Dependability Study of the LHC BLM Optical Link and Comparison to the Next Generation under Development

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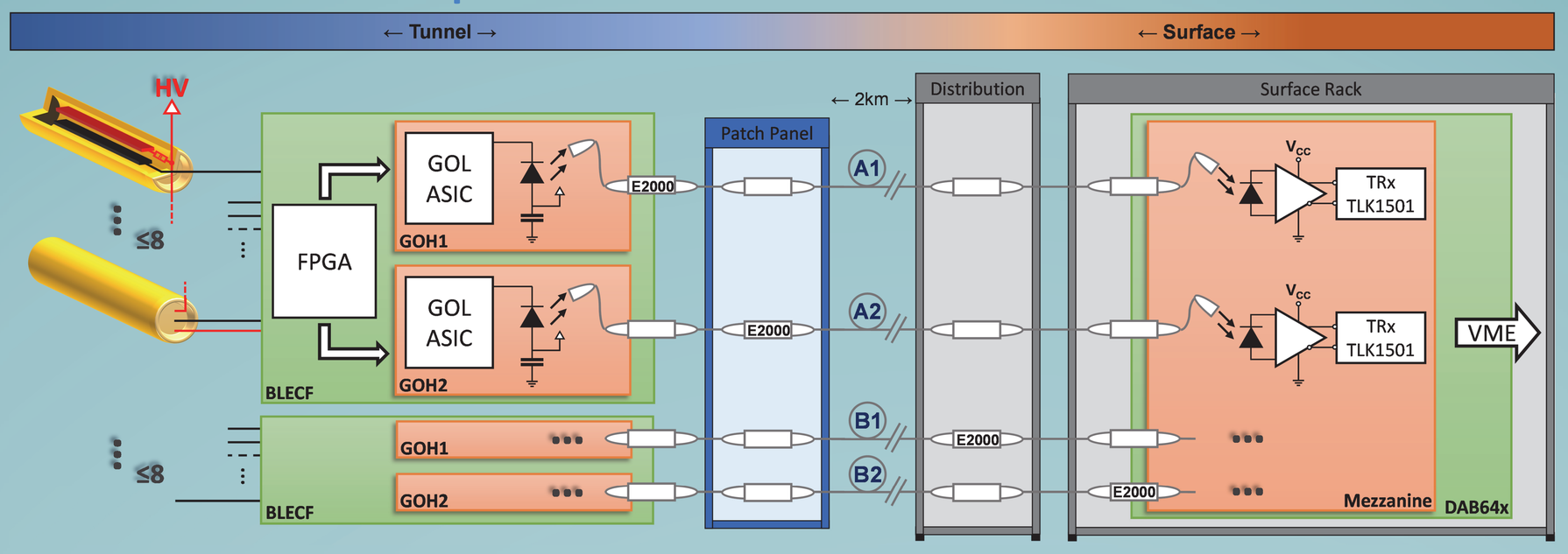
Abstract: The primary function of the Large Hadron Collider beam loss monitoring system is to protect the accelerator components from damage due to unacceptable beam losses. It acquires data from 4000 ionisation detectors distributed along the accelerator tunnel using radiation tolerant front-end electronics linked to surface electronics that perform continuous real-time processing. To connect these two parts approximately 1400 optical links transmit more than $3*10^7$ packets per second. Combining an extensive dependability study and many years of operational experience, this large and distributed system serves as the basis for developing a new link for future upgrades. This next generation link will employ the best performing parts of the existing system, but also introduce new, redesigned parts such as the surface transceiver module. The design differences with related advantages and disadvantages are compared, and two failure rate predicting models are presented including a sensitivity analysis for the observed failure mechanisms based on operational data.

optical link

Current Link:

- Ionisation Chambers (yellow colour) act as sensors which measure beam loss and provide a current signal to the tunnel electronics
- Up to 8 signals are converted to frequencies (BLECF) and conditioned by an FPGA which connects two mezzanines (GOH)
- 2 redundant GOL ASICs in the tunnel drive each a laser diode sending 320 bit packets every 40µs (**A1**,**A2**)
- The surface mezzanine card's photodiodes receive 4 optical lines (**A1**,**A2**,**B1**,**B2**) using a TLK1501 transceiver
- The surface electronics process the data and if necessary send a beam dump request to the Beam Interlock System



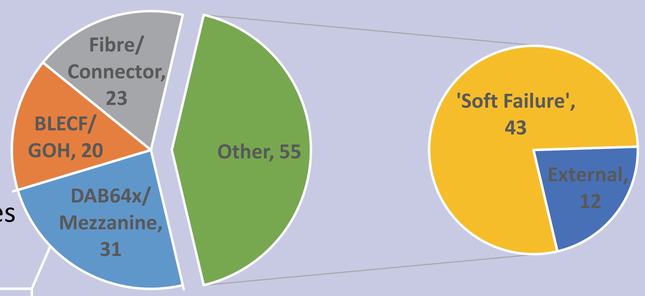
failure statistics

- System operational since **2008**; failure logging from **2012**
- ~ 150 logged issues → **129** actual failures until today:

74 'Hard' Failures

43 'Soft' Failures

12 External Causes



~ 1850 FIT

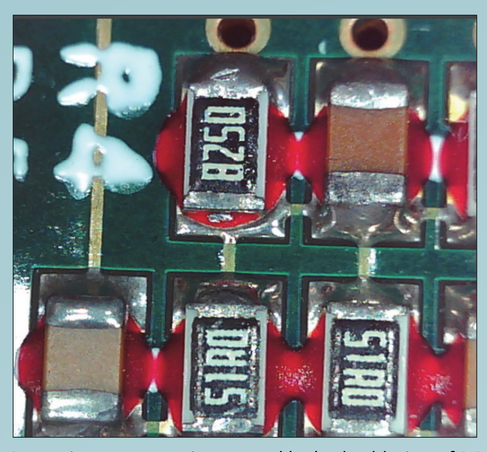
Hard: Solved by an intervention (replacement, cleaning,...)
Soft: Solved remotely (reset etc) or disappeared
External: E.g. triggered by a cooling failure

External data for the GOH:

Installed	#GOH	#Fail	FIT
2007	4900	40	63
2008	3500		
2009	2000	0	0
	10400	**40**	**≤ 53**

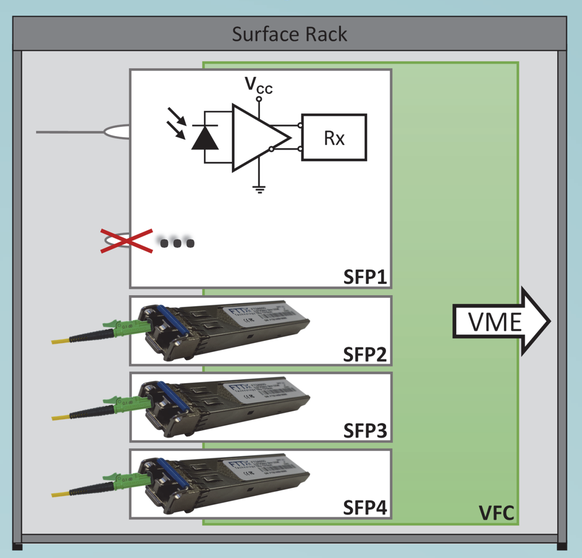
→ Dependable PCB to be re-used

[CMS calorimeter data]



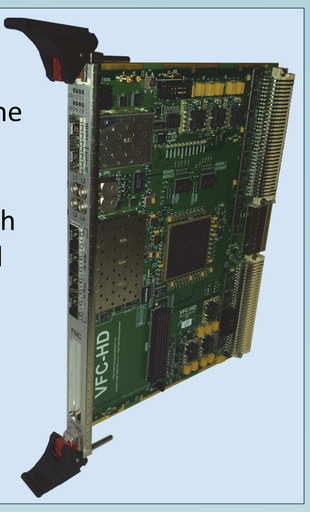
Intermittent connection caused by bad soldering of R4

Upgrade



Link Upgrade:

- Replacing the DAB64x + Mezzanine by the VFC card, currently under development, which hosts 4 commercial *Small Form-factor Pluggable* (SFP) transceivers
- Tunnel electronics and the fibre link remain the same



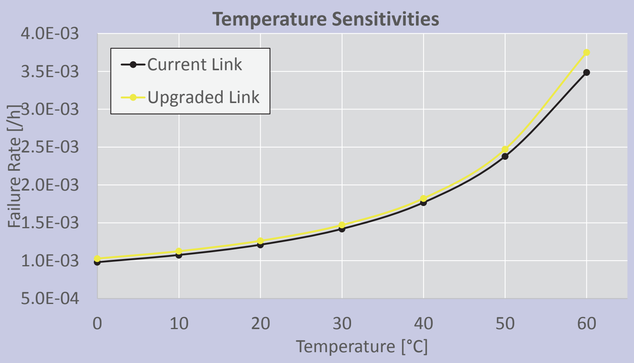
comparison

217+ Prediction and Sensitivity Analysis:

	BLECF	GOH	Conn.	Fibre	Mezz.	SFP	DAB64	VFC
217+ Prediction [FIT]	1023	(37)	46	47	144		324	~670
Test data [FIT]		53				387		
Installed Components	673	1346	5384	6730	348	1392	348	348
Total Failure Rate [/hr]	**6.9E-04**	**7.1E-05**	**2.5E-04**	**3.2E-04**	**5E-05**	**5.4E-04**	**1.1E-04**	**2.3E-04**

Current Link: **13** Failures/year

Upgraded Link: 18 Failures/year



- The new solution's prediction is currently worse than the previous
  - **424** components on DAB64x >< **1199** components on VFC
  - The VFC provides many more functionalities (not all used!)
  - Current SFP is tested < 100k hours, but with 0 failures; only receiver line is used
- High 217+ connector and fibre failure rates (But: redundant lines)
- The current link's prediction is more optimistic than the operational data
- An observed strong temperature/failure correlation (≥ 30°C) cannot be fully predicted

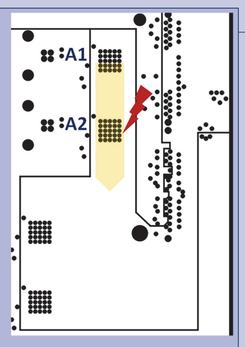
Direct Comparison:

DAB64x + Mezzanine

Design weaknesses

Several possible failure causes identified, e.g.:

- Noise influence of redundant A2 link on the power plane



Other:

- Drift of quartz (aging)
- Manufacturing quality
- Bottlenecks on the ground plane
- Line layout Transceiver pinout
- Design/Mezzanine solution flaws

Reliability:

217+ Prediction: ~ 470 FIT

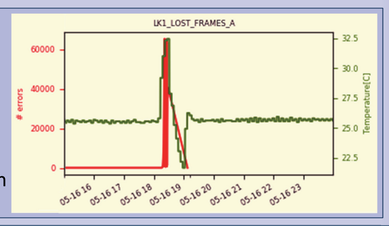
Operational data: ~ 1850 FIT

→ Higher Failure Rate than predicted!

Temperature:

Failure rate increase ~ 30°C*

*Humidity correlation possible



Lessons-learnt from previous system

VFC-HD + SFP

VFC Prediction: ~ 670 FIT (The board is still in the process of being optimized)

SFP HTOL-test: 387 FIT [0-failure,30°C,90%CL]

- **Goal: Reduced failure rate**
- SFP standard connector
  - No pigtail fibre
  - Hot swappable
  - Additional diagnostic functions
- No mezzanine anymore
  - identical transmission lines reliability (redundant A1,A2)
- New start of lifetime (new system)

- **Reduced failure rate to be shown**
- Possible new weaknesses
- Costs + Manpower
- The complex and extensive VFC board bears a reliability risk
- Tests to be performed for possible SFP temperature correlation

Conclusions:

- An upgrade of the optical link is necessary due to its high failure rate. The strategy to first redesign the surface card, then the tunnel acquisition card is reasonable because of different operational failure rates. Being already redundant, the fibre link remains the same. In parallel it is important to further improve the software part of the system, the maintenance strategy as well as carrying on and extending the failure logging. A more detailed failure analysis on the board level can help to improve general PCB design.
- Predicted failure rates for the VFC need to be considered with care, nevertheless indicate weak system parts. Amongst several qualifications, a proper manufacturing, burn-in and especially functional tests are inevitable. Before interchanging the system an acceptable low failure rate of the VFC/SFP replacement needs to be proven.

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