Development of a payload for the characterization of commercial microcontrollers to radiations
Requirements

Development of a payload tile for the AraMIS nano-satellite structure able to characterize the radiation behavior of a FRAM based microcontroller (MSP430FR6989). The project must be compliant with the UML AraMIS standards:

• Software:
  ➢ Introduce FRAM microcontrollers in the project (software porting)
  ➢ Write radiation characterization tests:
    ▪ Test FRAM & RAM memory of the micro-controller
    ▪ Test peripherals behavior
  ➢ Communication protocol: AraMIS1B45
  ➢ Compare a standard compiled code Soft Error Rate with an hardened one using the AraMIS software hardening library

• Hardware:
  ➢ Power consumption: < 300mW
  ➢ Power supply voltage: 3.3V according to 1B48 AraMIS module interface;
  ➢ Physical dimensions: 9 cm x 9 cm
Satellites environment

Depending on the chosen orbit, we have an interaction with the Van Halen radiation belts. Ionizing radiations cause problems to electronic systems.

Inner belt: mostly high energy protons trapped by the Earth's magnetic field.

Outer belt: high energy electrons trapped by the Earth’s magnetosphere.

α
β
γ

Paper  Aluminium  Lead
Space components

Components

Military/Space compliant
Commercial Off The Shelf (COTS) components
Space use
Vibration
Temperature
Pressure
Launch phase
Extreme Light
Darkness
No atmosphere
Low pressure
No convection dissipation

Radiation
Cumulative
Damages
Total Ionizing Dose

Specific tests & treatments
Cost ↑↑↑

Single Event Effect
Single Event Upset
Single Event Latch-up
Single Event Functional Interrupt

Cost ↑↑↑
No atmosphere
Low pressure
No convection dissipation

Extreme Light
Darkness
FRAM technology

Polarization of a Lead Zirconate Titanate film PZT

Non volatile

Read = Write

Read

Voltage on Plate Line

Sense induced charge on the Bit Line

Write

0

1

Voltage on Plate Line

Voltage on Bit Line

Data Retention Issues

Imprint

T↑ for long time → One logic state is preferred

Thermal depolarization

T↑ → Polarization↓
FRAMs: Pro and Cons

- **Power consumption**
  - No charge pumps like in FLASH
  - No refresh like in DRAM
  - High write endurance ($10^{16}$)

- **Physical dimensions**
  - FRAM$_{cell}$ > DRAM$_{cell}$
  - X No big memories

- **Radiation behavior**
  - Characterization!

Small satellites design parameters
Testing and Tools

Code written in UML class diagrams using Visual Paradigm as modelling software

Debugged and tested using IAR Embedded Workbench as IDE

And a Texas Instrument development board as testing hardware

The hardware developed using Mentor Graphics

Arturo Guadalupi
What is AraMIS

CubeSat satellite

Modular Architecture

Modular Architecture for Satellites (AraMIS)

Advantages

Less costs

Less time to mission

Flexibility

Based on tiles

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Every microcontroller within the AraMIS project follow a standard for the wiring of the various pins called 1B48. In this way tiles can be easily connected together.

<table>
<thead>
<tr>
<th>Conn</th>
<th>Pin</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>D0/RX/SOMI</td>
<td>11</td>
<td>P2.1/UART</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/UCA0SOMI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/UCA0RXD</td>
</tr>
<tr>
<td>D1/TX/SIMO</td>
<td>9</td>
<td>P2.0/UART</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/UCA0SIMO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/UCA0TXD</td>
</tr>
<tr>
<td>D2/SCL/SOMI</td>
<td>7</td>
<td>P1.7/I2C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/UCB0SCL</td>
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<tr>
<td>D3/SDA/SIMO</td>
<td>5</td>
<td>P1.6/I2C</td>
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</tr>
<tr>
<td>D4/CLK</td>
<td>3</td>
<td>P2.2/UART</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/UCA0CLK</td>
</tr>
<tr>
<td>D5/PWM</td>
<td>1</td>
<td>P6.5/TB0.1</td>
</tr>
<tr>
<td>D6/A0</td>
<td>12</td>
<td>P1.0/A0</td>
</tr>
<tr>
<td>D7/A1</td>
<td>10</td>
<td>P1.1/A1</td>
</tr>
<tr>
<td>D8/ID/INT</td>
<td>4</td>
<td>P1.4</td>
</tr>
<tr>
<td>D9/EN/PWM2/INT</td>
<td>2</td>
<td>P2.4/TB0.3</td>
</tr>
</tbody>
</table>

10 Pins forms the so called MODULE

MSP430FR6989 is a 100 pins micro-controller

8 MODULES

Arturo Guadalupi
Once decided the pin wiring according to the 1B48 standard, each micro-controller is encapsulated in a Menthor Graphics reusable block that expose all the modules and have inside the basic electronics like quartzes and decoupling. In this way a new design can be started in a faster way.
The chosen micro-controller was never used before in the AraMIS project, so the first step was to write all the drivers in order to enable the peripherals features according to the ones already implemented (drivers porting). Furthermore a new MSP430FRxxx uC can be easily introduced.
AraMIS 1B45 and Hardening

AraMIS has already implemented a communication protocol called 1B45 that has a built-in CRC, timeout ecc. This protocol has been used to communicate with the OBC

1B45

- Command Only
- Command + Read Data
- Command + Write Data

The software hardening library is based on the use of appropriate C++ classes from the hardened data (Hdata) package developed in house, which can be used in a standard C++ program instead of standard data type. For instance, a short can be substituted by the so-called TripleShort, which automatically and transparently stores three copies of the same value and votes or recovers data whenever required.

<table>
<thead>
<tr>
<th>Normal program</th>
<th>Hardened program</th>
</tr>
</thead>
<tbody>
<tr>
<td>short a=3, b=5; short c; c = a+b;</td>
<td>TripleShort a=3, b=5; short c; c = a+b;</td>
</tr>
</tbody>
</table>
Software tests

Type of tests
- Characterization tests
  - Count SEUs, SELs
    - Check nominal operation

Memory
- Free Memory
- Generate & Fill
- Verify Seed SS Memory
- Check Program

Peripherals
- RTC
  - Read RTC
- PWM
  - Filter
  - One Output
  - Two Output
- ADC
  - Single Ended
  - Differential
- UART
  - Read RTC
The developed software class starts the tests according to the commands listed in the enumeration Commands and gives back the results using the AraMIS House-Keeping management who responds to the requests listed in the enumeration HK_FIELDS.
Conclusions

Software:
- ✔ Drivers porting for MSP430FRxxxx family
- ✔ Drivers test
- ✔ Radiation effects test
- ✔ Peripherals normal operation test
  - o Add more tests
  - o Use the FRAM micro-controller in other tiles

Hardware:
- ✔ Mentor Graphics reusable blocks for feature developments
- ✔ PCB design
- ✔ Compatibility with AraMIS bus
- ✔ Modular and hierarchical design
- X PCB manufacturing and mounting
- X PCB on-board test
  - o Add hardware to give support to other tests

Legend:
- ✔ Done
- X To be done
  - o Possible feature developments
Thank you for listening!