Politecnico di Torino

Department of Electronics and Telecommunications

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

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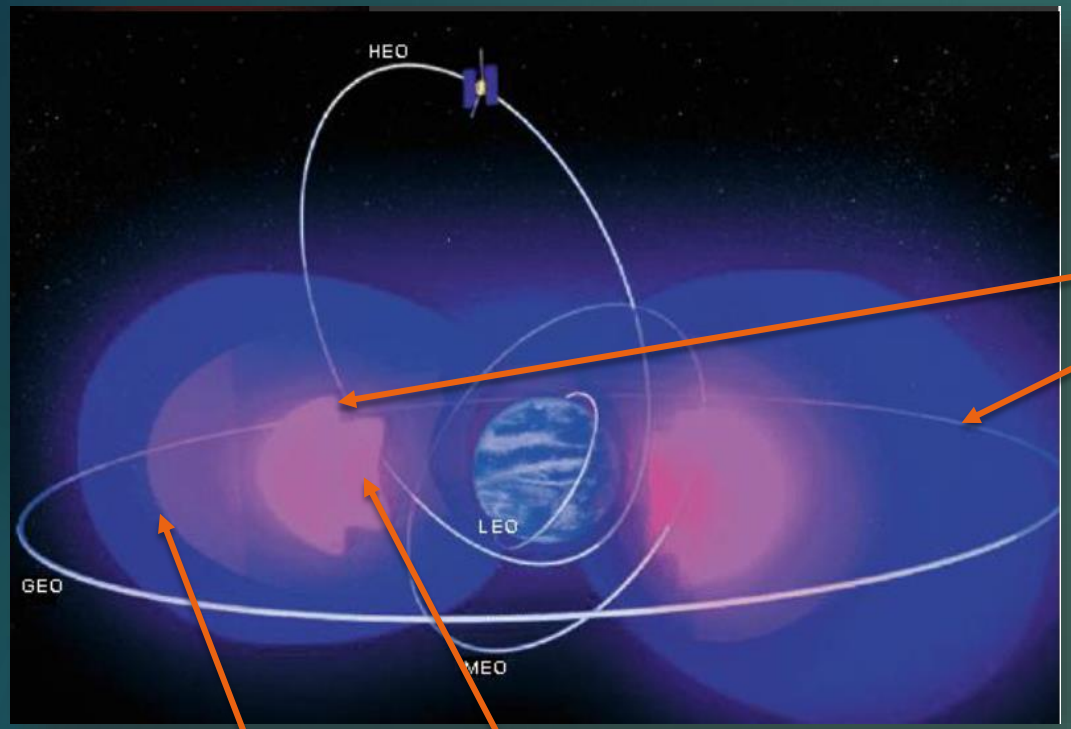
Requirements

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 a interaction with the

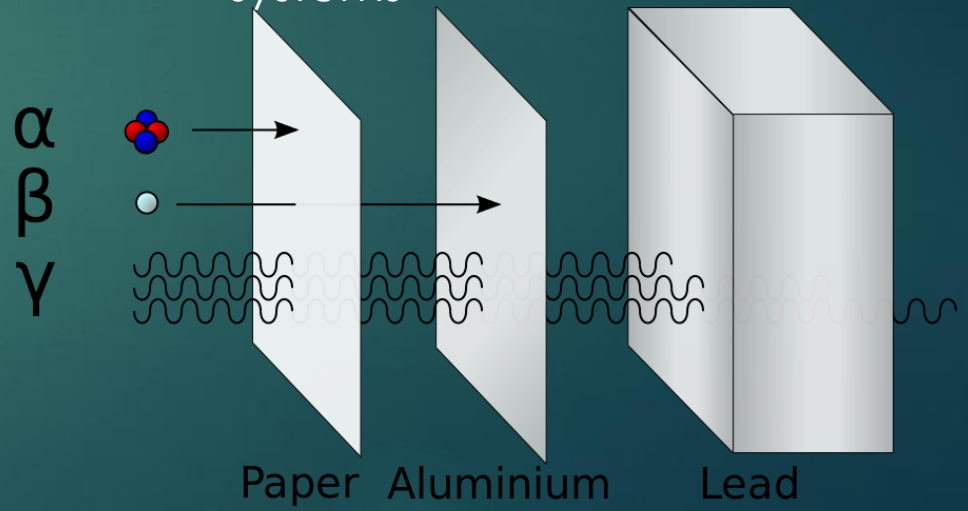
Van Halen radiation belts

Ionizing radiations

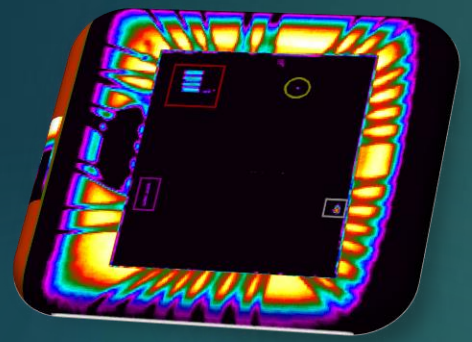
cause problems to electronic systems

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

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



Space components

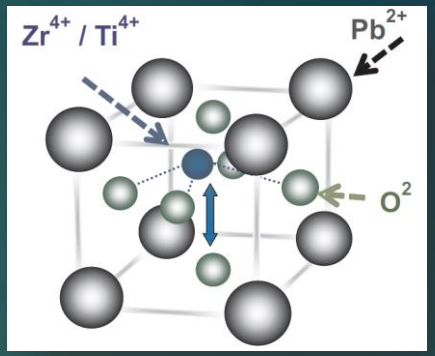


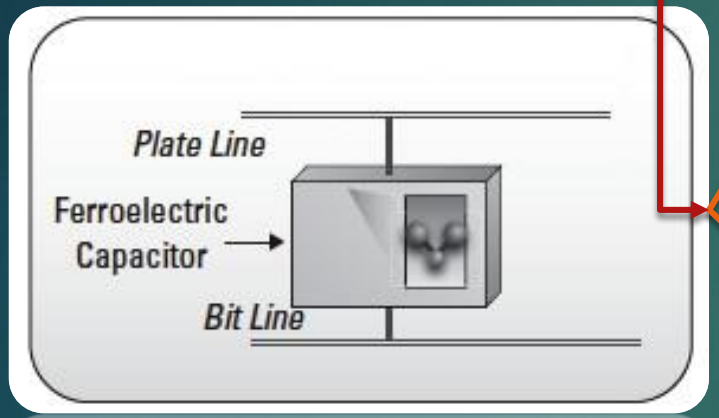
- Components
  - Military/Space compliant → Specific tests & treatments → Cost ↑↑↑
  - Commercial Off The Shelf (COTS) components
    - Space use
      - Vibration → Launch phase
      - Temperature
        - Extreme Light
        - Darkness
      - Pressure → No atmosphere
        - Low pressure
        - No convection dissipation
      - Radiation
        - Damages
          - Cumulative
            - Total Ionizing Dose
          - Single Event Effect
            - Single Event Upset
            - Single Event Latch-up
            - Single Event Functional Interrupt

FRAM technology

Ferroelectric RAM → Polarization of a Lead Zirconate Titanate film PZT

- Non volatile
- Read = Write





- Read → Voltage on Plate Line → Sense induced charge on the Bit Line → Reading is destructive!
- Write
  - 0 → Voltage on Plate Line
  - 1 → 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

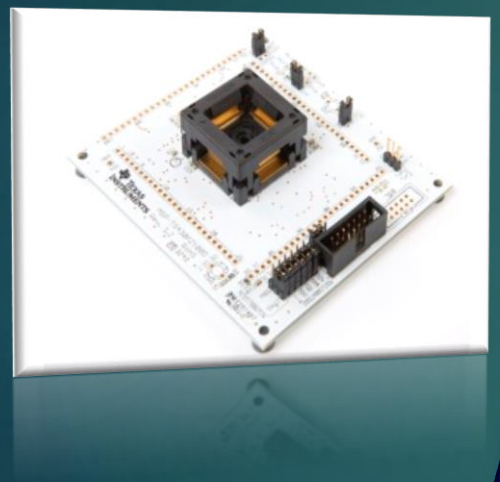
Small satellites design parameters

- 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!

Testing and Tools

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

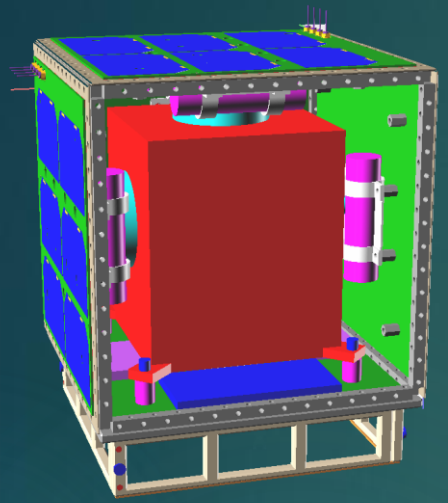
Debugged and tested using IAR Embedded Workbench as IDE

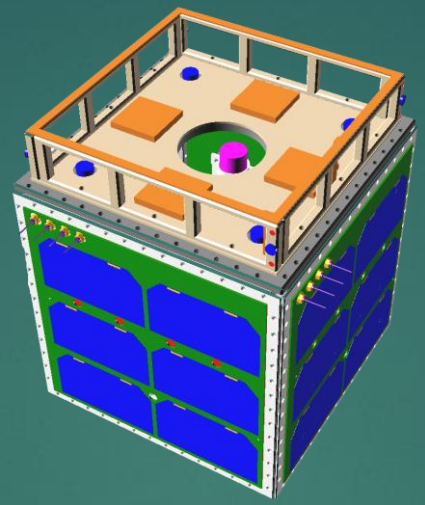


And a Texas Instrument development board as testing hardware

The hardware developed using Mentor Graphics

What is AraMIS





CubeSat satellite +

Modular Architecture =

Modular Architecture for Satellites (AraMIS)

Tiles

Based on tiles → Advantages

- Less costs
- Less time to mission
- Flexibility

AraMIS 1B48

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

Conn	Pin	A
D0/RX/SOMI	11	P2.1/UCA0SOMI /UCA0RXD
D1/TX/SIMO	9	P2.0/UCA0SIMO /UCA0TXD
D2/SCL/SOMI	7	P1.7/UCB0SCL
D3/SDA/SIMO	5	P1.6/UCB0SDA
D4/CLK	3	P2.2/UCA0CLK
D5/PWM	1	P6.5/TB0.1
D6/A0	12	P1.0/A0
D7/A1	10	P1.1/A1
D8/ID/INT	4	P1.4
D9/EN/PWM2/INT	2	P2.4/TB0.3

UART

I2C

SPI

10 Pins forms the so called MODULE

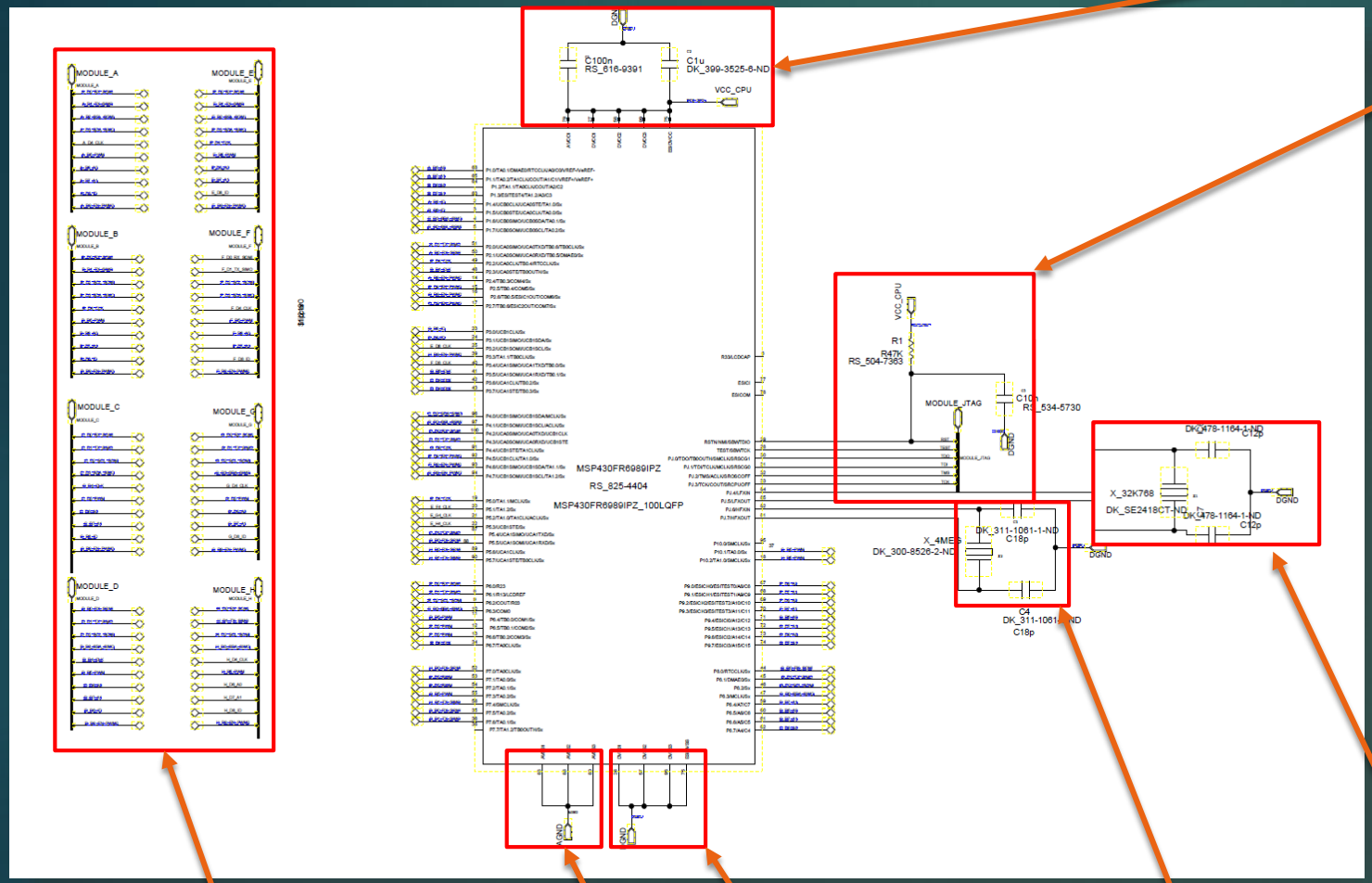
↓

MSP430FR6989 is a 100 pins micro-controller

↓

8 MODULES

AraMIS 1B42



Decoupling

JTAG

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.

HF quartz

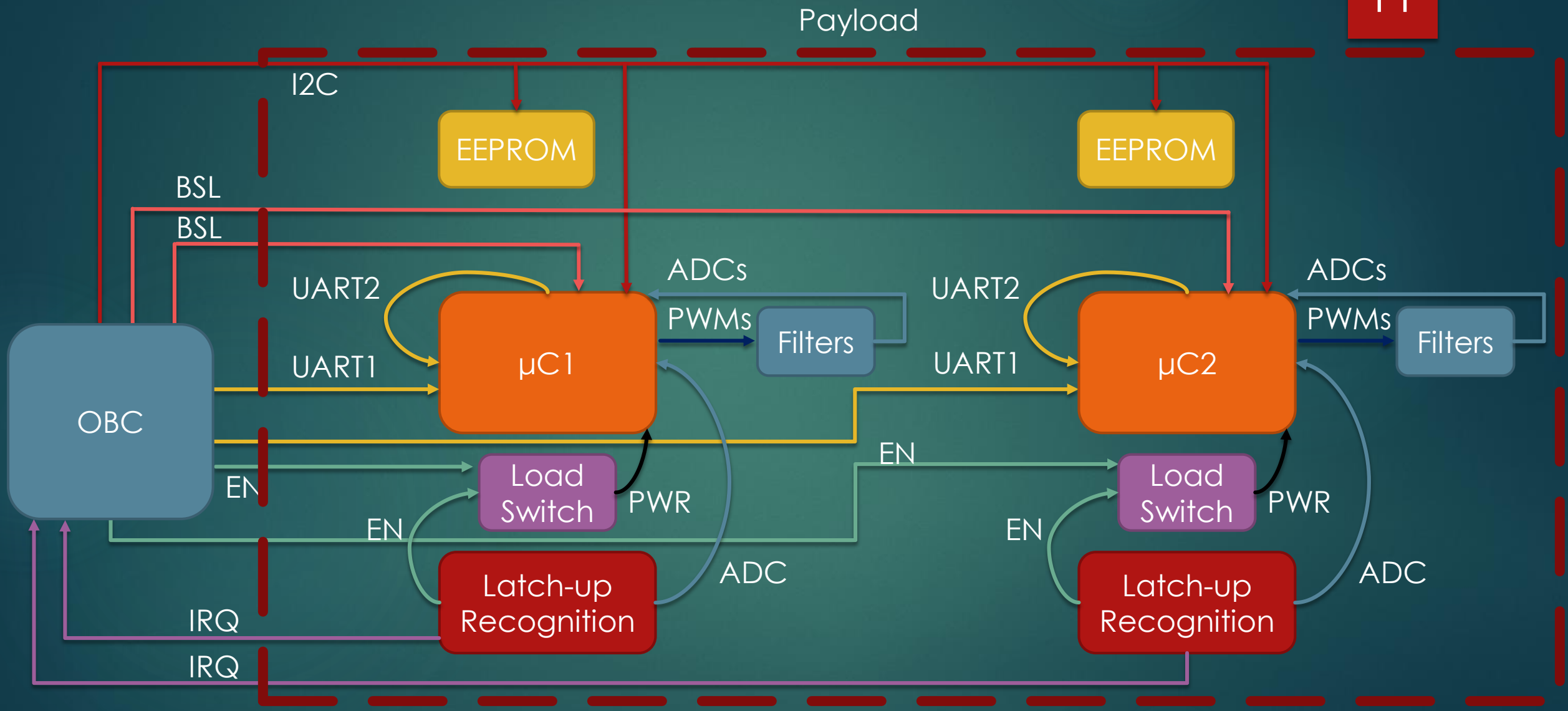
Modules

DGNDs

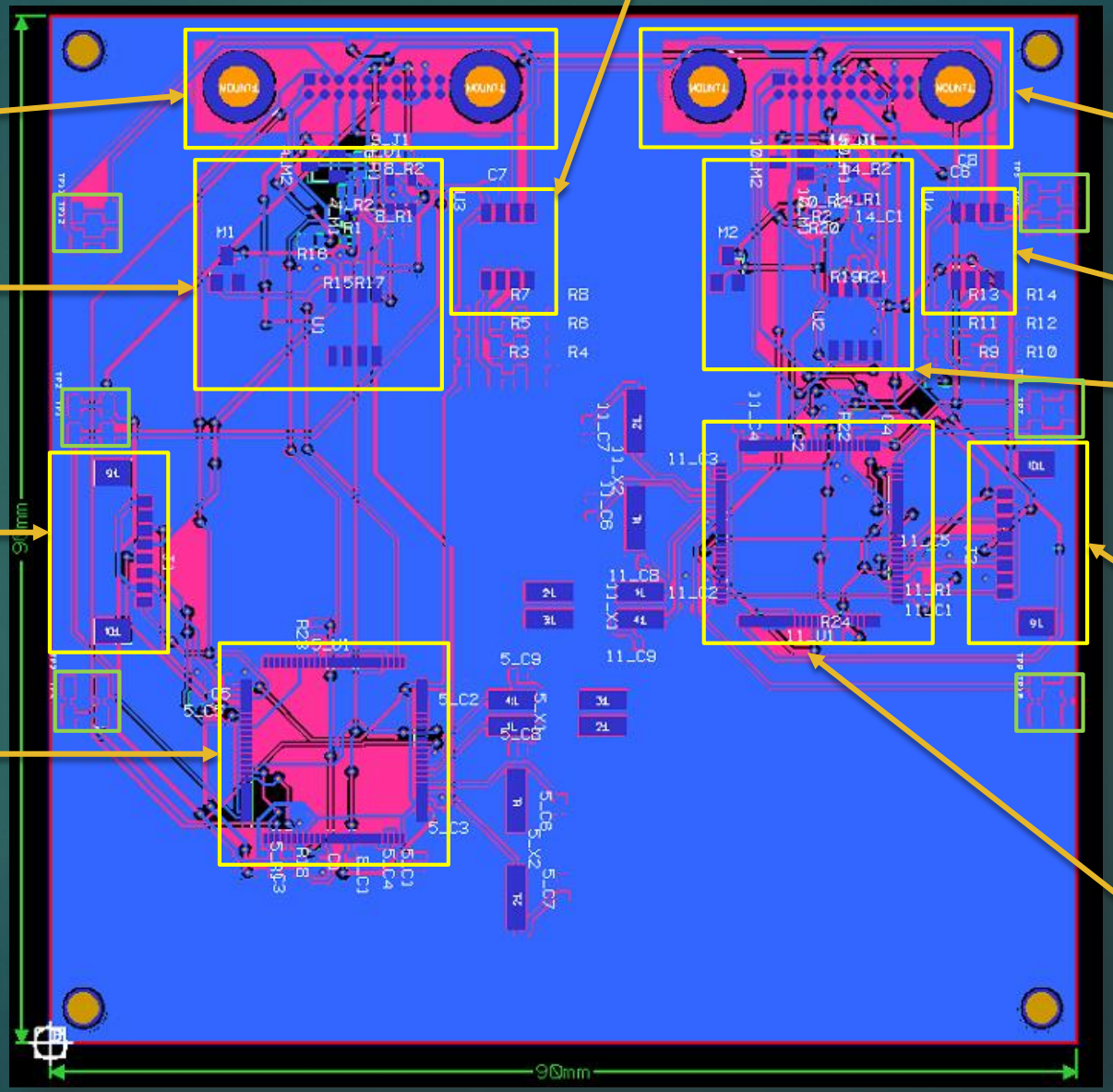
AGNDs

LF quartz

Hardware

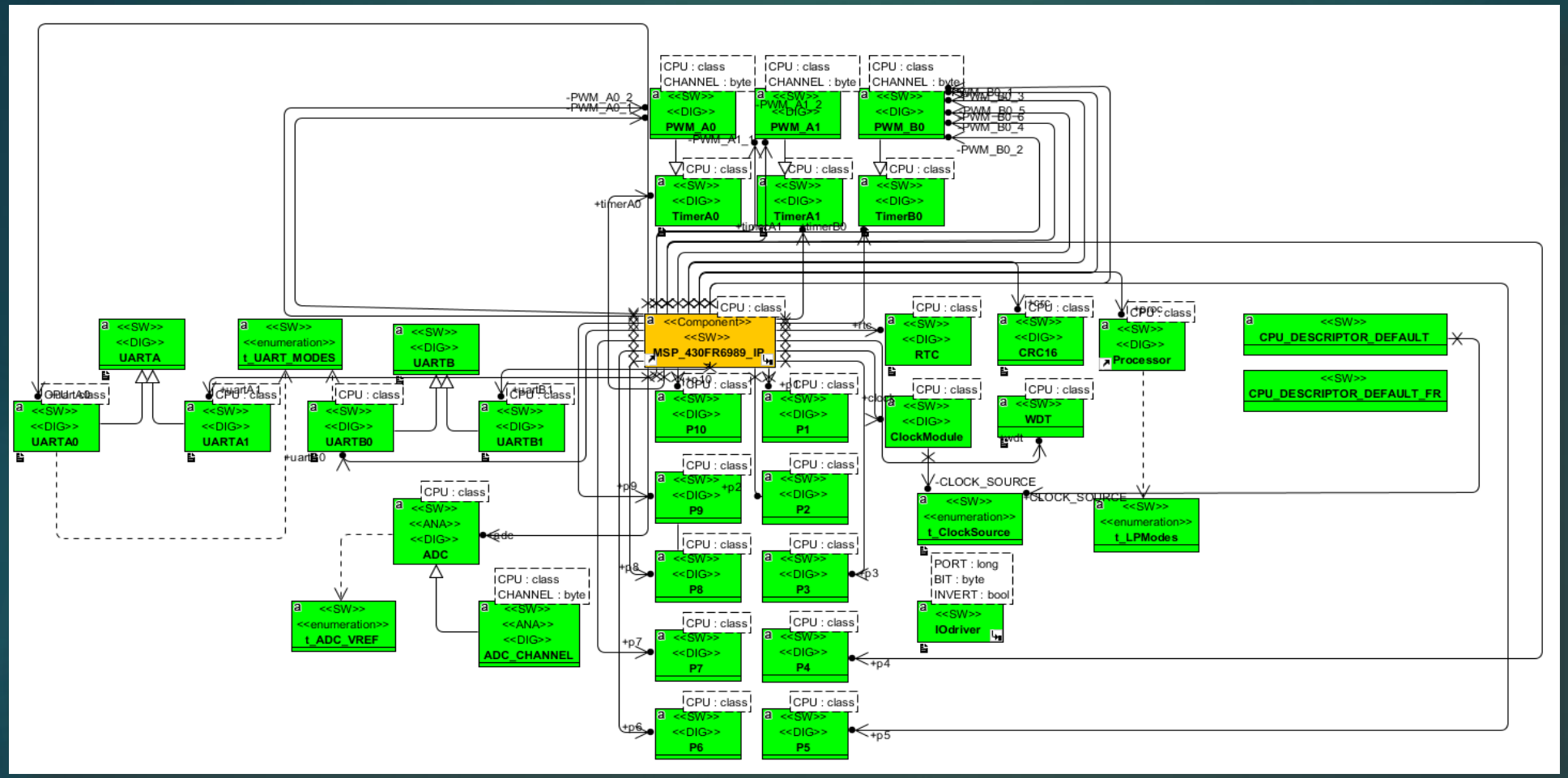

Payload
I2C
EEPROM
EEPROM
BSL
BSL
UART2
ADCs
UART2
ADCs
PWMs
Filters
PWMs
Filters
UART1
µC1
UART1
µC2
OBC
EN
EN
Load Switch
PWR
EN
EN
Load Switch
PWR
ADC
ADC
Latch-up Recognition
Latch-up Recognition
IRQ
IRQ

PCB



Arturo Guadalupi

Software: Drivers



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 MSP430FRxxxx uC can be easily introduced.

AraMIS 1B45 and Hardening

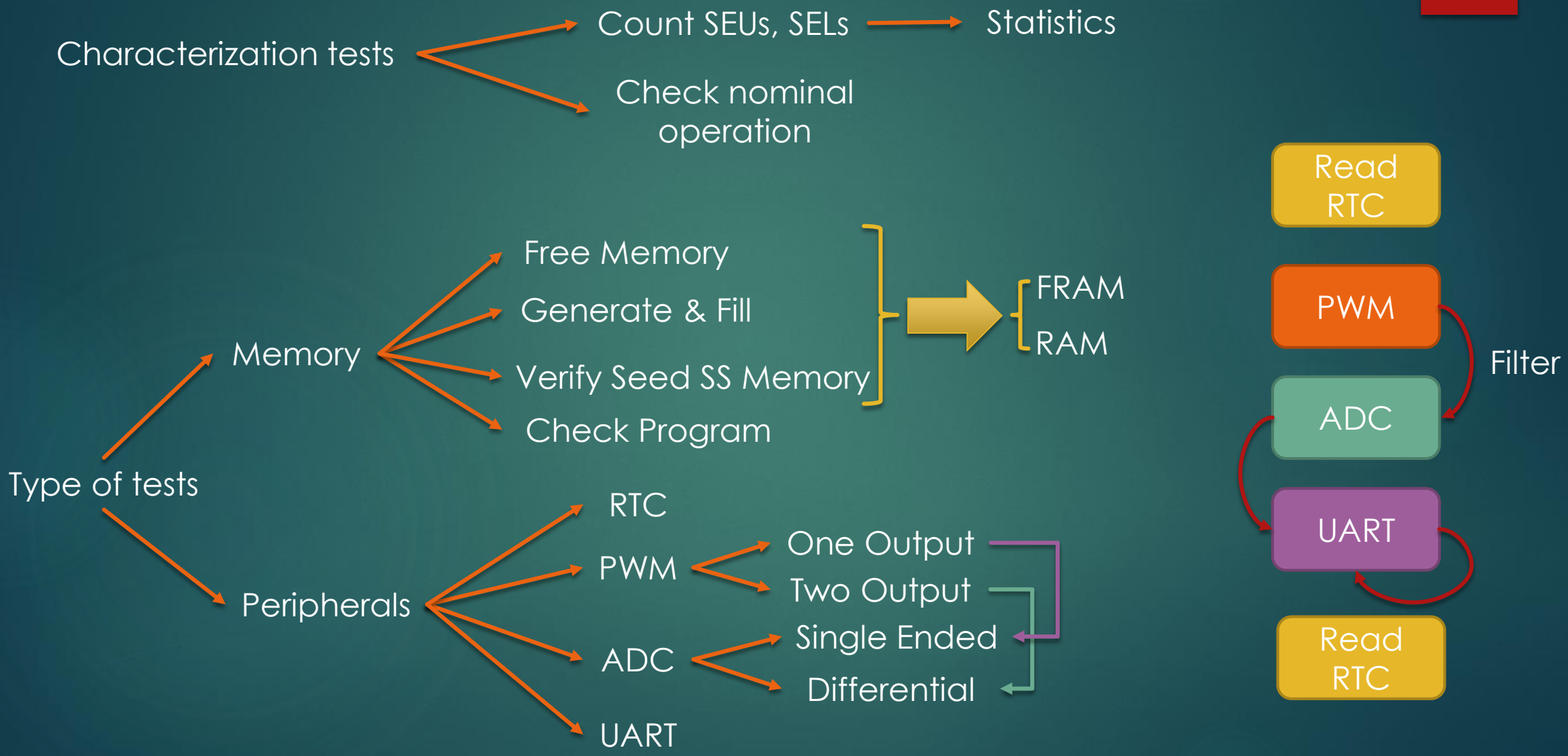
AraMIS has already implemented a communication protocol called 1B45 that has a built-in CRC, timeout ecc. This protocol has been used to communicate with the OBC

The software hardening library is based on the use of appropriate C++ classes from the hardened ata (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.

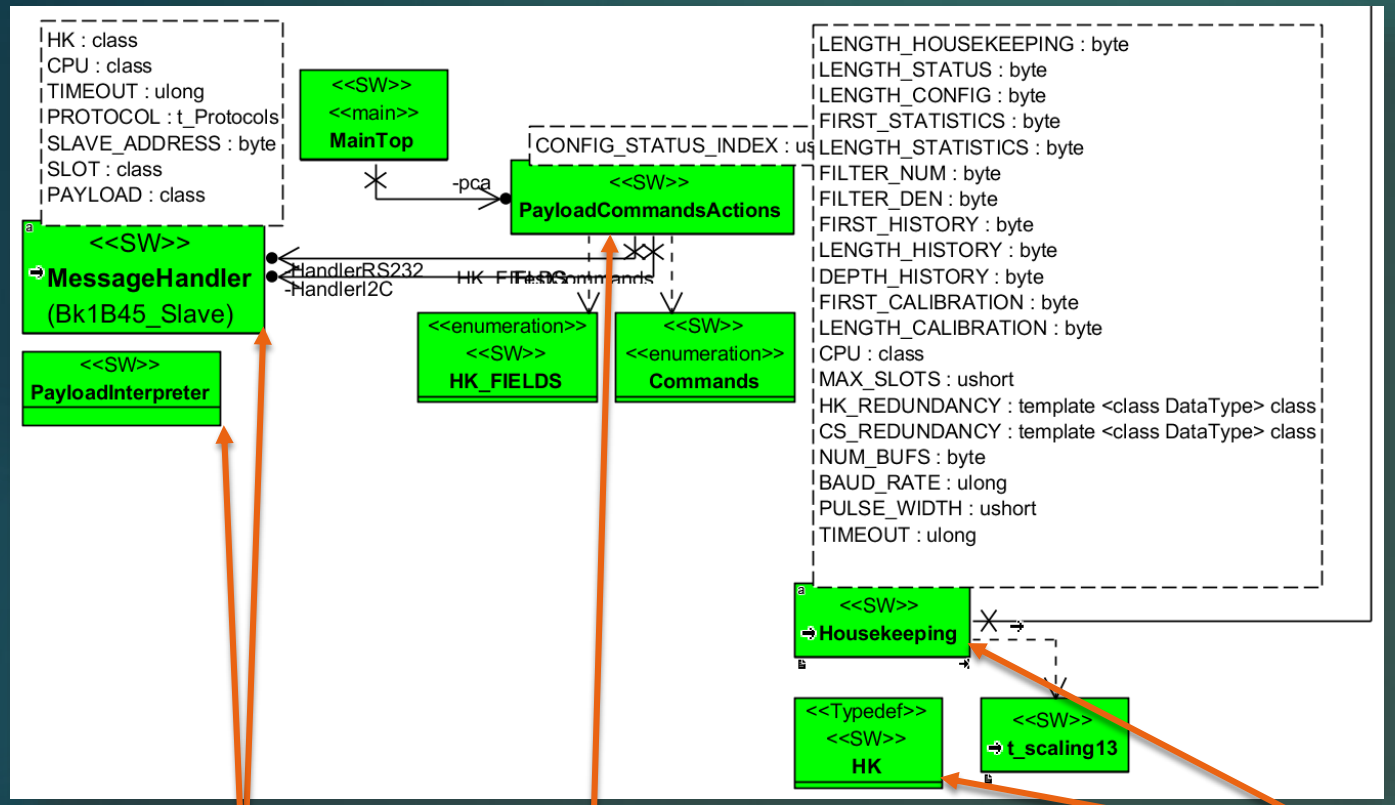
Normal program	Hardened program

short a=3, b=5;
short c;
c = a+b;
	TripleShort a=3, b=5;
	short c;
	c = a+b;

Software tests



Software Tests Class



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!