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The Embedded Local Monitor Board upgrade proposals

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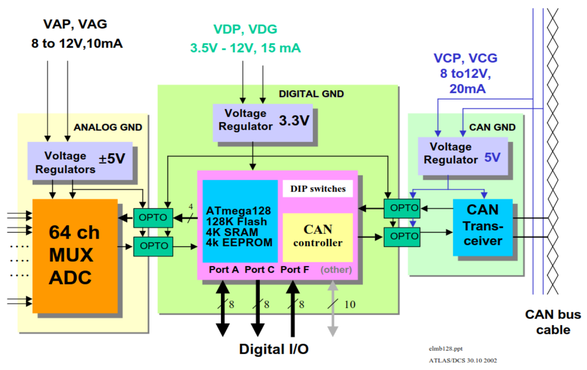
The Embedded Local Monitor Board (ELMB) – reminder

- Plug-on board used in LHC experiments for a range of different front-end control and monitoring tasks
- CAN, Digital and Analog sections galvanically isolated - flexible powering scheme
- Based on CAN serial bus system



Main features:

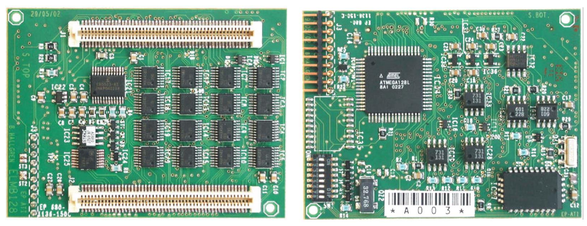
- 64 analog differential inputs
- 16-bit ADC with switchable range
- 24 Digital I/Os
- USART, SPI
- ISP
- Very reliable CAN communication

Radiation tolerance:

- 10^{12} 1MeV neutrons/cm^2
- TID: 14krad

Facts:

- Compact size 50x67mm
- Low power consuption
- 20000 boards produced



Motivation for upgrade

- Obsolescence of some components
- Higher requirements in terms of radiation tolerance in view of the High Luminosity upgrade of the LHC
- Missing functionalities: JTAG, I2C, analog outputs
- Despite being a slow-control system, the throughput of the system could be higher (currently mainly 125kbps)

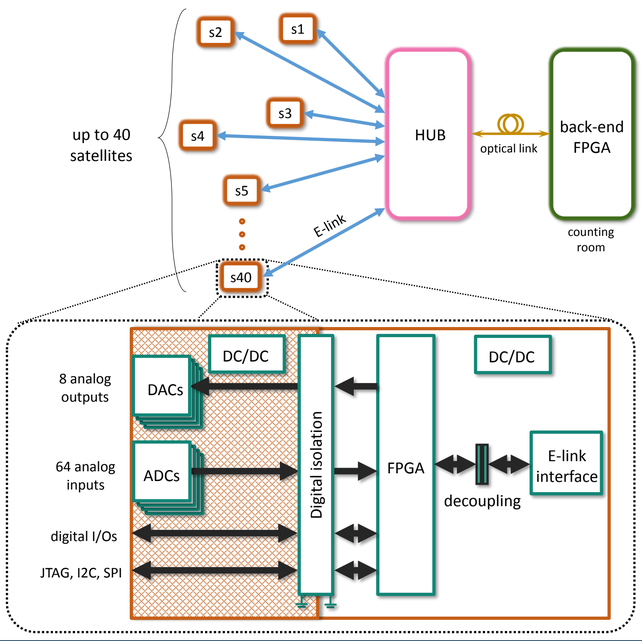
Development paths

	ELMB++ FPGA	ELMB++ GBT-SCA	ELMB2
Topology	star	point-to-point	bus
Infrastructure preserved	no	no	yes
Functionality	enriched	enriched	no change
Powering scheme	flexible	local	flexible
Throughput	high	moderate	low

It is not possible to design a system which meets all requirements and allows to use the existing infrastructure. There have been 3 different development paths created.

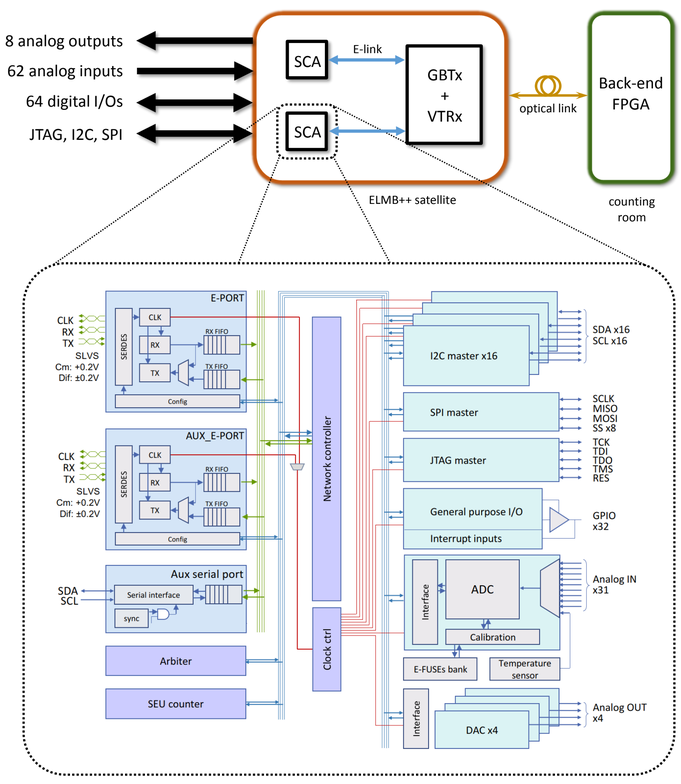
One called ELMB2 is aimed to keep full backwards compatibility with the original ELMB in terms of cabling infrastructure, hardware interfaces and read-out software. The other two named ELMB++ are aimed to assure higher radiation tolerance.

Concept I: ELMB++ with FPGA-based satellite



- Star tolopogy
  - HUB connected via optical link with control room and via E-links with ELMB++ Satellites
- Satellites spread up to 20m from the HUB
- Powering scheme as in ELMB
  - Communication part of the satellite is galvanically isolated from local electronics; can be supplied either locally or remotely;
- Features can be fit to the user.
  - FPGA in the satellite of ELMB++ allows to introduce user-specific features
- HUB might be based on GBTx or FPGA
  - Some pre-processing of a data might be introduced inside FPGA-based HUB

Concept II: ELMB++ with GBT-SCA-based satellite

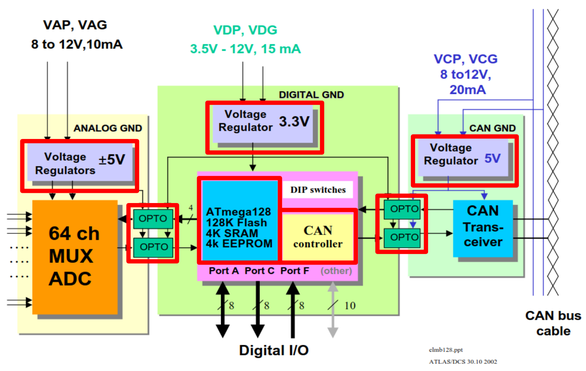


- Based on the GBT chip set
  - All components are radiation hardened by design, SEE free
- Point-to-point topology
  - Each satellite directly connected with the control room via optical link
- GBT-SCA chip[1] has all required functionalities
  - 31 analog inputs, 4 analog outputs, 32 GPIOs, JTAG, SPI, I2C
- Must be powered locally
  - Single-ended ADC integrated inside the GBT-SCA needs to have the same ground reference as signals being measured.
- Prototypes soon available
  - Users can already use the VLDB boards for testing and development

Concept III: ELMB2

Since the main advantage of the ELMB2 is backward compatibility with the ELMB, the aim was to achieve as high radiation tolerance as possible with COTS. The radiation tests[2] of ELMB provided information about the weak points and those have been improved for ELMB2 using CERN's experience with radiation testing of COTS components:

- Optocouplers are sensitive for neutron displacement damage, they stop working sooner than the other components on the board. They have been replaced by digital isolation.
- CAN controller is obsolete. It has been replaced by an equivalent component.
- Voltage regulators have been replaced by more radiation tolerant ones
- Microcontroller has been replaced by a space graded version with exact same functionality



The PCB was designed in the way which enables using also another microcontroller, with embedded CAN controller. This option does not aim in high radiation tolerance, but in compatibility and cost efficiency.

Radiation tests of ELMB2

Testbench:

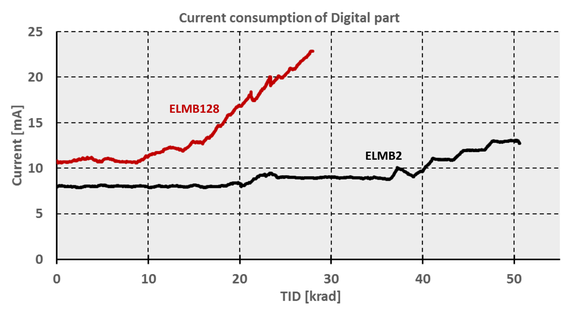
12 boards of ELMB2 have been irradiated in CHARM facility. Conditions differed from the ones during ELMB128 (latests version of the ELMB) radiation tests, so few of ELMB128 were irradiated as well for comparison. CHARM facility provides mixed-field environemt, what means there were conditions from TID, NIEL and SEU tests combined together which is close to the real operating conditions. Thus the testbench has been prepared in the following way:

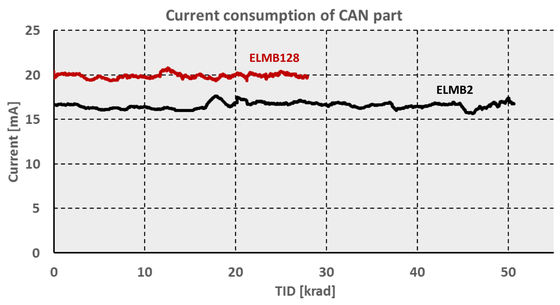
- Current consumption of each section of each board was measured separately
- A special firmware has been prepared for test purposes, it tests RAM, EEPROM and FLASH memories as well as ADC, CAN and microcontroller registers for single event upsets every 5 seconds and reports the results via CAN
- ADC inputs were connected to voltage references to check the performance of ADC measurements in radaition environment

Results of Total Ionizing Dose test:

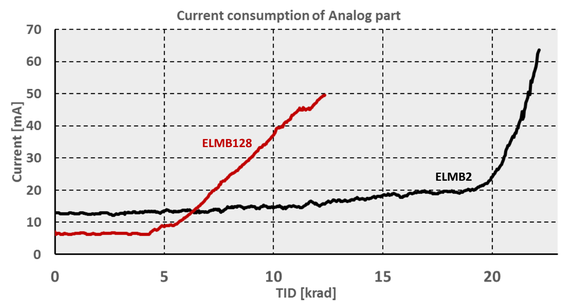
The plots show the current consumpiton of analog, CAN and digital part of one representative ELMB2 and one ELMB128 for comparison. The curves show only the range where certain part was fully functional.

Communication and digital features of ELMB2 were working properly even after 50krad of TID, when the test ended, while for the predecessor, ELMB128 stopped after reaching 28krad.



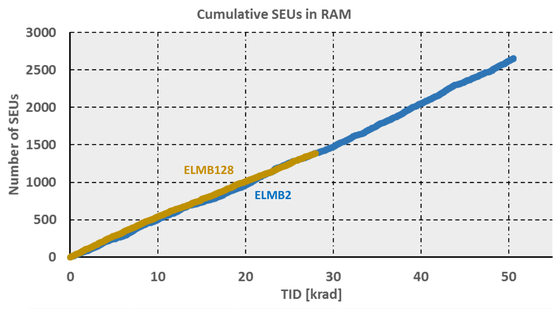


Communication with ADC and performing the measuremets of analog values were possible up to 22krad of TID for ELMB2, while it was not possible after reaching 12krad of TID for ELMB128. The impovement in analog part comes from replacing the voltage regulator and optocouplers.

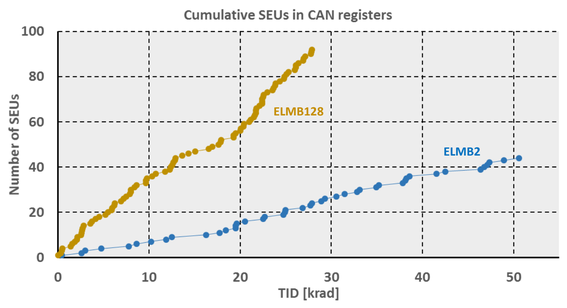


Results of Single Event Upset test:

The plots show the cumulative number of SEUs detected in SRAM memory of microcontroller and internal registers of CAN controller. As the ELMB128 also the ELMB2 has watchdog-based mechanism to reinitialize the CAN controller in case of interrupted communication. However, as new CAN controller is more robust against SEUs, the communication is more reliable.



The measurements show that SEU rate for SRAM memory is similar for ELMB128 and ELMB2. Other tested memories and registers did not produce enough SEUs to plot their amount over TID, so the estimated cross-section is presented in the table.



Tested part	Number of tested bits	Number of SEUs	Fluency [HEH/cm^2]	Cross-section [cm^2/bit]
RAM	16384	2652	1.94×10^{12}	8.34×10^{-14}
EEPROM	16384	<1	1.94×10^{12}	3.14×10^{-17}
FLASH	327680	<1	1.94×10^{12}	1.57×10^{-18}
MCU registers	80	3	1.94×10^{12}	1.93×10^{-14}
CAN registers	272	44	1.94×10^{12}	8.34×10^{-14}
ADC registers	288	2	9.87×10^{11}	3.58×10^{-15}

Presented analysis is based on chosen, representative boards. More precise results related to all irradiated boards are to be published soon.

Conclusion

- 3 development paths have been defined
- Backward compatible ELMB2 was designed and firmware developed, ready for production of two versions: one oriented for cost-efficiency and one based on space-grade microcontroller
- Radiation tests of ELMB2 show significant improvement of radiation tolerance in comparison to the original ELMB

References

[1] A. Caratelli et al 2015 JINST 10 C03034, *The GBT-SCA, a radiation tolerant ASIC for detector control and monitoring applications in HEP experiments*

[2] H. Boterenbrood and B. Hallgren, 2004, *SEE and TID Qualification of the ELMB128 Series Production, ATL-DQ-EN-0033, EDMS Id 811704, https://edms.cern.ch/document/811704/1*