Investigation of submicron Si-Ge BiCMOS technology node behaviour for two ASIC under proton beam irradiation

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Study motivation

- **R**ead**O**ut **C**hips designed by OmegaMICRO for harsh mixt-field radiation environment (high energy physics (HEP) detectors, astrophysics laboratories and medical imaging).
  - ASICs reliability in hard hadron spectra with at leas one component peaking above 1 GeV.
  - Semiconductor structure tolerant beyond 400 krad (Si).
  - High Energy Hadrons (HEH) expected fluencies in LHCb, $1.2 * 10^{12}/cm^2$.
- Accelerated irradiation tests, data analysis and extrapolation to a given environment.

MAROC3

➢ Large Hadron Collider beauty (LHCb) single-arm spectrometer.
- ASIC considered for Ring Imaging Cherenkov (RICH) sub-detector: front-end readout upgraded to 40 MHz (LHC bunch crossing at 25 ns spacing).

SPACIROC2

➢ JEM-EUSO - Japanese Experiment Module on the International Space Station.
- extremely high-energy cosmic rays space observatory: focal surface with over 5000 Multi-Anode Photo Multiplier Tubes (MaPMT).

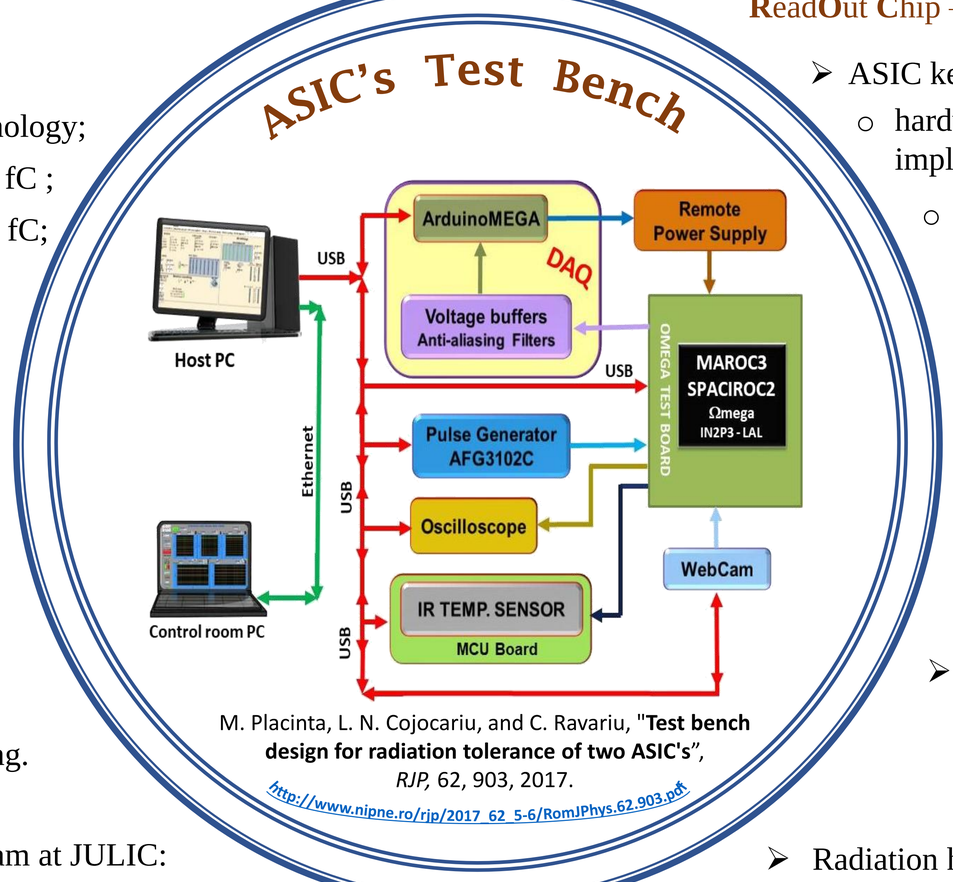
MAROC3

Multi-**A**node **R**ead**O**ut **C**hip – 3^{rd} generation

➢ Full readout ASIC specifications:
- 64 input channels in 0.35 μm SiGe BiCMOS technology;
- channel to channel cross talk of 1% and noise of 2 fC ;
- 100% trigger efficiency for low input charge of 50 fC;
- single photon-electron counting capability;
- MaPMT channels gain spread correction;
- power consumption: 3 mW/channel;

➢ Mainstream application: front-end chip for HEP experiments which use 64 channels MaPMTs.

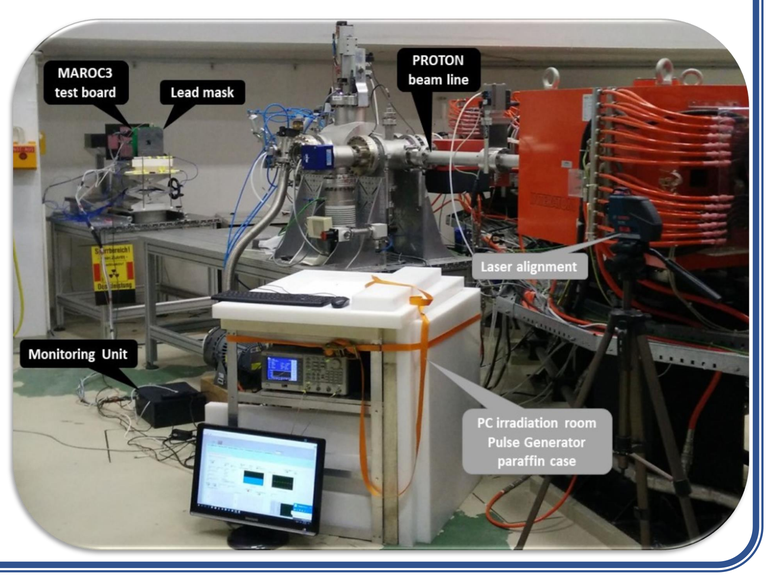
➢ Test bench implemented to fulfil ASICs monitoring strategy:
- electrical parameter measured at every 50 ms and saved in ASCII file;
- device under test reconfiguration and power cycling.



➢ Radiations tolerance testing using 35 MeV proton beam at JULIC:
- 3 samples tested with a total ionizing dose (TID) of 200 to 400 krad (Si);
- proton flux: typically $1.3 * 10^8$ p/cm²/s to maximum of $7.8 * 10^8$ p/cm²/s;
- proton fluencies: $0.9 * 10^{12}$ p/ cm² to a maximum of $1.8 * 10^{12}$ p/ cm².

Observations and effects at high dose rate:
- above 70 krad (Si) the chip power consumption increases on both rails;
- leakage currents increases sharply within semiconductor layers with TID;
- built-in circuitries as DACs well behaved up to 400 krad (Si), beyond this dose the configuration registers became stuck and ASIC Slow Control registers latched;
- triggers efficiency influenced by TID beyond 100 krad (Si), though DACs linearity remained unchanged;

No sings of permanent effects have been detected after irradiation once rapid annealing process had taken place at room temperature within 1 h time.



JULIC - Juelich Isochronous Cyclotron facility based in the Nuclear Physics Institute of the Research Centre Juelich, Germany.

SPACIROC2

Spatial **P**hotomultiplier **A**rray **C**ounting and **I**ntegrating **R**ead**O**ut **C**hip – 2^{nd} generation

➢ ASIC key features:
- hardware triple modular redundancy (TMR) design implemented in several critical circuitries of the chip;
- process node 0.35 μm BiCMOS inheriting some of MAROC3 functional blocks;
- 64 input channels thru gain-adjustable preamplifier for single photon-electron counting capability;
- compliant with low power space-like applications, 1 mW/channel;
- built-in Q-to-T convertor and ASIC readout via 9 data serial outputs.

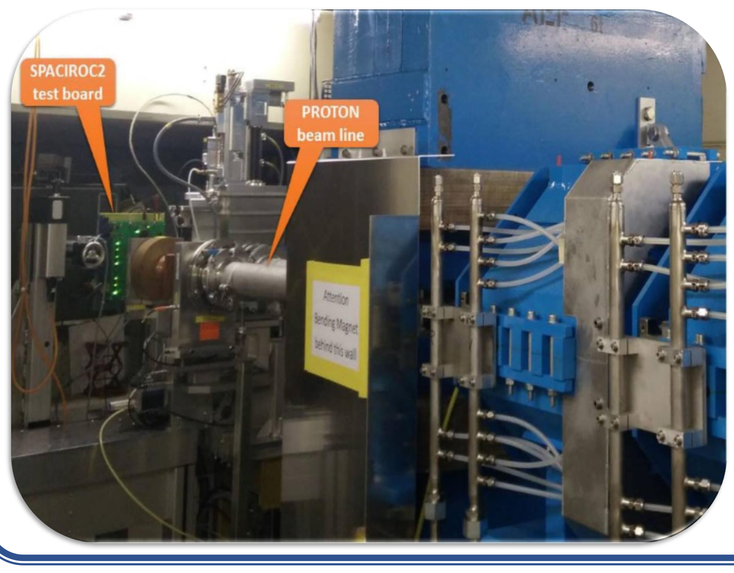
➢ Target application: JEM-EUSO space observatory.

➢ Same test bench used for monitoring, but slightly different firmware for DAQ system to enable more inputs/outputs for data taken.

➢ Radiation hardness study done whit 200 MeV proton beam at PIF:
- 3 samples exposed to 100 krad (Si);
- proton flux: $1.089 * 10^9$ p/cm²/s;
- beam fluency per device: $0.46 * 10^{12}$ p/cm².

Behaviour to radiation exposure:
- TID effects proceeded at 60 krad (Si) in complex digital part of SPACIROC2;
- cumulated dose and leakage current dependence observed in power consumption;
- failure of DACs linearity, while 7 out of 10 configuration bits were latch;
- triggers efficiency downfall mainly by DAC linearity step transitions;
- singular events removed through reconfiguration or power cycling, yet carefully to be approached in future tests.

Temporary TID effects have been mitigated by rapid annealing at room temperature, while permanent effects were not found in ASIC operation.



PIF - Proton Irradiation Facility from Paul Scherrer Institute (PSI), Switzerland.

Conclusions

✓ We estimate the rapid annealing process to overcome the effect of leakage current increase with TID in the target applications for both ASICs, given the low dose rate of the environments.

✓ The observed failures have a very low occurrence probability for MAROC3 chip in LHCb-like environment where dose rate is estimated to $7.8 * 10^{-6}$ rad/s TID(Si).

✓ Although, the ASICs functionality should be investigated against the particles with high linear energy transfer (LET), e.g. heavy ions, to measure Single Event Effects (SEE) threshold for upsets in configuration bits and Single Event Latchup (SEL).