LOWERING THE COST OF SPACECRAFT AVIONICS
BY IMPROVING THE RADIATION TOLERANCE OF COTS ELECTRONIC SYSTEMS

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Overview

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Introduction

• This presentation is about a new strategy to receive the maximum amount of telemetry data from any spacecraft operating in a radiation environment for the minimum cost.

• Ensuring the tolerance of on-board electronics to radiation effects can be one of the most challenging aspects of the spacecraft avionics system design.

• This paper will discuss how a novel approach from Curtiss-Wright, based on the innovative Smart Backplane technology tackles radiation mitigation at COTS board level rather than component level.

• This new approach has been demonstrated to significantly lower the cost involved in the design, certification, manufacture and deployment of spacecraft telemetry data handling systems.
Semiconductor components are essential building blocks of modern spacecraft electronics

As radiation interacts with a semiconductor it produces ionization which can temporarily or permanently change the electrical characteristics of the material

Cumulatively, these radiation induced events cause degradation of material characteristics and are known as Total Dose Effects

Individually, these radiation induced events can temporarily or permanently disturb the function of a device, a phenomena known as Single Event Effects (SEE)

Total Dose Effects

Single Event Effects (SEE)
Single Event Effects

Radiation effects on electronics are a complex area of study but fundamentally any system has to continue to function after exposure to the mission radiation environment.

- **Single Event Upset (SEU)** – an event like a bit flip resulting in a data error only.

- **Single Event Latchup (SEL)** – an event where the device has an abnormal conduction path established by ionizing radiation leading to an input current change. Power must be cycled to prevent damage to the device.

**Note:** Other single event effects such as SEGR, SEFI, SEB, SET etc. create different input current signatures at board level and these will be studied in future characterisation test programs for the Smart Backplane and KAM-500 COTS modules.
The Curtiss-Wright Space COTS Approach

- **Space COTS Motivation**
  - Designers of spacecraft systems have been encouraged by funding agencies to look at COTS products for space missions in order to:
    - Make better use of limited budgets => More Missions with available funding
    - Meet the overall Mission Assurance requirements at lower cost
    - Reduce development schedule time and risk

- **Space COTS Qualification**
  - The approach taken by Curtiss Wright designers focuses on the characterization of existing commercial technologies and their modification and optimization for use in space environments through a 4 step process leading to Space COTS Qualification
    - Space COTS Characterization
    - Space COTS Mission Mapping
    - Space COTS Adaptation
    - Space COTS Qualification
Step 1 - Space COTS Characterization

<table>
<thead>
<tr>
<th>Radiation Tests</th>
<th>Vibration/Shock Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Radiation Test Image" /></td>
<td><img src="image2" alt="Vibration/Shock Test Image" /></td>
</tr>
<tr>
<td>Thermal Vacuum Tests</td>
<td>EMC Tests</td>
</tr>
<tr>
<td><img src="image3" alt="Thermal Vacuum Test Image" /></td>
<td><img src="image4" alt="EMC Test Image" /></td>
</tr>
</tbody>
</table>
Step 2 - Space COTS Mission Mapping
Step 3 - Space COTS Adaptation

Adaptations include mechanical, thermal and electrical re-packaging of the core COTS Data Acquisition Modules in order to match the specific mission requirements.
Step 4 - Space Qualification

Acra KAM-500 COTS equipment is Qualified for specific space mission requirements.

- **Mechanical Environmental testing**
  - Acceleration
  - Shock
  - Vibration

- **EMC testing**

- **Radiation Testing**
  - 5000 Rad(Si) Total Ionizing Dose (Box Level)
  - 200 MeV Proton Irradiation (Board Level)

- **Thermal Vacuum Testing**
  - TV Test from -40°C to +85°C at <1.0 x 10^{-5} mBar
Smart Backplane Introduction

- The COTS Acra KAM-500 provides baseline tolerance to Single Effect Events (SEEs) due to radiation
  - Flash based FPGA and EEPROM technology and State Machine operation
- However, standard components are susceptible to damaging SELs

- The Smart Backplane has module level latch-up detection and power cycling to allow re-use of existing KAM-500 COTS modules in radiation intensive space applications
- The Smart Backplane is designed using Rad-Hard components in one location only
- The operation of Smart backplane with KAM-500 COTS modules has been verified with radiation tests
The KAM-500 is a COTS networked data acquisition system originally designed for flight test applications. The system is highly modular, consisting of common chassis and over 100 plug-in modules for interfacing with various sensors and avionic busses.

Smart Backplane variant of KAM-500 chassis employs an active electronic safety net to protect against radiation induced effects at the module level.

The design of KAM-500 Smart Backplane provides a cost-effective mechanism for detecting Single Event Latch-Up through monitoring the power consumption of individual modules hosted in the KAM-500 chassis.

If an anomaly in the power consumption profile of a hosted module is detected, the Smart Backplane initiates the failure isolation and recovery of the affected module.
Smart Backplane – Autonomous Detection and Recovery from SEL Events #2

- Each module slot in the KAM-500 Smart Backplane features a monitoring and switching circuit.
- The monitoring circuit in the Smart Backplane continuously measures the power consumed by the hosted plug-in module on each of the power bus rails +5V, +/-7V and +/-12V.
- The switching circuit controlled by the Smart Backplane logic allows the plug-in module to be disconnected from the data bus and power lines when an anomaly in the power consumption profile is detected. The slot is re-activated after a pre-defined recovery interval.
- Power consumption limits are set by the user individually for each secondary voltage line of each module slot, together with the desired duration of the recovery interval.
Smart Backplane Radiation Test Results #1

• The design of KAM-500 Smart Backplane has been verified through a series of radiation tests. The KAM-500 Smart Backplane was successfully tested with high-energy protons and heavy-ions at the following facilities:

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Test Facility</th>
<th>Test Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>200Mev proton test</td>
<td>Proton Irradiation Facility, Paul Scherrer Institute, Switzerland</td>
<td>June 2014</td>
</tr>
<tr>
<td>200Mev proton test</td>
<td>Massachusetts General Hospital, MA, USA</td>
<td>May 2015</td>
</tr>
<tr>
<td>Heavy ion (Krypton) test</td>
<td>NASA Space Radiation Laboratory, Brookhaven National Lab, NY, USA</td>
<td>May 2015</td>
</tr>
<tr>
<td>200Mev proton test</td>
<td>Proton Irradiation Facility, Paul Scherrer Institute, Switzerland</td>
<td>May 2016</td>
</tr>
</tbody>
</table>

• During each test, individual KAM-500 plug-in modules were irradiated while hosted in the KAM-500 Smart Backplane chassis. The functional performance of each test article was continuously monitored and any failures and interrupts were recorded.
Smart Backplane Radiation Test Results #2

- Single Event Latch-Up’s events (SEL's) were observed on each test article during the radiation tests.
- Each event was successfully detected by the Smart Backplane and the impact on the system was subsequently mitigated by the Smart Backplane recovery cycle.
- During all tests the Smart Backplane successfully protected hosted modules from a permanent failure induced by radiation and each module performed nominally at the completion of the tests after multiple radiation induced events that resulted in power cycling by the Smart Backplane.
- The test results are summarized in the following table:

<table>
<thead>
<tr>
<th>Test Article</th>
<th>Proton Test [200MeV]</th>
<th>250MeV Krypton Test [250MeV with LET of 4.2MeV/mg.cm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fluence [p/cm²]</td>
<td>SEL Events</td>
</tr>
<tr>
<td>KAM-500 Controller module</td>
<td>$1 \times 10^{10}$</td>
<td>$5 \times 10^{5}$</td>
</tr>
<tr>
<td>KAM-500 Interface module</td>
<td>$1 \times 10^{10}$</td>
<td>$5 \times 10^{5}$</td>
</tr>
</tbody>
</table>

- Note: Total data loss from a typical data acquisition module due to power cycling of the module by the Smart Backplane due to the induced SEL events for the duration of the radiation tests was approximately 2%. 
Benefits of the Smart Backplane Approach #1

- **Improved FDIR for COTS Based Systems**
  - The Smart Backplane technology implements an innovative board level FDIR approach for COTS electronics in spacecraft data acquisition avionics systems. It provides autonomous failure detection at board level and can isolate the board from the system without the intervention of spacecraft operators.

- **Real-time Power Management**
  - The Smart Backplane approach to SEL protection of COTS boards also allows the spacecraft operator to manage in real-time the power consumption and hence the energy budget of the spacecraft through the control of the power supply to individual boards or modules in the data acquisition system.

- **Life Cycle Cost Saving**
  - The Smart Backplane combined with high performance COTS electronics boards has enabled spacecraft designers and operators to make significant cost savings in all aspects of the spacecraft life cycle in three main areas:
    - Use of High Performance COTS Boards in Space Radiation
    - Reducing Number of Avionics Boxes through Integration of Functions
    - Grouping Sensors and Reducing Harness Mass/Cost
Future Smart Backplane Applications

- The Smart Backplane has a wide range of potential space applications including:
  - **Launch Vehicle** - Telemetry Data Handling
  - **Spaceplanes** - Flight Instrumentation
  - **Re-entry Vehicle** - Flight Instrumentation
  - **Interplanetary Spacecraft** – EDL DAS
  - **Cube-Satellites** - COTS Boards Backplane

- Affordable data acquisition without compromising reliability or mission safety requirements
Conclusion

- **Space Industry Driven Innovation** - The global space sector is looking to benefit from the lower cost of deploying COTS electronics equipment in ever more demanding space radiation environments and increasing levels of mission criticality.

- **Lowest Cost Approach** - There are a number of approaches to achieve the required radiation tolerance in space electronics where the use of a fully radiation-hardened design may yield the most protection but is also the highest cost option.

- **Demonstrated Cost Savings** - The innovative Smart Backplane chassis, developed by Curtiss-Wright, has been demonstrated to lower the cost of spacecraft data acquisition systems by up to 75% while minimizing the loss of telemetry data due to radiation events to less than 2% for a typical LEO application.

- **Wide Range of Space Applications** - The radiation tolerant Smart Backplane KAM-500 data acquisition system has already been selected for manned and un-manned re-entry vehicles as well as launcher upper stages is being considered for the instrumentation system on future planetary re-entry vehicles, and as the basis for low cost COTS based small satellite avionics systems.