Single gain radiation tolerant LHC beam loss acquisition card

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Abstract: *The beam loss monitoring system is one of the most critical elements for the protection of the LHC. It must prevent the super conducting magnets from quenches and the machine components from damages, caused by beam losses. Ionization chambers and secondary emission based detectors are used on several locations around the ring. The sensors are producing a signal current, which is related to the losses. This current will be measured by a tunnel card, which acquires, digitizes and transmits the data via an optical link to the surface electronic. The usage of the system, for protection and tuning of the LHC and the scale of the LHC, imposed exceptional specifications of the dynamic range and radiation tolerance. The input dynamic allows measurements between 10pA and 1mA and its protected to high pulse of 1.5kV and its corresponding current. To cover this range, a current to frequency converter in combination with an ADC is used. The integrator output voltage is measured with an ADC to improve the resolution. The radiation tolerance required the adaption of conceptional design and a stringent selection components.*

Introduction of BLM System

3680 Ionization chambers

290 Secondary emission monitors

650 LHC beam loss acquisition cards
In the arc the cards are installed underneath the magnets
In the strait section the cards are installed nearby side tunnels, because of the reduced radiation levels
Up to 6 x 19" crates with 10 DACs are installed in the straight section
Signal cable with length up to 600 m
Optical fiber with a length up to 2500 m

340 threshold comparators (TC)
including the BLM mezzanine card with optical receiver

25 VME creates are distributed around the LHC
1 powerPC for data logging
1 Combiner card connected to the interlock system
2 timing cards (CTRV, BOBR)
up to 16 TCs

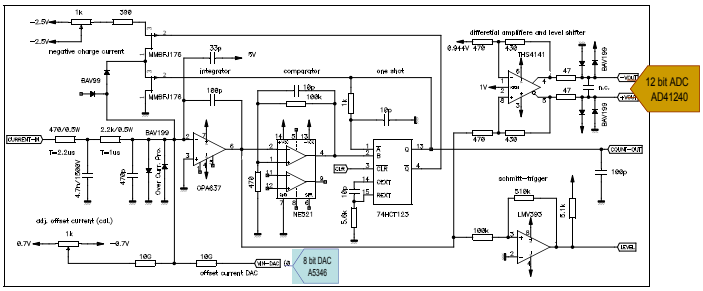
5 BLECFT tester
with USB readout, for test, development, DAC calibration and installation commissioning

Specification of the data acquisition card

Current measuring range	2.5pA	1mA
Error from 1nA to 1mA	-25% / +25%	
Error from 10p to 1nA	-50% / +100%	
Maximal input current	561mA	
Input voltage peak	1500V @ 100us	
Radiation	500Gy in 20yr	
Digital supply	+ 2.5V	
Analogue supply	+/- 5V	
HV monitor input	0V	+5V

The exposition to radiation leads to the requirement of a tolerance of a maximum of 400Gy integrated dose for 20 years LHC life-time.
For the system and the performed tests a maximum value of 500Gy was chosen to ensure a safety margin.
The employment of the system for the LHC protection requires a high reliability of the CFC card.
To achieve a reliability level SIL3 (10^{-7} to 10^{-8} failure/h) of the system, several different test modes, status information, protection circuits and a redundant data transmission are implemented.
For the verification, different tests have been performed, like irradiation, temperature and burn-in test. An additional test in magnetic field was included.

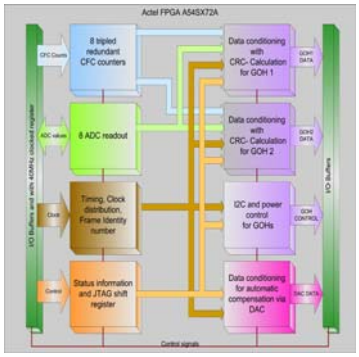
The data acquisition card



Current to frequency converter (CFC)
Very large dynamic range
No charge loss/ no dead time
ADC to measure partial counts
decrease of response time
increase of dynamic rang
DAC for automatic feedback loop
compensation of leakage current due to integrated dose

Schmidt Trigger for integrator output survey
sends warning to surface electronics
Input over voltage and current protection
fast protection diode
high voltage capacitors
leaded input resistors
Irradiation test of single components
JFET, OP, Comparator, One-shot
ADC, DAC, FPGA

Functional description of the FPGA



Block diagram of the Actel FPGA A54SX72A

All input signals are registered with 40MHz, due to some malfunctions of finite state machines (FSM) and other logical parts of the FPGA.

Due to the limited FPGA size (an overall of 6036 cells), only the CFC counters, which are most critical, have been tripled.

The ADC values are insignificant for the threshold value comparisons. Tripling will decrease the probability of a fault beam dump provoked by a SEU.

The two GOH interfaces are redundant blocks, which are connected to the GOHs. The GOH interface is calculating the CRC and sending the data to the GOH.

The 40MHz system clock is connected to the hardwired HCLK and to the 4 quadrant QCLK. This opens the possibility to distribute the 40MHz internally in accordance to the importance of the blocks.

Tests, test-modes and error detection

To ensure the system is working properly and to increase the reliability, several tests, test modes and error detection system have been added.

• Before the installation, a calibration and an initial test are performed using a BLECFT USB card, which performs an automatically generated functional test pattern. This system will also be used for additional tests after tunnel installation.

• The constantly performed test using 10pA offset current, provides a count every 20s. After absence of the count for more than 120s, an error bit is activated.

• For the data transmission a CRC is added, which will be verified at the TC. Due to the redundant link, even if one transmission is corrupted, data are still available.

• The card identity number CID is sent and checked every transmission to ensure the used threshold table belongs to the correct chamber.

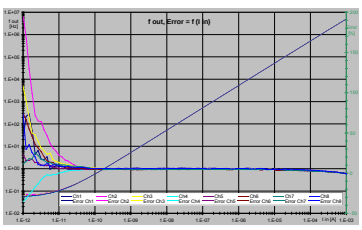
•Lost data transmission will be detected by the check of the frame identity number FID at each data transmission.

•With the CFC_TEST activated (HV ≥ 1655V for 240s), 100pA are added on the input of the CFC, to test the corresponding response of the acquisition chain. It is foreseen that this test will be carried out before each beam fill.

•A HV modulation test uses capacitive current injection via chamber electrodes to detect the degradation of the complete acquisition chain. This test will be carried out before each beam fill.

•There is also 32 status bits which are sent and readout every transmission. Depending on the indicated malfunction a beam-dump is initiated.

Measurements



Measurement: Only CFC input circuit

• Dynamic range over 9 decades from 1mA to 1pA

• From 1nA to 1mA error smaller than 6%

• From 10pA to 1nA error smaller than 25%

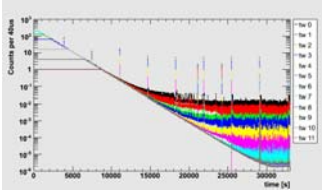
• From 1pA to 10pA error smaller than 200%

Measurement: Complete data acquisition chain
(input current decreased in logarithmic steps starting 1mA)

• Max values of the 12 running sums

• Running sums from 40us to 84s

• 8 orders of magnitude



Conclusion

• An acquisition system to measure current in the range of 2.5pA to 1mA has been constructed and tested.

• An error smaller than the 6% from 1mA to 1nA and smaller 25% from 1nA to 10pA has been measured. Smaller error than 200% at 1pA (2.94pA measured value)

• A radiation tolerance of 500Gy has been achieved, two components.

• The one shot 74HCT123 showed some malfunction at 340Gy but it recovered after stopping the irradiation.

• The antifuse FPGAs form Actel did withstand radiation between 480Gy to 790Gy, no SEU was detected up to $1x10^{12}$ p/cm².
• Several protection and supervision circuits are build in and were tested successfully.

• The optical link is radiation tolerant due to its design and in a test setup installed in HERA, no CRC occurred for several months.

• The system passed a temperature test (0 to 70°C) which caused some CRC errors while data transmission.

• The complete system was also tested in a magnetic field up to 1000Gauss with a small offset current change.