QUALIFICATION of ELECTRONICS for the LHC RADIATION ENVIRONMENT

- Introduction
- Radiation Test Facility for LHC Tunnel Electronics
- Some Results from 6 Experiments (out of 20)
- Conclusions
Why Electronics in the LHC Tunnel?

- Benefits of Electronics Closer to Sensors:
  - Lower Signal Noise, Higher Bandwidth (BPM)
  - New Possibilities for Data Pre-Processing (CPS)
  - Better Remote Diagnostics
  - Less Cables to Alcoves, Galleries and Access Pits

- But
  - More Activated Material
  - No Access Possible During LHC Operation
Objectives of the Radiation Tests

- Qualify COTS Electronics for the LHC Tunnel
  (COTS – Commercial Off The Shelf)
- Identify Radiation Sensitive Components and Replace with Radiation Hardened Items
- Qualify Complete Systems
- Improve Global Radiation Hardness and Evaluate Equipment Life-Time
- Accelerated Testing of Equipment
  - 1 Year in Zone \( \sim = 20 \) Years in LHC
3 Different Types of Radiation Damage

- Single Event Upsets (SEU)
  (Charge Deposited on Critical Node in a Chip)
- Ionising Energy Loss
  (Ionising, Excitation, ex: Gamma Rays)
- Non Ionising Energy Loss
  (Displacement Effects)

- Need to know for LHC:
  - Dose = Gray (Energy Absorbed Locally per Unit Mass)
  - Hadron Flux >20 MeV
SPS - North Experimental Hall

SPS Layout

TCC2 Hall and Beam Lines

Radiation Damage Test Area

TAX collimator

M2 beam line

T6 Target
Secondary SPS Beam Lines

Lau Gatignon

Target Heads:

0 - out
1 - 500 mm
2 - 500 mm
3 - 100 mm
4 - 40 mm

Primary SPS Beam at 400 GeV
(1.2x10^{13} protons/cycle)

Secondary SPS Beams
(5x10^{12} protons and 5 x10^{12} pions, kaons, …)

M2 Beam Line
(2 10^8 muons/cycle from 2 10^{10} pions)

P61 beam line

TAX

Q6D

Q1D Q2D Q3F Q4F Q5 B1 B2 B3

Radiation Test Area
Simulated TCC2 Spectrum

Claire Fynbo

Single Event Errors >20 MeV

Total Dose Effect (Grays)

Energy (GeV)

$E \times \varphi$

- neutrons
- protons
- charged pions
TCC2 Dosimetry

**Active Dosimeters**:
- PMI - (Protection Monitoring Induced activity)
  Designed for Personnel Protection
  - Air filled Plastic Container
  - Ionising Radiation Creates Electrons Collected by an Electrode
  - Small Current Converted in Sieverts/h (On-Line Measurement)
  - In TCC2 Risk of Saturation (Special Setting)

**Passive Dosimeters**:
- PAD - Polymer-Alanine-Dosimeter
- RPL - Radio Photo Luminescent
- PIN diodes - $p$-*intrinsic*-*$n$ Diode
  - Compact, Simple and Cheap
  - Integrate the Dose over a Longer Period
  - Need to be Taken-Out & Processed Periodically
2001 Radiation Test Campaign

- 20 Experiments Taking Data On-Line
- Short Presentation of 6 Experiments:
  - Modular Power Supplies (COTS)
  - Radiation Tolerant Quench Heater Power Supply
  - WorldFIP Equipment
  - Instrumentation for Cryogenics
  - Pressure Transducers and Sensors
  - Vacuum Equipment
Modular Power Supplies

Test of 3 Different Technologies:
- Serial Regulation
- Switching with Bipolar, Transformer Coupling
- Switching with MOS-FET, Transformer Coupling

28 Units Tested – 11 Types – 6 Manufacturers

Remarks:
- Some Units Do Not Restart after Switch-Off
- Output Voltage Drifts With or Without Input Power
Some Examples of Power Supplies Tested

CN17BCE-T1S1  Module HUHN Open  ROS01.T22.05.50.15
Serial Regulation

Type:
- LFE 151k230 (2 Modules)
- Serial Regulation
12 - 18V/1A

Notes:
- Load = 50mA
- Output Voltages Change With or Without Input Voltage
- Output Voltage (b) Restores Partially after End of Irradiation (Annealing)

End of Irradiation
Annealing Effect
One Week Power Off

~ 450 Grays
Switching Power Supplies

**Type:**
- VERO PK55 (2 Modules)
- Triple Switching
+ 5V/5A and 2x 5-15V/1A

**Notes:**
- Measurement on 5 Volt Output Only
- Load = ~ 4 Amp
- Output Voltages increase with the Radiation Dose
- Both 5 Volt Output Voltages Start to Deteriorate at ~ 5 Grays
Switching and Transformer Coupling

Type:
- SYKO ROS 01B 2005 (3 Modules)
- Switching, Transformer Coupling
+ 5V/6A and + 12V/2A

Notes:
- Load = ~ 5 Amp and 1,5 Amp
- All Three Output Voltages Drop at ~380 Grays Simultaneously
- Excellent Stability
- Very Low Output Noise
- Same Results for both 5 Volt and for 12 Volt Output Voltages
Preliminary Results

- Conventional Technology (CNB up to 510 Gy)
  - Serial Regulation - (Low Efficiency)

- Switching Technology
  - Old Technology - Bipolar Transistors, Bipolar Control Circuit with Transformer Regulation Coupling (CNB up to 550 Gy)
  - Modern Technology MOS-FET with Transformer Regulation Coupling (SYKO up to 380 Gy)

- Possibility to Select Good COTS General Purpose and Modular Power Supplies
Development of a Radiation Tolerant Quench Heater Power Supply

Reiner Denz - LHC/ICP

- In-house design using COTS
- About 6200 units in LHC
  - Energizes quench heater strips in case of a magnet quench.
  - 4 units per MB, 2 units per MQ
  - ~ 6000 to be installed under the main dipoles in the regular arc and the dispersion suppressors
  - ~ 200 in UA, UJ …
- Useful lifetime ~15 to 20 years
- Minimum radiation tolerance required:
  - 200Gy and 2 x 10^{12} ncm^{-2}
Test Strategy

Identification of critical components
- Aluminium electrolytic capacitor
- Phase control thyristor
- Isolation amplifier
- Miscellaneous semiconductors

Selective test of these components

Test of sub-units
- I.e. trigger circuit

Test of prototype devices
- Prototype HCDQHDS001-CR000001 tested in TCC2

Batch test of qualified components

Test of pre-series & series devices
Tunnel Location of Rad-Tolerant Electronics
Quench Heater Power Supply Test Results

0 200 400 600 800 1000 1200 1400 1600 1800 2000

0.0 0.2 0.4 0.6 0.8 1.0

before irradiation

1st test: 160Gy 1.5x10^{12} ncm^{-2}

start 2nd test

2nd test: 380Gy 4.2x10^{12} ncm^{-2}

Charging voltage [kV]  Time [s]

Courtesy of Reiner Denz –LHC/ICP
Preliminary Results

- Design and Construction of Radiation Tolerant Quench Heater Power Supply using COTS is Feasible.
- Phase Control Thyristors are the Weak Point of the Device.
- Batch Tests of Selected Components are Necessary.
- Qualification of other MP Equipment to be Continued.
- Life after LHC:
  - ~ 6200 Units Represent about 90 Tons of Non Combustible Potential Radioactive Waste.
  - The Modular Construction Allows Easy Dismantling and Separation of Metallic from Electronic Components.
Test of Standard Industrial COTS Equipment:
- 2 x TBX Modules 16 Digital Output
- 2 x TBX - 16 Digital Input + 16 Digital Output
- 2 x TBX - 8 Analog Input + 8 Analog Output (10 Bits)
- 2 x Momentum Modules 16 Digital In. + 16 Digital Out.
- 2 x Momentum - 8 Analog In. + 16 Analog Out.

Test of WorldFIP Interfaces:
- 2 x FULLFIP2 Components in TCC2
- 6 x MicroFIP Daughter Board (CC131-Modules in TCC2)
- 3 x MicroFIP (CC131-Modules at UCL in Louvain (B))
PLCs and WorldFIP Interface
WorldFIP Preliminary Results

Tests Results:

◆ 1998 Test : Static Test on FULLFIP2 Component
  
  Radiation: OK at 220 Grays.

◆ 1999 Test : On-Line Test with MicroFIP Technology in TTC2
  
  Radiation : OK at > 650 Grays

◆ 1999 Complementary Test on 5 MicroFIP Modules (SL/PO)
  
  => Same results, Error Rate : 1/500byte/day

◆ 2000 Complementary Test on 3 MicroFIP Modules (LHC/ACR)
  
  UCL Louvain  (60 Mev Protons - 2*10^8 p/cm^2/s)

  Radiation: All Boards Survived to a TID of 700 Grays (5*10^{11} p/cm^2)
Instrumentation for Cryogenics

Miguel Rodriguez - LHC/ACR

- **Radiation Qualification of Components:**
  - Conditioners, OP Amplifiers, ADCs, MUXs, FPGAs,
  - Fieldbus Controller, Power Supplies

- **Digital Transmission via WorldFIP**
  - MicroFIP ASIC Link Sensors & Actuators to PLCs
  - 120 Bytes of Internal Memory for Process Data
  - Include Galvanic Isolation by Transformer
  - FPGA Used to Control Access to MicroFIP Registers
Type of Equipment
Memory State Changes

Fluence [p/cm^2]

- zero test
- random test 1
- random test 2
- random test 3

Fluence [p/cm^2]
Effect on Current Consumption

TID [Gy (Si)] vs. Current [mA]
Preliminary Results

• Radiation Tests Done on MicroFIP:
  • At CERN in TCC2 for Total Ionizing Dose (TID)
  • At UCL Cyclotron Louvain (B) for Single Event Effect (SEE)
    (Proton Intensity $2 \times 10^8$ p.cm$^{-2}$s$^{-1}$ & Proton Energy 60 Mev)
  • Test of 4 MicroFIP Boards (C131 Type)
  • Duration of Irradiation: 1 Hour

• Results:
  • All boards survived to a TID of 700 Grays ($5 \times 10^{11}$ p.cm$^{-2}$)
  • No Latch-Up detected
  • Some Memory Cells Transitions
  • One Single Hard Error Involving a Reset
Pressure Transducers and Sensors

Troels Bager - LHC/ACR

Control room

100 mbar pressure reference

Cable gallery

SS tube

Irradiation zone

manifold for 100 mbar transducers

3 bar pressure reference

manifold for 3 bar transducers

20 bar pressure reference

manifold for 20 bar transducers

ambient temperature

GHe, 200 bar

100 mbar pressure reference

3 bar pressure reference

20 bar pressure reference

vacuum pump

vacuum pump

As short as possible

TT01

160 m
Installation for Pressure Sensors Tests

<- Measurement at the Surface

<- 160 m ->

Sensors in the Test Area ->
### Summary of Test Results

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type</th>
<th>Technology</th>
<th>Failure type</th>
<th>Dose at Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosemount</td>
<td>2088/3051</td>
<td>SS membr., oil, piezo resist SG chip integ. 4-20 mA, HART</td>
<td>SEE, later drift --&gt; sat</td>
<td></td>
</tr>
<tr>
<td>Keller</td>
<td>PAA-23</td>
<td>SS membr., oil, piezo resist SG chip integ. 4-20 mA</td>
<td>drift --&gt; sat</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Kistler</td>
<td>RAG 50</td>
<td>SS membr., oil, piezo resist SG chip integ. 4-20 mA</td>
<td>drift --&gt; zero, later suddenly zero</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Haenni</td>
<td>ED 510</td>
<td>piezo resistive SG chip</td>
<td>drift --&gt; zero</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Druck</td>
<td>PDCR 314</td>
<td>piezo resistive SG chip</td>
<td>drift --&gt; zero</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Baumer</td>
<td>PDAB</td>
<td>SS membr. no oil, metal thin film SG integ. 4-20 mA</td>
<td>drift --&gt; zero</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Trafag</td>
<td>8893</td>
<td>SS membr. no oil, DIVIS SG glued</td>
<td>drift --&gt; zero, later suddenly zero</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Effa</td>
<td>LPX 2380</td>
<td>2 coils, inductance</td>
<td>integ. 4-20 mA</td>
<td>0 Gy</td>
</tr>
<tr>
<td>E+H</td>
<td>PMC 131</td>
<td>Al₂O₃ membr., no oil, capacitive. integ. 4-20 mA</td>
<td>drift --&gt; zero, later suddenly sat.</td>
<td>0 Gy</td>
</tr>
<tr>
<td>Effa</td>
<td>LPR 2000</td>
<td>metal membr., change induct. of 2 coils</td>
<td>56 kHz, remote elec.</td>
<td>no failure</td>
</tr>
<tr>
<td>HBM</td>
<td>P8AP</td>
<td>SS membr. no oil, metal thin film SG 0 - 20 mV/V remote elec.</td>
<td>no failure</td>
<td>&gt;1000 Gy</td>
</tr>
<tr>
<td>Baumer</td>
<td>PDAA</td>
<td>SS membr. no oil, metal thin film SG 0 - 20 mV/V remote elec.</td>
<td>no failure</td>
<td>&gt;1000 Gy</td>
</tr>
</tbody>
</table>
Vacuum Equipment

Christian Billy - LHC/VA

Type of Equipment under Test:

- PLC SIEMENS S7/215
- BALZERS Gauges (2xPKR251, PKR265) with Integrated Control Electronics
- EDWARDS Gauge AIM-X (Penning) and WRG-S Gauge (Combined Pirani-Penning) with Integrated Electronics
- Turbo-Molecular Pump Controller ALCATEL ACT/600
- Ion-Pump Power Supply Unit
Preliminary Results

- PLC - First Error (Isolated Effect) at < 1 Gy
  - After Reload, Systematic Memory Error 4-8 sec. 5 Gy
  - No Reply 20 Gy
- Edwards Gauges (With Integrated Electronics)
  - Gauge AIMX-X 50 Gy
  - WRG-S 1000 Gy
- Balzers Gauges
  - 2 Gauges PKR 251 290 Gy and 430 Gy
  - 1 Gauge PKR 265 450 Gy
Preliminary Results

- Turbo-Molecular Pump Controller Alcatel ACT/600
  - No More Remote Control at 20 Gy
  - Turbo Pump OK up to, then Stop 50 Gy
- Ion Pump Power Supply (Two Parts)
  - High Voltage Part (With BYW 96 Diode) > 1000 Gy
  - Controls Part (+/-15V, +24V, +7V) 200 Gy

Failing Components but Possible Improvement:

◆ Positive Results: - One Type of Electronic Gauge
  - Ion Pump Power Supply
◆ Negative Results: PLC and TMP Controller
Lessons Learned

- Electronic Equipment that Will not Work Reliably in the LHC Tunnel:
  - Intelligent Sensors and Actuators (Few Exceptions) (Remote Electronics and Cables Required)
  - Complete Industrial PLCs (COTS)
  - Intelligent I/O Modules (COTS) with Micro and Memory
  - Conventional Switching Power Supplies (NMOS)
  - Processors Without Error Correction Memory
Lessons Learned

- LHC Electronic Equipment That Needs to be Tested or Selected before Installation:
  - Passive Components (Optical Fibers, Resistors, Capacitors)
  - Active Components (Signal Conditioners, MUXs, Op.-Amp., ADCs, DACs, FPGAs, EPROMs SRAMs with EDAC)
  - Sensors, Actuators, Gauges, Positioners, Valves, Flowmeters
  - Modular Power Supplies (Serial Regulation, Bipolar Transistors, Transformer Coupling Feedback, No OptoCouplers)
Lessons Learned

◆ RadHard Developments are Required for:

  ● Simple Input/Output Modules with Fieldbus Interfaces to WorldFIP or Profibus (Command/Response Operation)
  ● Dedicated Power Supplies (Quench Protection)
  ● Orbit Corrector Power Converters
  ● Control Processors with EDAC Memory and Remote Reset Capability.
Conclusions

Results Obtained So Far Suggest that ALL Electronic Systems, Intended for Installation in the Tunnel, Should be Radiation Qualified

The Radiation Test Facility is Qualified to Provide a Radiation Environment Similar to That of the LHC Tunnel (Arcs)

The On-Line Test Facility can be Used for the Final Qualification of Complete Working Systems