Second International Workshop on Analog and Mixed Signal Integrated Circuits for Space Applications
Cascais/Sintra, Portugal 1 September 2008

Radiation Hardened SMPS, Power Converter and Integrated Circuit Design Controller

Mauro Santos
Carlos Pires
Jorge Guilherme
Nuno Horta

INSTITUIÇÕES ASSOCIADAS:
INSTITUTO SUPERIOR TÉCNICO
Faculdade de Ciências e Tecnologia da Universidade de Coimbra
universidade de aveiro
PT Inovação
SIEMENS Communications

instituto de telecomunicações

creating and sharing knowledge for telecommunications

Outline

- **Introduction**
  - **Design Requirements and Constraints**
  - **Motivation and Goals**
- Power Converter
  - Topology Selection
  - Converter comparison
  - Multiple Outputs Converter
  - Secondary side components affecting efficiency
- Controller Circuit
  - Controller Features
  - Radiation hardening by design
- MATLAB Controller model
- Simulation Results
- Conclusions and Future Work

Design Requirements and Constraints

- Radiation Resistance
- High Efficiency
- Small Volume and Low Weight
- Low Cost
  - Use of Commercial Of The Shelf (COTS) parts is preferable
  - When possible, preference should be given to automotive industry parts (due to stringent testing)
- Wide range of operating temperatures
- Multiple outputs
- Galvanic isolation between the input and the output
- High mechanical resistance (for space applications)
- Filter capacitor restrictions (for space applications, electrolytic capacitors are forbidden)

Motivation and Goals

- Motivation
  - Project motivated by an ESA invitation to tender for a converter of this type
- Goals
  - Analysis of several candidate power converter topologies and selection of the most suitable
  - Development, integration in AMS 0.35µm BULK CMOS technology and radiation testing of the controller circuit
  - Development and testing of the power converter
  - Mechanical and vacuum testing

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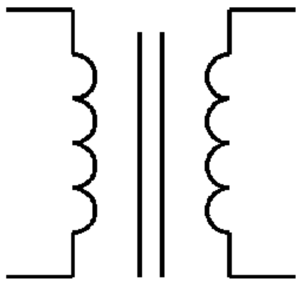
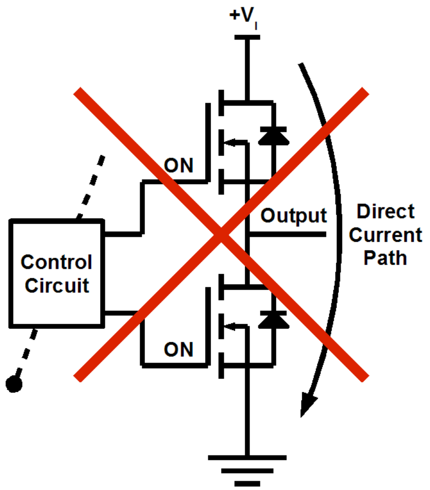
Topology Selection

- Provide isolation between input and output
  - Requires galvanic isolation either by using a transformer or coupled inductors



- Cannot create a short circuit in the input rail in the event of an upset

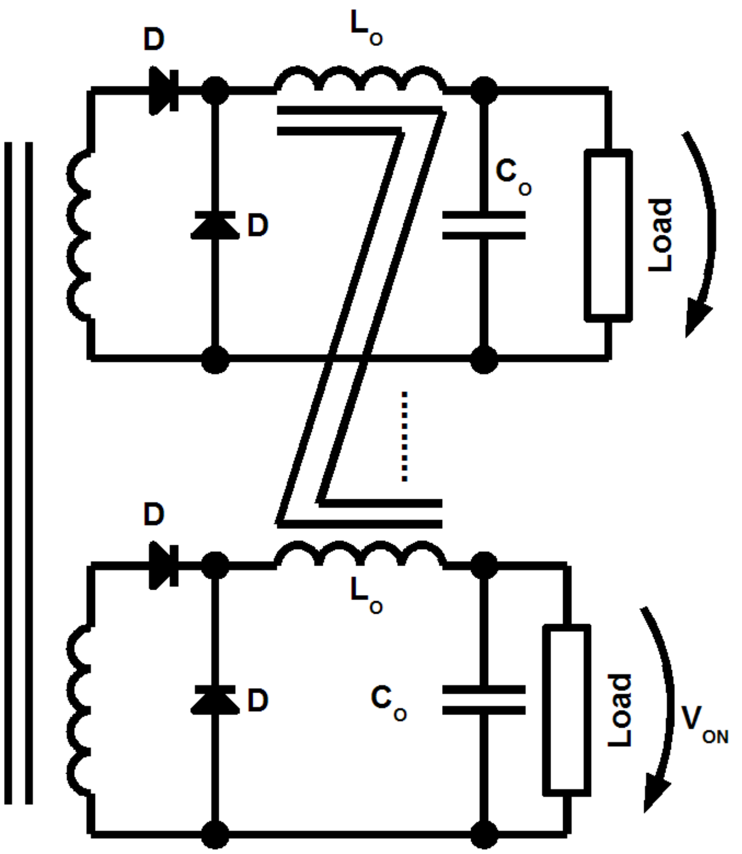


Converter comparison

Converter type	Advantages	Disadvantages
Forward	Simpler controller, smaller output capacitor and current ripple, allows the use of coupled inductors in the outputs	Large component count, complex transformer
Flyback	Complex controller, larger output capacitor and current ripple	Small component count, simple “transformer”
Flyback + 3 buck, or Forward + 3 buck or Boost push-pull + 3 buck	Smaller output capacitor, no need of feedback from output to input, excellent load and line regulation, individual protection for each output	Large component count, complex transformer (Forward and Boost push-pull), requires the use of three independent buck converters

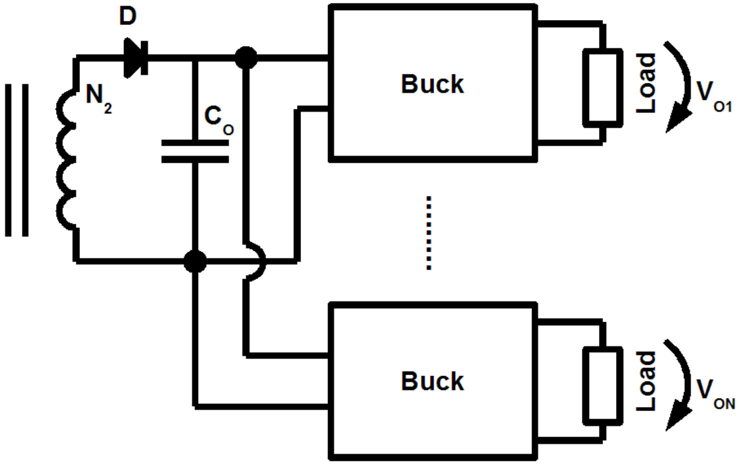
Multiple Outputs Converter (#1)

- Multiple output windings
  - Cross regulation is a problem
  - Output voltage sensing requires isolation
    - Using an opto-coupler – characteristics degrade with TID
    - Using an auxiliary winding – provides supply for controller circuit but output regulation is poor
  - Forward topology is more appropriate



Multiple Outputs Converter (#2)

- One output winding, multiple buck converters
  - More expensive – increase in the number of components
  - More design freedom, easily add or remove outputs
  - Each output is regulated independently
  - Flyback topology more appropriate



Secondary side components affecting efficiency

- Higher output filter capacitor ESR
  - Introduces a zero that helps stability
  - Degrades output voltage filtering
  - Decreases efficiency
  - Forces the use of more capacitors or a second stage of filtering

- Synchronous rectification
  - Increases efficiency
  - Increases total cost
  - Increases complexity

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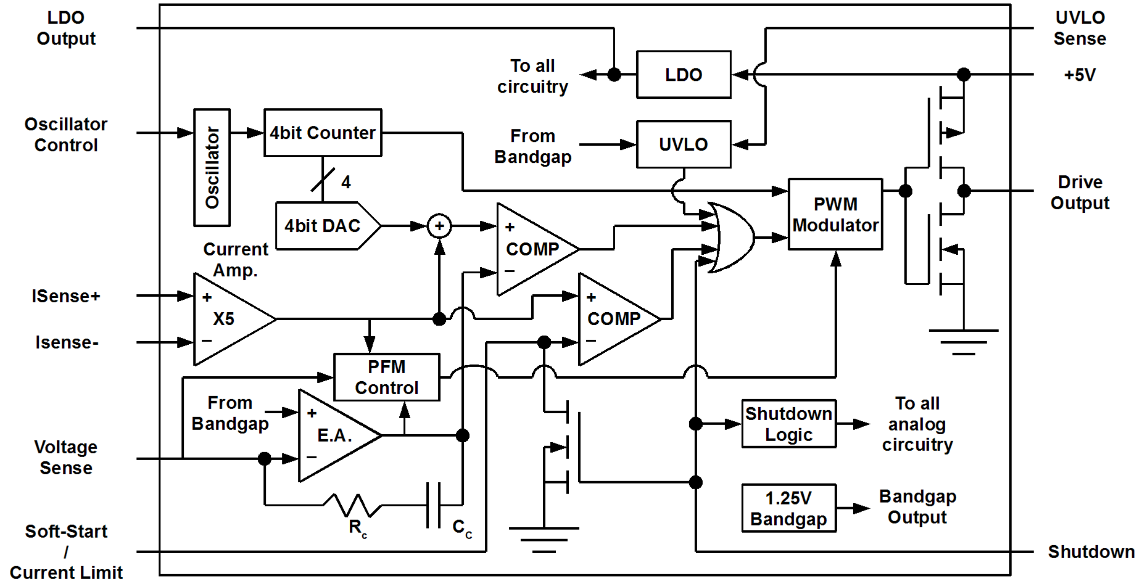
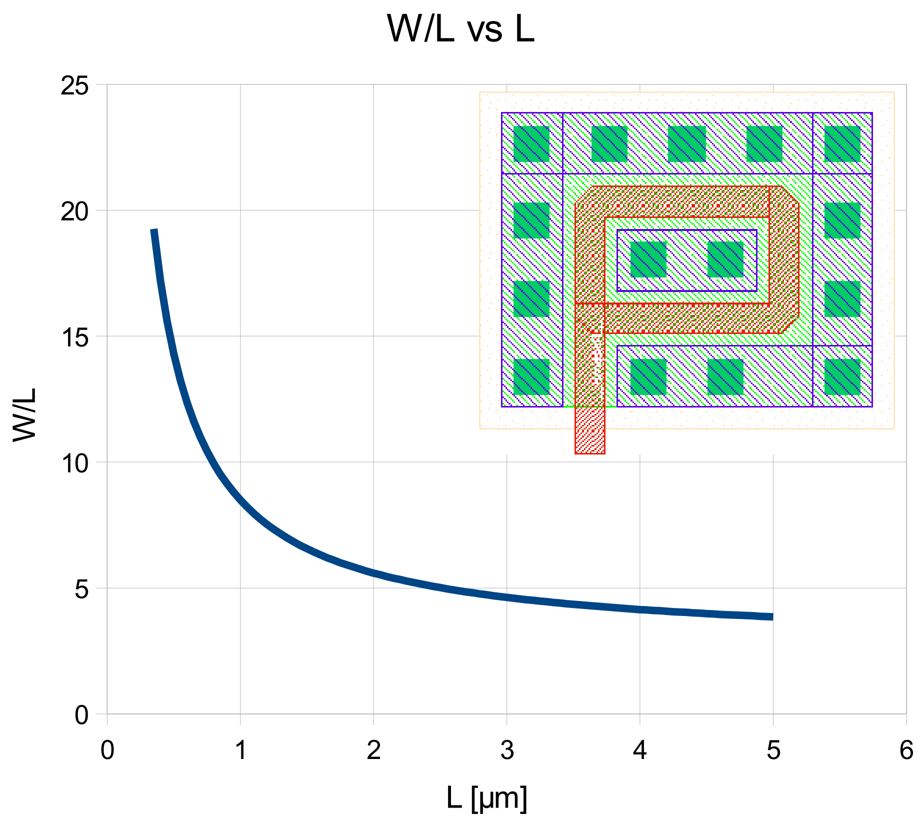
Controller Features

- Current mode control, cycle by cycle current limit
- Up to 2nF drive capability (to drive external power MOS)
- Soft-Start
- External shutdown/enable pin
- Adjustable oscillator frequency (up to 2MHz) using a single resistor
- PFM control mode for light loads to improve efficiency



Radiation hardening by design

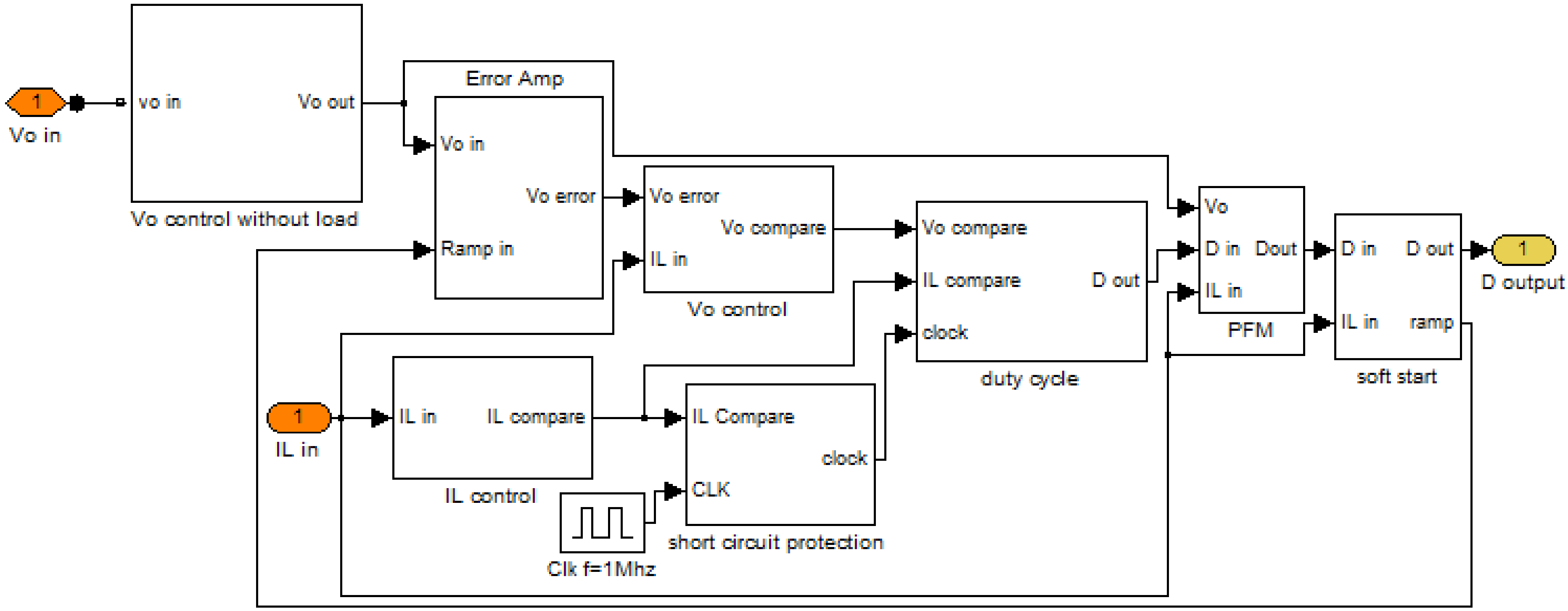
- Guarantee minimum current in every branch of the circuit
- Use redundancy and a voting circuit in elements with memory
- Use of enclosed layout transistors and guard rings
  - An ELT P-Cell was developed for this purpose
  - This ELT topology imposes W/L restrictions



Outline

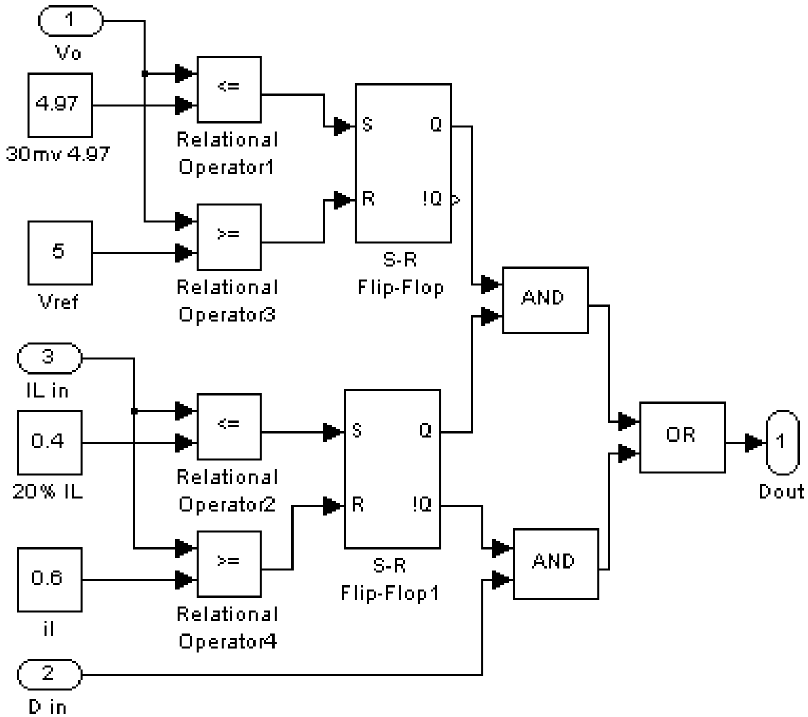
MATLAB Controller model (#1)

- A MATLAB model of the controller was developed allowing fast simulations and fine tunning



MATLAB Controller model (#2)

- PFM Control
  - Low inductor current (output current) or low error voltage (reduced duty-cycle)
  - High output voltage
- PWM Control
  - Medium / High Inductor current (output current) or medium / high error voltage
  - Output voltage within normal range



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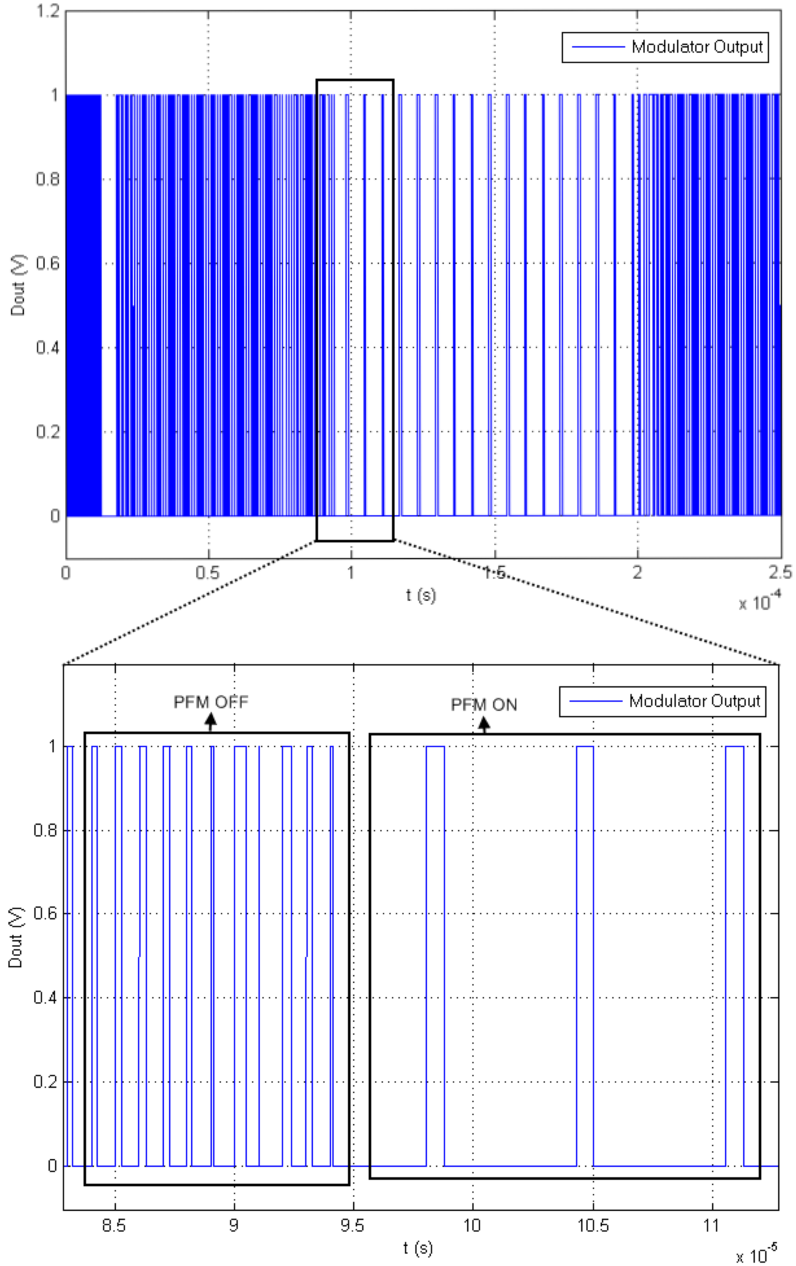
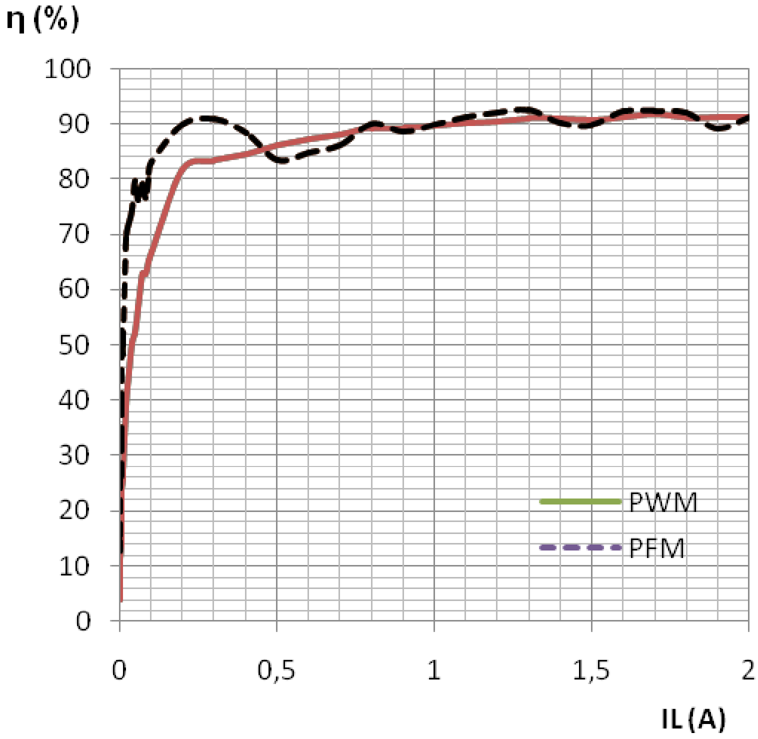
Simulation Results (#1)

- Simulation results show the two control modes
  - Current mode control
  - PFM control mode
- Transition between modes is performed based on the analysis of several switching cycles



Simulation Results (#2)

- Current mode control for medium and high loads
- PFM control mode for light loads improves efficiency
- Transition point must be carefully selected to maximize efficiency



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Conclusions and Future Work

- By developing a fully custom SMPS its possible to implement state of the art control modes which lead to increased efficiency, less volume and weight
- By using European technology ESA projects are technologically independent of foreign countries, leading to less money spent on licensing and importing and therefore making projects development faster
- System level simulation was performed using MATLAB
- Design solution will be validated by a integration prototype in AMS 0.35µm BULK CMOS technology and samples will be submitted to vacuum, mechanical and radiation tests