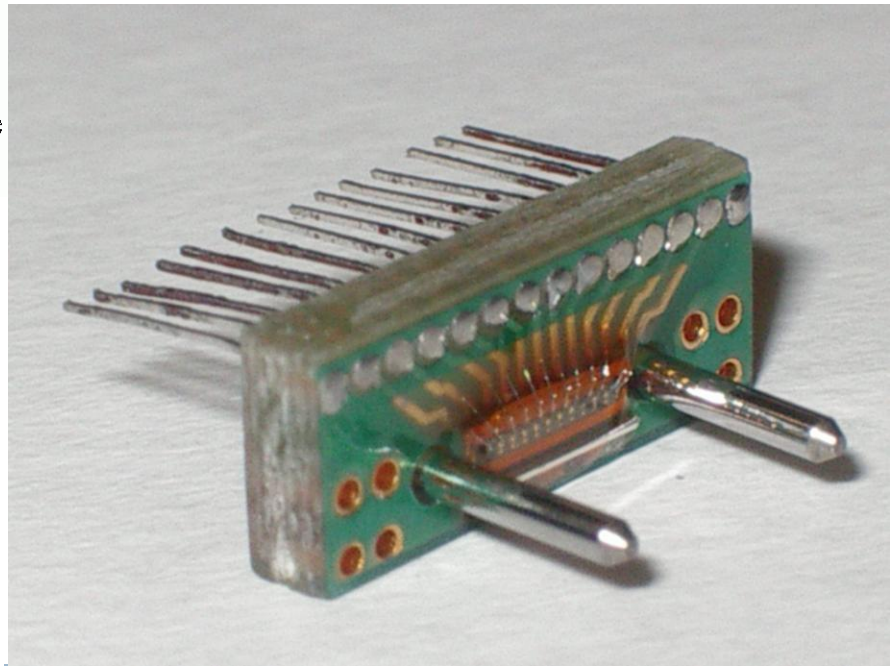
SCT/Pixel Off-detector VCSELs

- VCSELs are located on small plugins being assembled to a 9U VME card (BOC) in USA15.
  - MT packaged VCSELs
  - Truelight VCSELs, packaged colleagues in Academica Sinica, Taiwan
  - Same package used by SCT & Pixels
  - Pixel uses 8 channels out of 12, SCT all 12. Early Pixel plugins had 8-way laser array, now all Pixel plugins have also 12-way arrays.

The opto package



Epoxy Epo-Tek 353ND over active surface of VCSEL



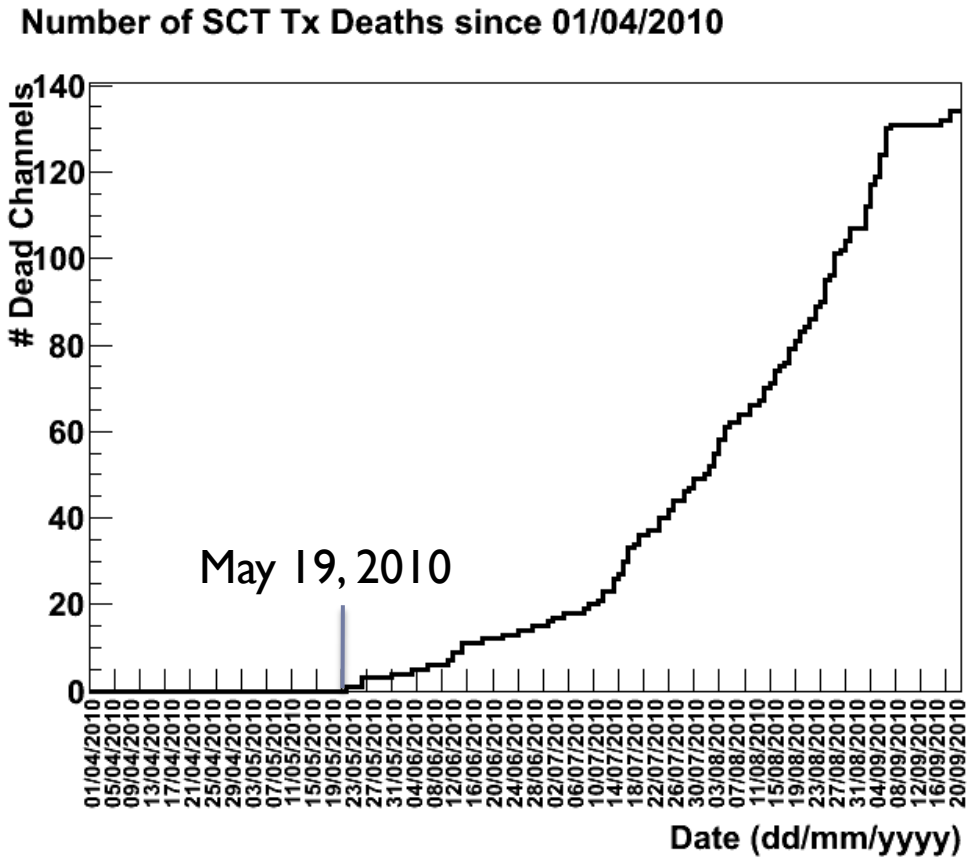
Jig used for precision placement of array wrt guide pins ➔ purely passive alignment

MT-connector inside Infineon housing with spring

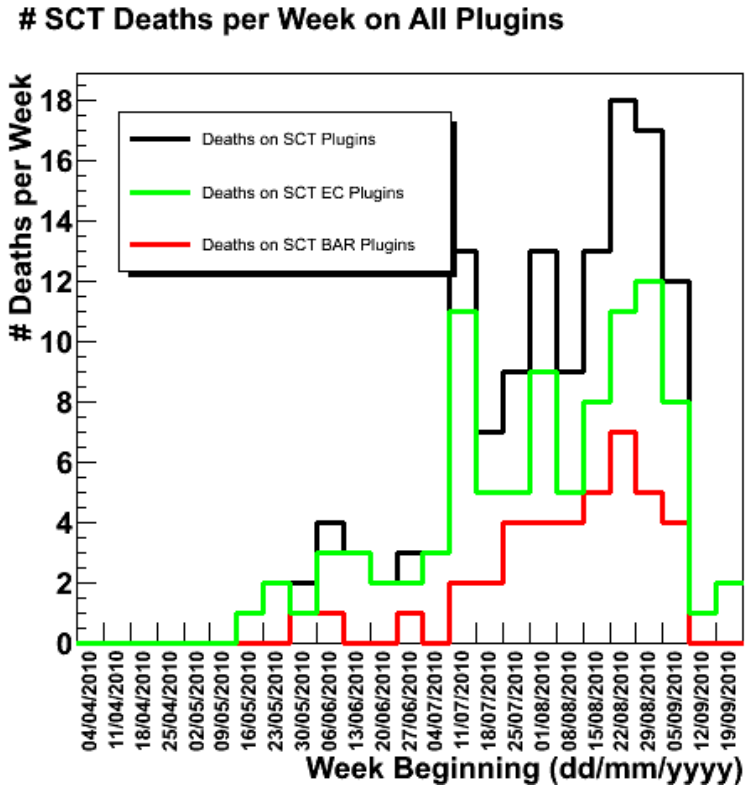
New Production for 2009

- After encountering massive failures in 2008, new TXs were produced in 2009 with very much improved ESD precautions and extra ESD QA (that was our assumption at that time).
- Complete new installation in summer 2009 for SCT and Pixel
- 4 channels SCT TX failed in 2009
  - Early failures "delayed infant mortality"
  - Burn-in @ 70C much lower than Truelight used, therefore early failures not surprising.
- Similarly there were 6 early failures for the Pixel TXs.
- No failures for > 6 months and then …

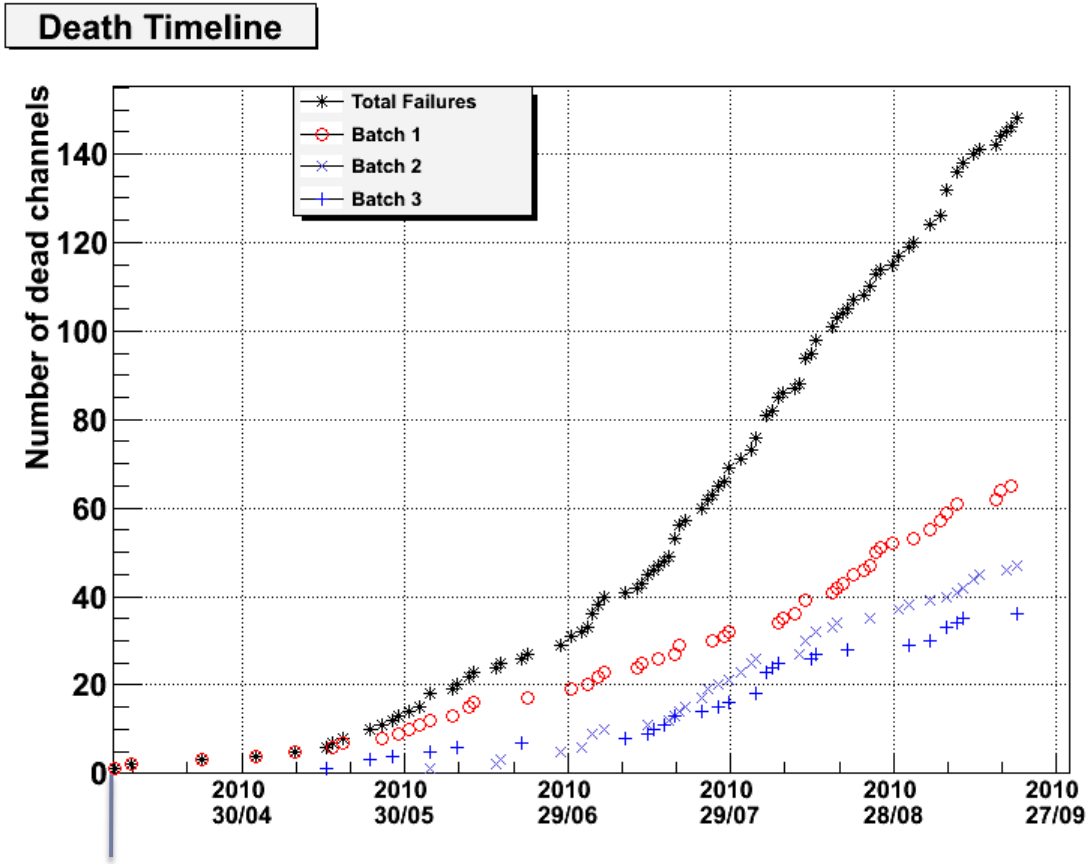
SCT Failure Rates



~135 failed channels
Rate is ~15/week

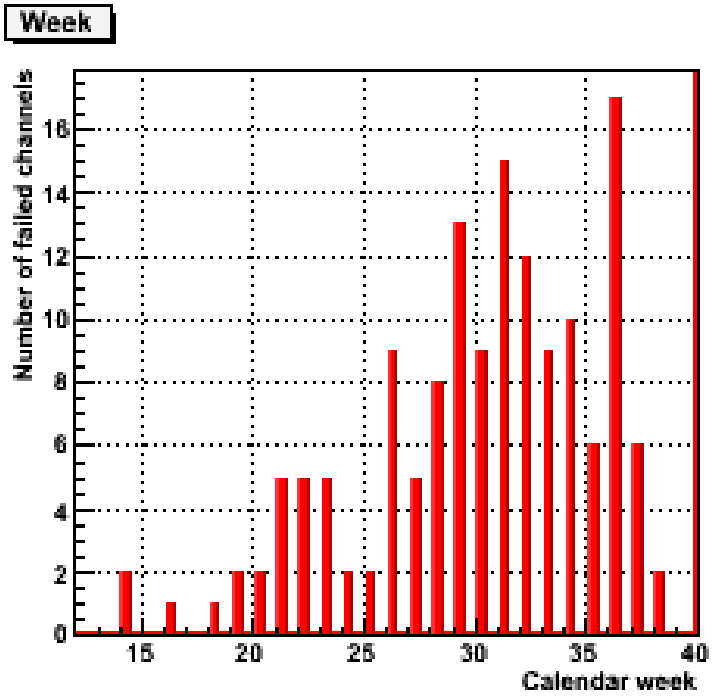


Pixel Failure Rates



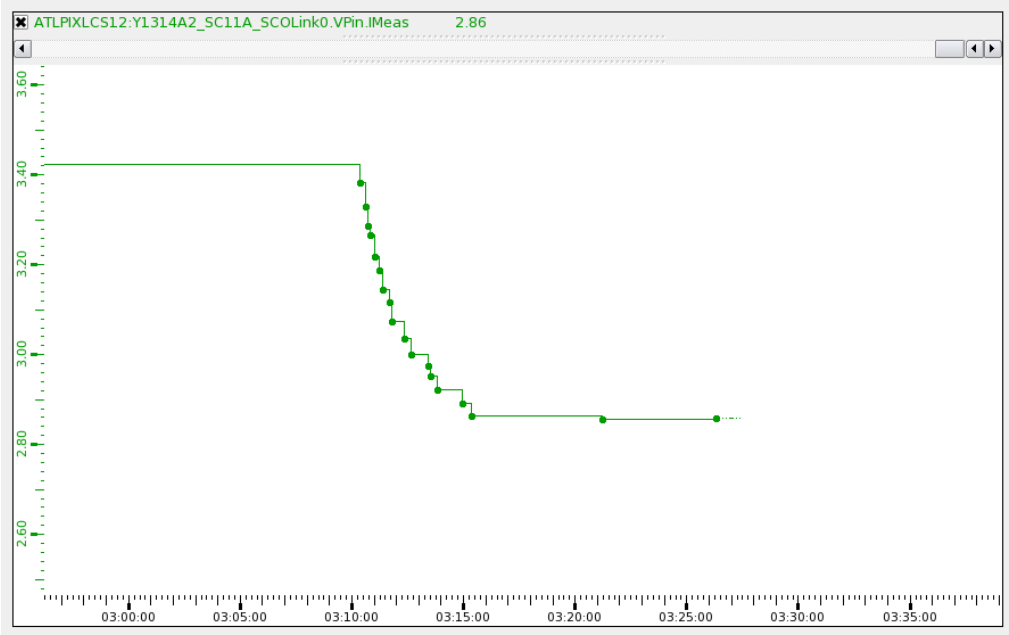
April 08, 2010

~145 failed channels
Rate is ~13/week



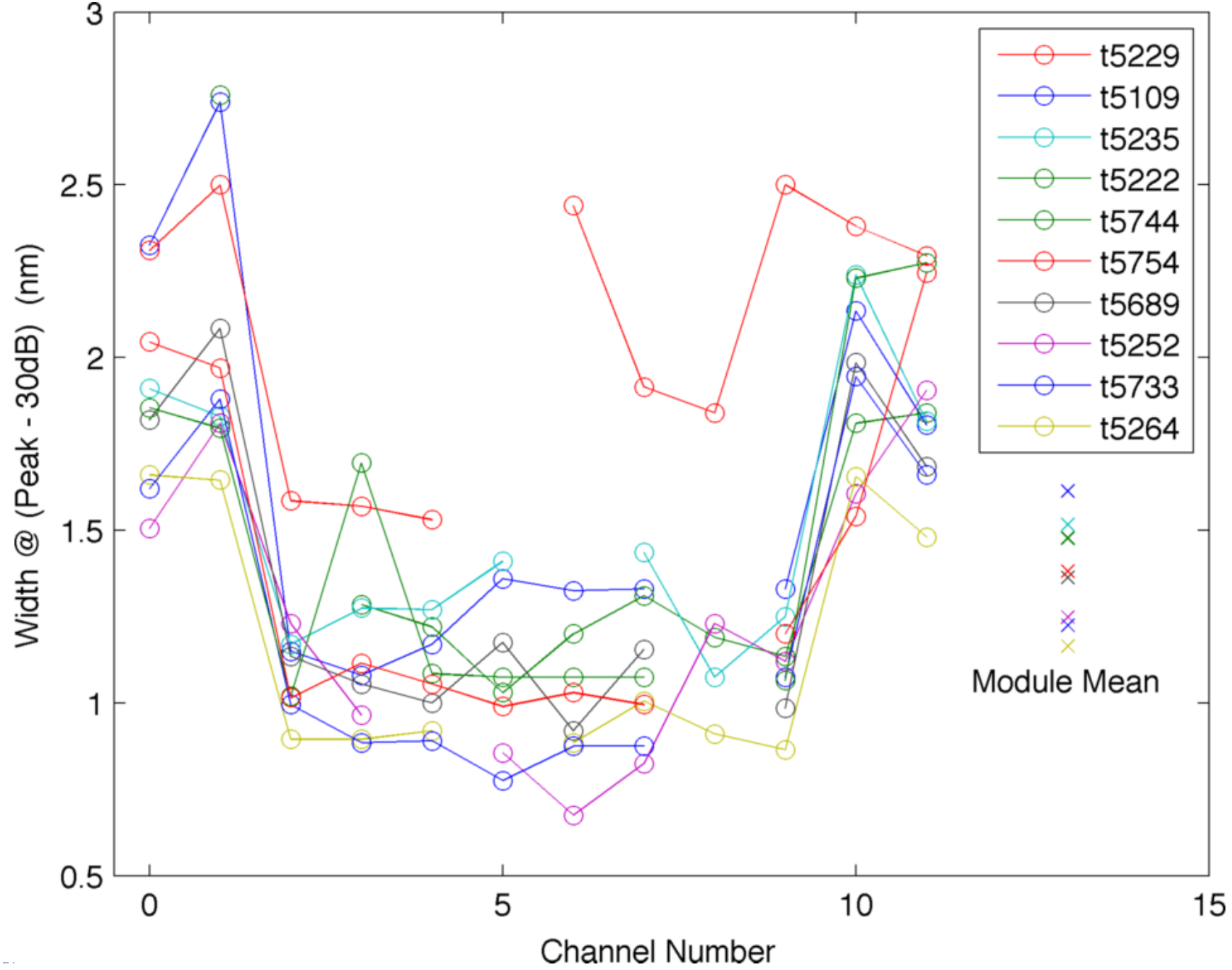
Characteristic

- The light output power of the array is measured in the pixel setup (all channels together).
- It is stable just before the dead of a channel
- While dying the light power drops over 5-10 mins.
- And the it is stable again.
- The lost channel does not emit any light anymore.



Optical Spectrum Studies

- Measure optical spectra with Optical Spectrum Analyser (suggested by LArg group after they had some VCSEL failures)
- Define width at (peak amplitude – 30) dBm
  - Very sensitive to higher order transverse modes.
- Widths of channels that have been operated are narrower than those that have not
- Look at pixel TXs which had 8 out of 12 channels operated (next slide)
- OSA measurements can indicate a damage of the laser before power falls.

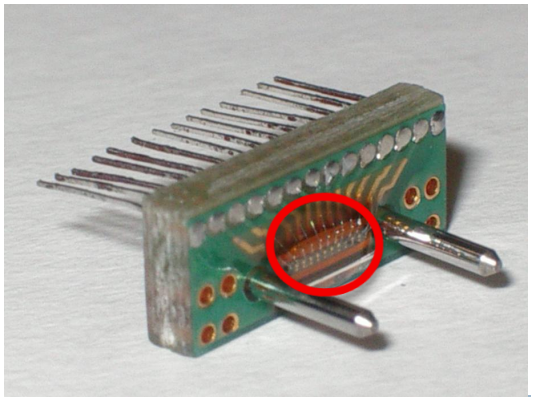

Width @ (Peak - 30dB) (nm)
Channel Number
t5229
t5109
t5235
t5222
t5744
t5754
t5689
t5252
t5733
t5264
Module Mean

Possible Causes of Failure (1)

- Electro Static Discharge "ESD" (not so likely)
- Electrical over Stress "EoS"
  - Special PCBs to monitor spikes on VDD installed in RODs in USA15.
  - No confirmed spikes seen, VDD looks very clean.
- Temperature
  - IR camera and OSA measurements.
  - VCSEL temperature does not appear to be very high (30-35°C), can't explain failure rates.
- VCSEL or package

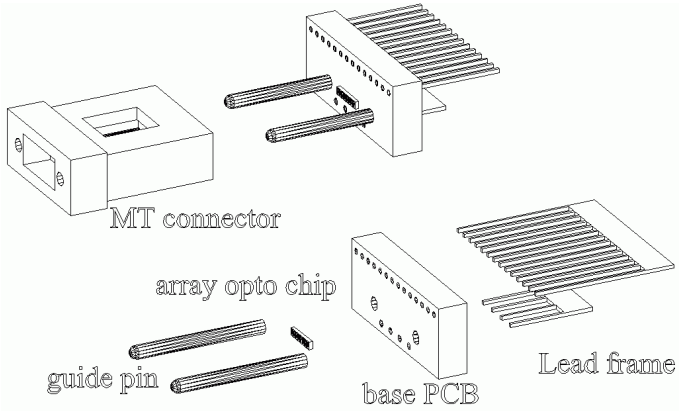
Possible Causes of Failure (2)

- VCSEL
  - Truelight VCSEL array was modified to obtain increased power by adding a passivation layer (SiN)
  - Gives lower reflectivity ➔ higher threshold and higher slope efficiency ➔ higher power at 10 mA.
  - Device could be more sensitive to oxidation? Might explain damage growing from outside of oxide aperture towards inside, hence loss of higher order modes and narrower spectra.



Possible Causes of Failure (3)

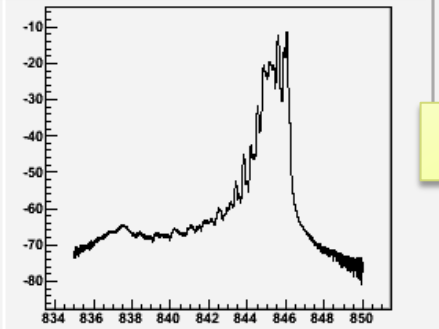
- Packaging
  - Damage from wire bonding
    - Standard gold wire bond process used
  - Epoxy on VCSEL surface causing strain?
  - Infineon spring exerting force on VCSEL and causing damage to lattice?



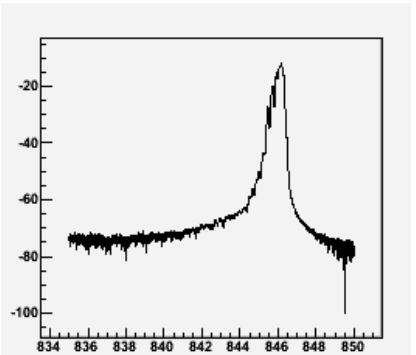
Ongoing Studies

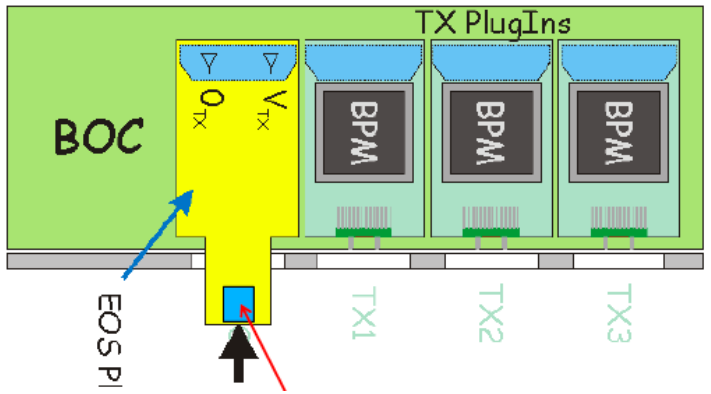
- OSA for VCSELs on TXs with failed channels and old production TXs.
  - LAr found narrow spectra was good indicator for OTx failures.
  - Look at more failed TXs and compare with new production TX spares.
- EoS Monitoring
  - Continue long term monitoring to detect rare events.

Normal Spectrum



Narrowed Spectrum



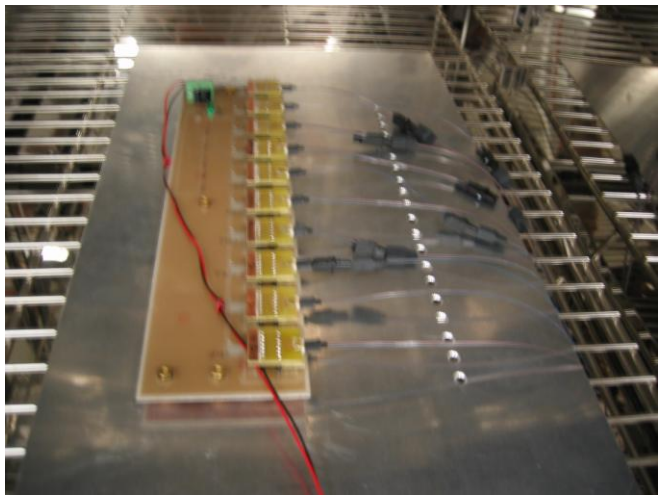


Alternative Manufacturer

- Perform accelerated aging test of AOC VCSELs
- 10 MT coupled AOC VCSEL arrays packaged
- Operate in environmental chamber at 70C
- Power 80 channels at 10 mA and measure pin currents

- Running since June 4, 2010.
- No death has been observed.
- Spectrum did not change compared to a reference laser array not under stress after ~ 2 month of operation at DC drive current.

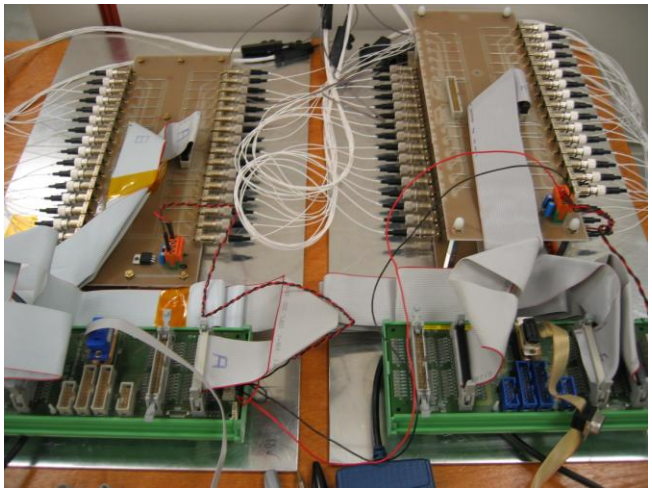
AOC Lifetime Tests



VCSEL arrays on plug-in PCBs

10 mA DC drive current.

Environmental chamber T=70C



Started 4/6/10 no failures so far
Will perform OSA analysis on all channels and on reference array

Photodiodes current read out via standard hardware used in the DCS systems (ELMB).

Optical Spectrum Studies

- Use Optical Spectrum Analyzer (OSA) as a tool to identify damage early before devices die.
- Stress tests for Truelight arrays with
  - Array with Infineon connector
  - Array with MT w/o Infineon connector
  - Array w/o glue on surface
  - Array connected with a glued wire (no wire bonding)
- Periodical test with OSA to look for spectral narrowing
- Run at room temperature and 70C.
- First indications are that spectral narrowing can be observed after ~ 2 weeks

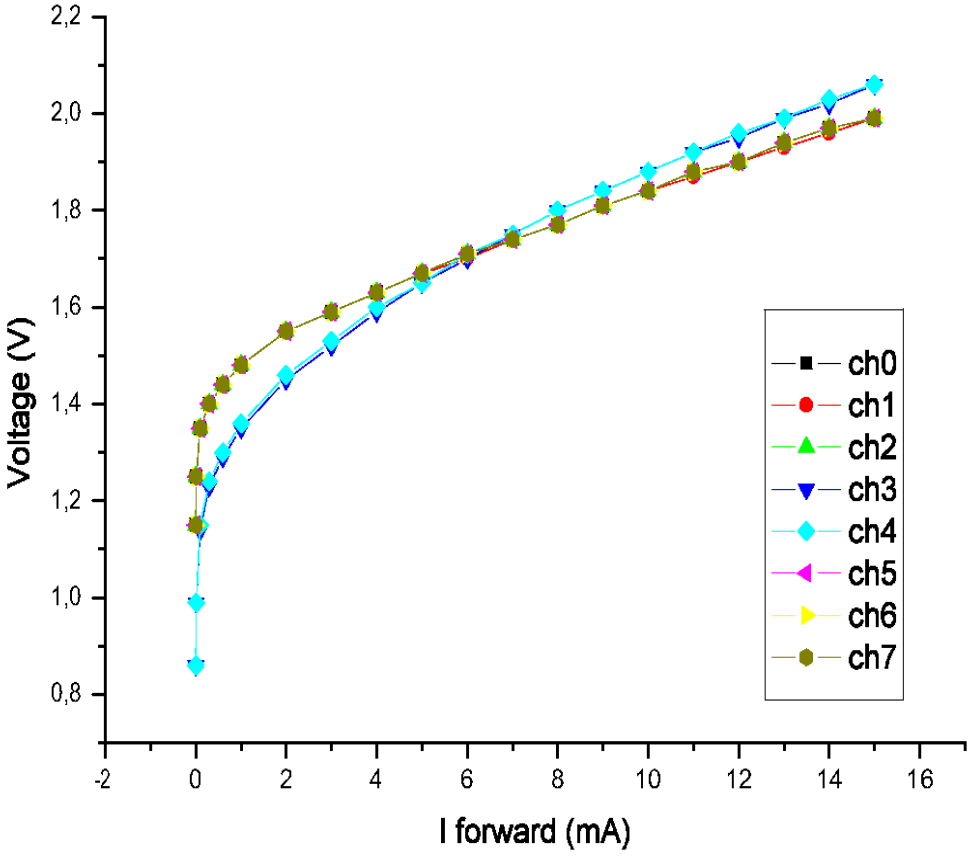
Outlook – How to overcome?

- To keep the detectors running:
  - Make spare TXs with current design as quickly as possible.
  - Reuse old production for (2nd class) spares. (deinstalled 2009)
- Understand problem and make new and better TXs to be installed during 2011 shutdown.
  - Needs an understanding of the VCSEL failure reason.
  - Make sure, that a new plugin does not suffer from the same kind of problem

BACKUP

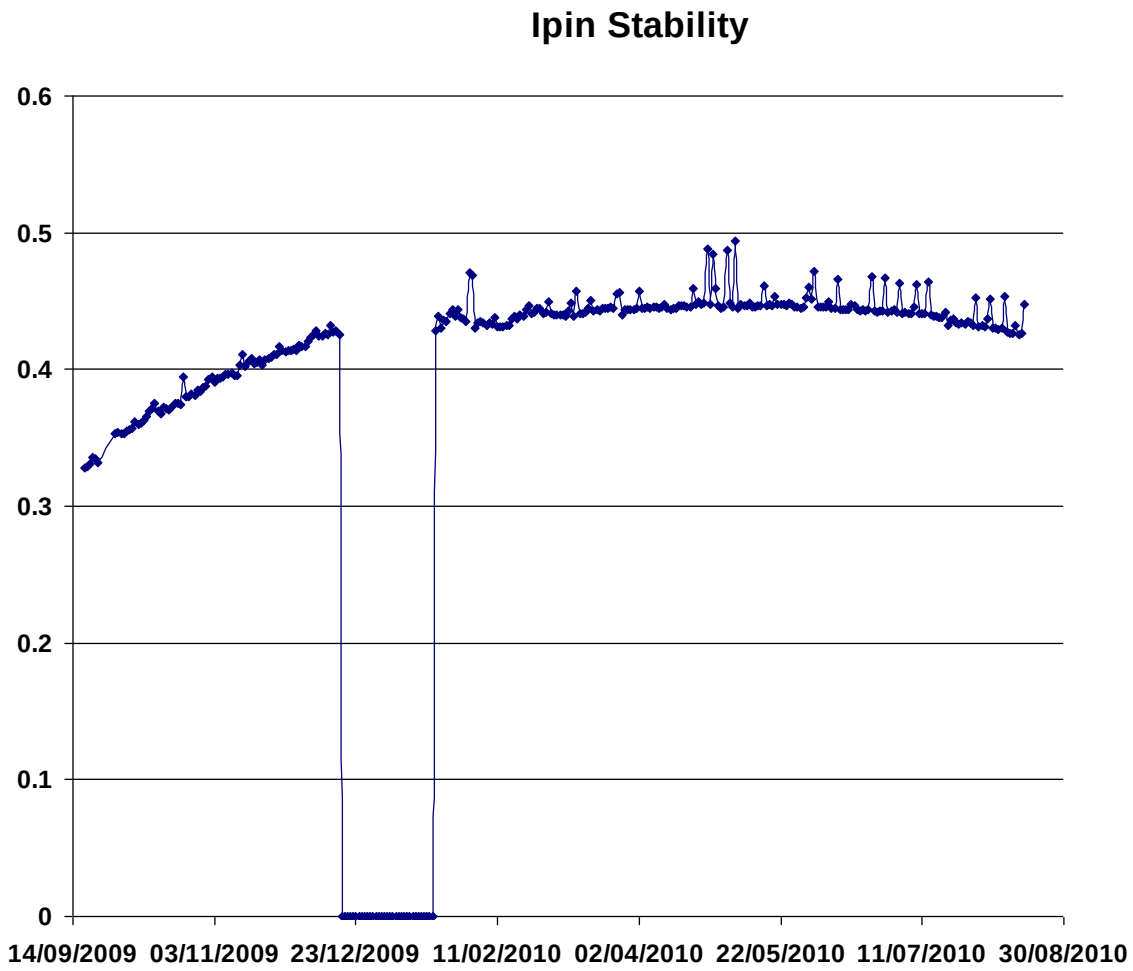
First Failures

- Many failures with original production in 2008.
- Dead channels showed shifted IV curves
- Consistent with ESD.
- VCSELs are very sensitive to low level ESD (damage threshold 400V).



ESD=Electro Static Discharge

Long Term Stability of Light Power



Effect of turning down TXDAC values estimated to be 3%

Spikes associated with calibration runs