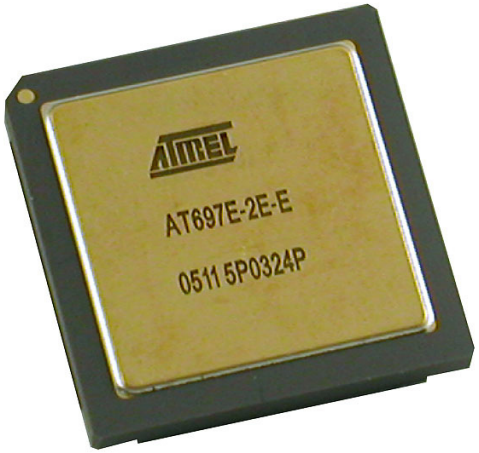
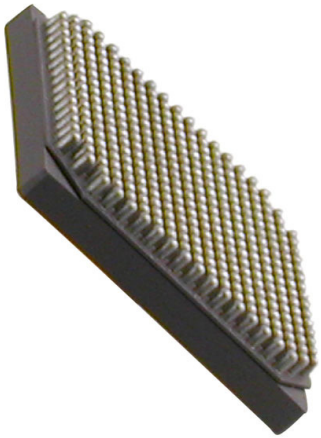
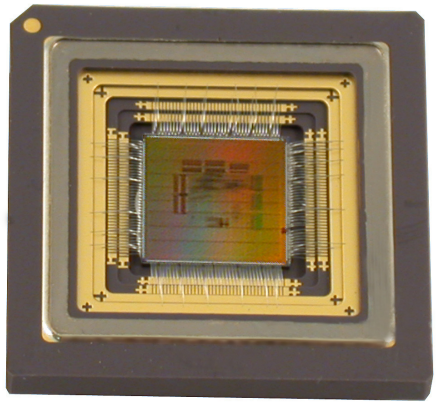
AT697E LEON2-FT
Final Presentation

ESA contract 15036/01/NL/FM







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Overview

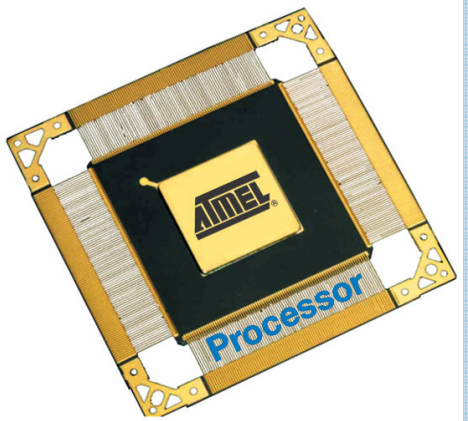
- Initial objectives – design phase
- Validation and characterisation results
  - Performance results
- Radiation results
  - Total dose
  - Single Event Effects
- Hardware / software / documentation status
- Conclusion

ATMEL Sparc microprocessor family

- ESA/CNES funding

- A chipset version (ERC32) for IU-FPU-memory controller
  - CMOS 0.8 µm - Flight version in 1997 – Phased out

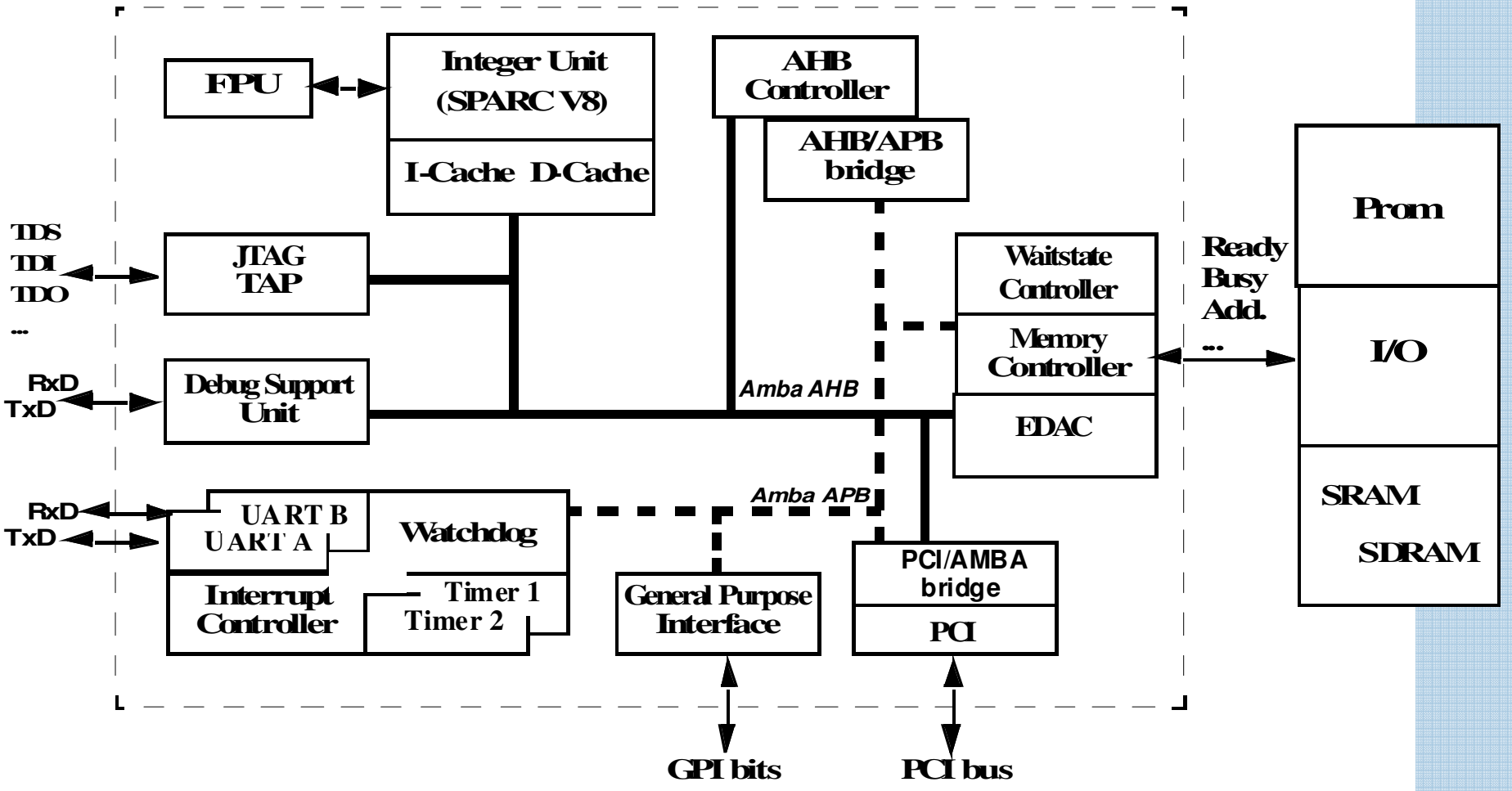
- TSC695F : current Sparc space processor (ERC32 SC)
  - CMOS rad-hard 0.5 µm technology
  - Sparc V7 with FPU; 25 MHz max; 5V ± 0.5V
  - 20 Mips / 5 MFlops at 25 MHz ; 230 mA
  - MQFP-F 256 & die form
  - Total Ionizing dose : 300 Krad
  - No Single Event Latch up below 80 MeV/mg/cm2
  - Excellent SEU immunity
    - E.g : SEU error rate better than 3 E-8 / device / day in GEO orbit
  - SCC B & QML V
  - Flight version in 2000 – now available
  - Flying since a few years
    - Launchers – telecomm satellites – various scientific missions – defense applications
  - A 3.3V version available : the TSC695FL



AT697E development

- The AT697E was developed under ESA contract
  - Design, manufacturing, validation and characterization of a SPARC V8 LEON processor (LEON2-FT prototype – phase 2)
- Implements LEON2 FT ESA VHDL model
  - Version 1.0.9.5
- Fault tolerance by design
  - Triple Modular Redundancy with skew
    - SEU and SET protection
  - EDAC on register file
  - Parity on the caches

AT697E block diagram



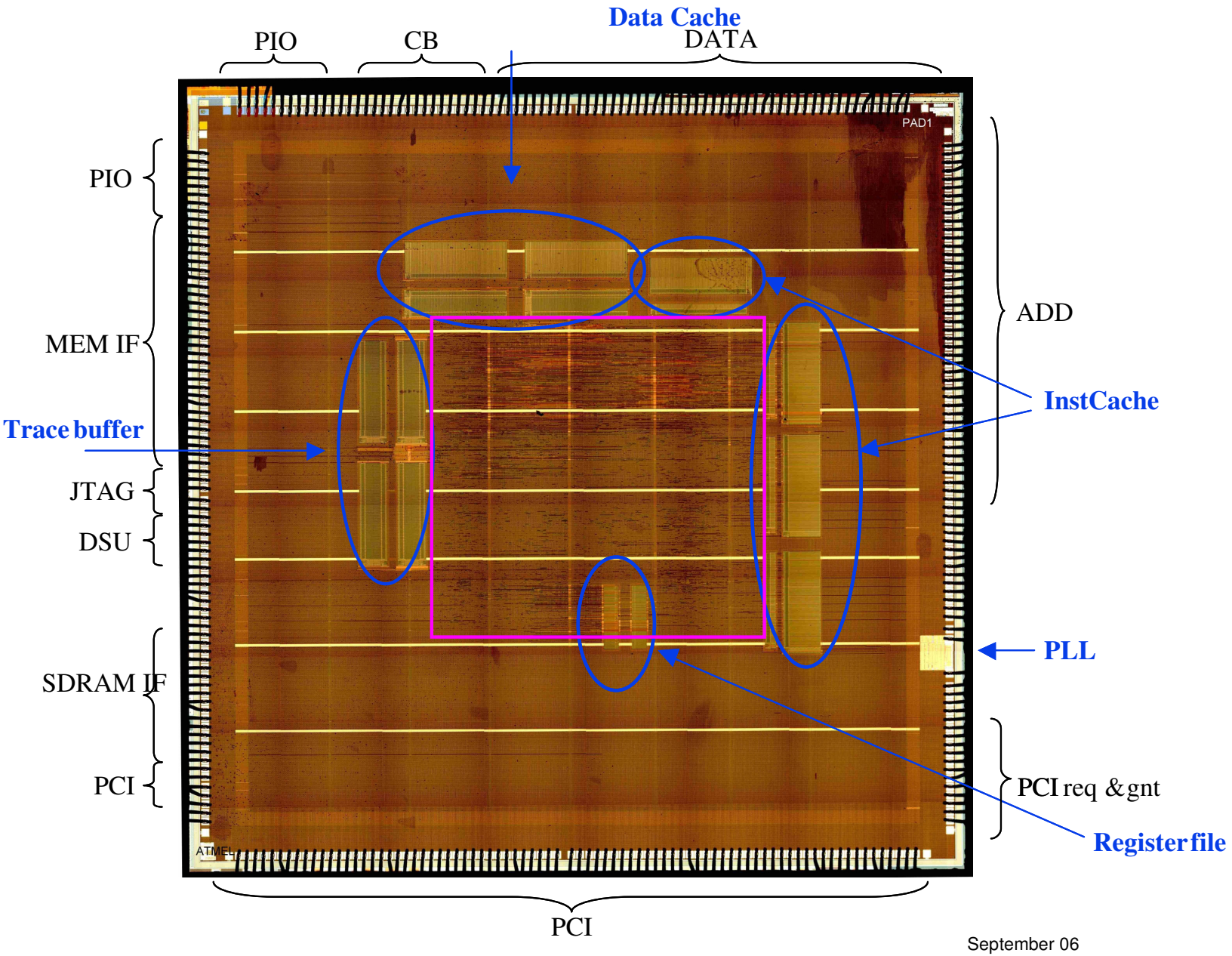
AT697E design phase (1)

- ATC18 standard cell library (CMOS 0.18 µm)
- 1.8V bias for the processor itself, 3.3V bias for buffers
- Die size : 8,6 mm x 8.6 mm
  - Pad limited
  - Space assembly rules fulfilled
- MCGA 349 package advantages
  - Weight, size, thermal resistance, space qualified

AT697E design phase (2)

- Fault coverage > 96 %
- Design simulations : 100 MHz in worst case conditions
- Gate count: 850 Kgates
  - Processor logic : 280 Kgates (PCI excluded)
    - IU : 67 Kgates,
    - FPU : 29 Kgates,
    - memory controller : 87 Kgates
  - PCI logic : 117 Kgates

The chip


Data Cache
PIO
CB
DATA
PIO
MEM IF
Trace buffer
JTAG
DSU
SDRAM IF
PCI
ADD
InstCache
PLL
PCI req &gnt
Register file
PCI
PAD1
ATMEL

Presentation progress

- Initial objectives – design phase
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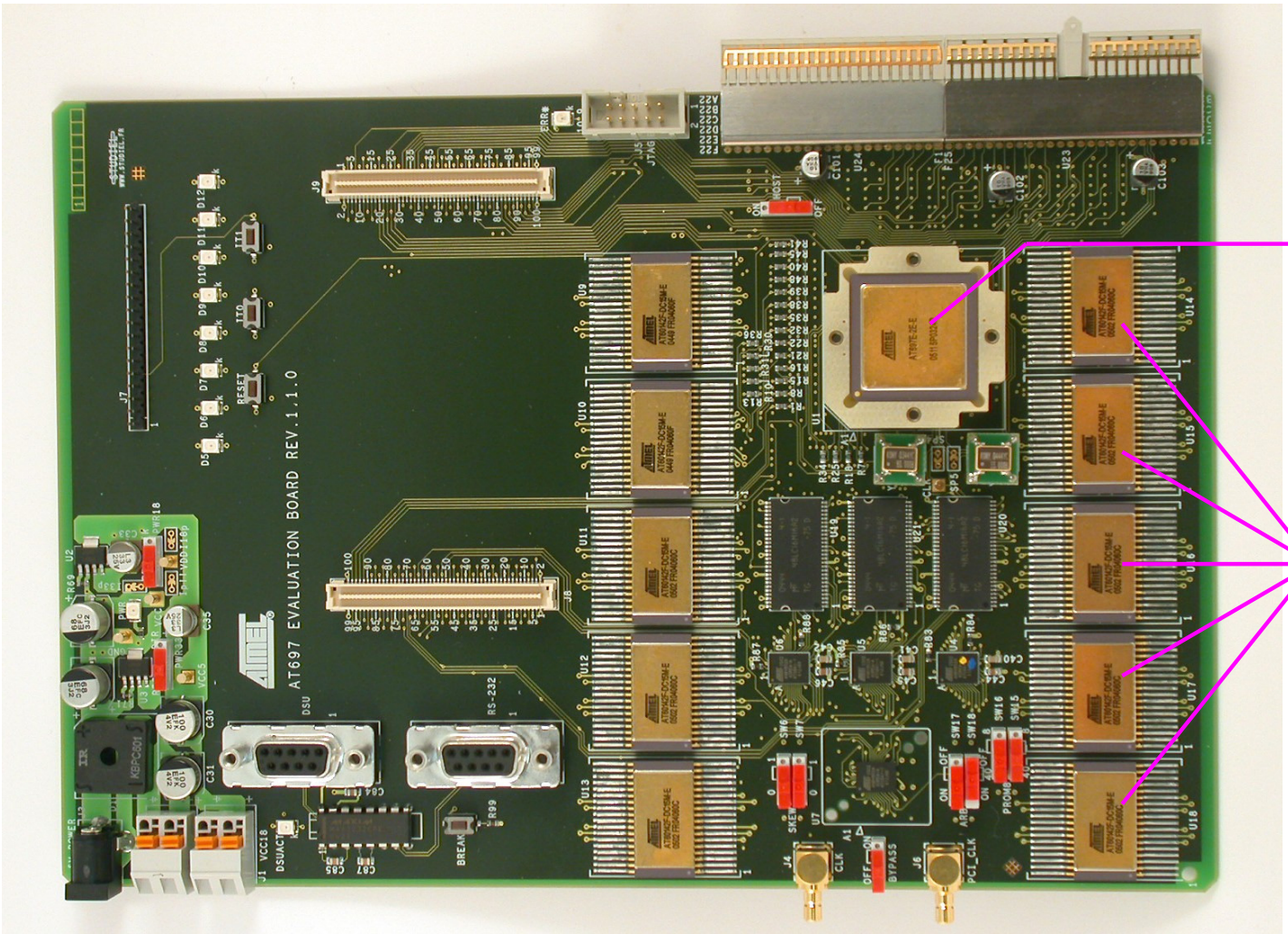
Organisation of the validation

- AT697E samples available since April 2005
- ATMEL internal validation
- ESA : subcontracted an AT697E validation to Gaisler Research
  - Final presentation mid June 05
- Three « formal » alpha customers :
  - Saab Ericsson Space (Göteborg, Sweden)
  - EADS Astrium (Velizy and Toulouse, France)
  - Alcatel Space (Toulouse, France)
- Some early design starters

ATMEL validation environment (1/2)

- 6U format Compact PCI Evaluation board



ATMEL validation environment (2/2)

- PCI validation
  - Passive backplane with two 64 bits PCI slots
  - TA700 PCI analyser engine from Catalyst
- Development and Debug environment
  - Compiler
    - RCC and BCC
  - Debugger
    - GRMON (1.0.12 and 1.1.5, the latest being adapted to the AT697-EVAB)

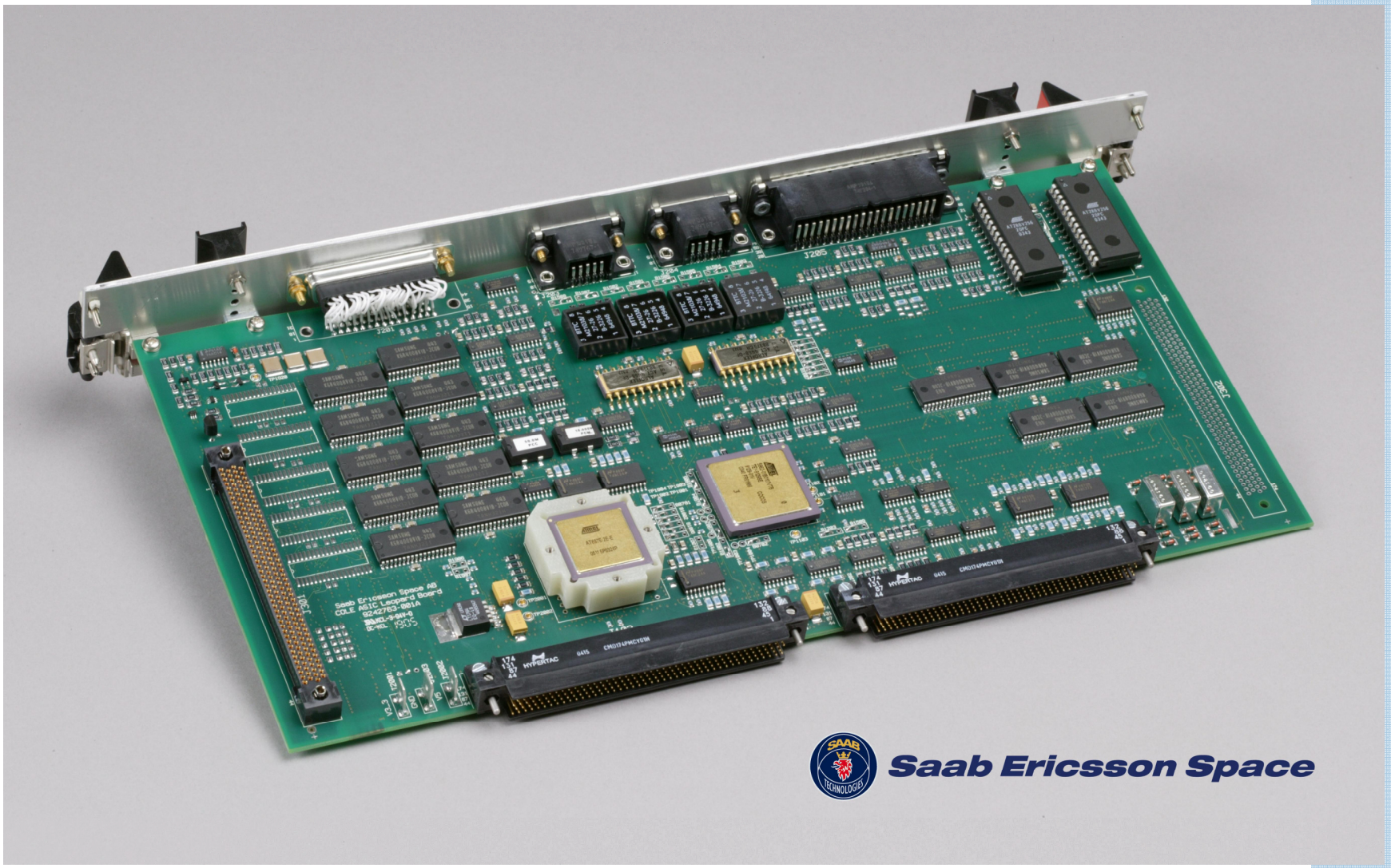
ATMEL validation results (1)

- **Processor validation**
  - No additional bugs than the ones coming from the LEON2-FT 1.0.9.5 model
    - These bugs are listed in the AT697 errata sheet
    - See ATMEL web site http://www.atmel.com/products/radhard/
- **Power consumption**
  - 7 mW / MHz
    - Core : 0.5W
    - I/O : 0.2 W
    - At 100 MHz and for high activity
  - Idle mode : power consumption reduced by 20 %

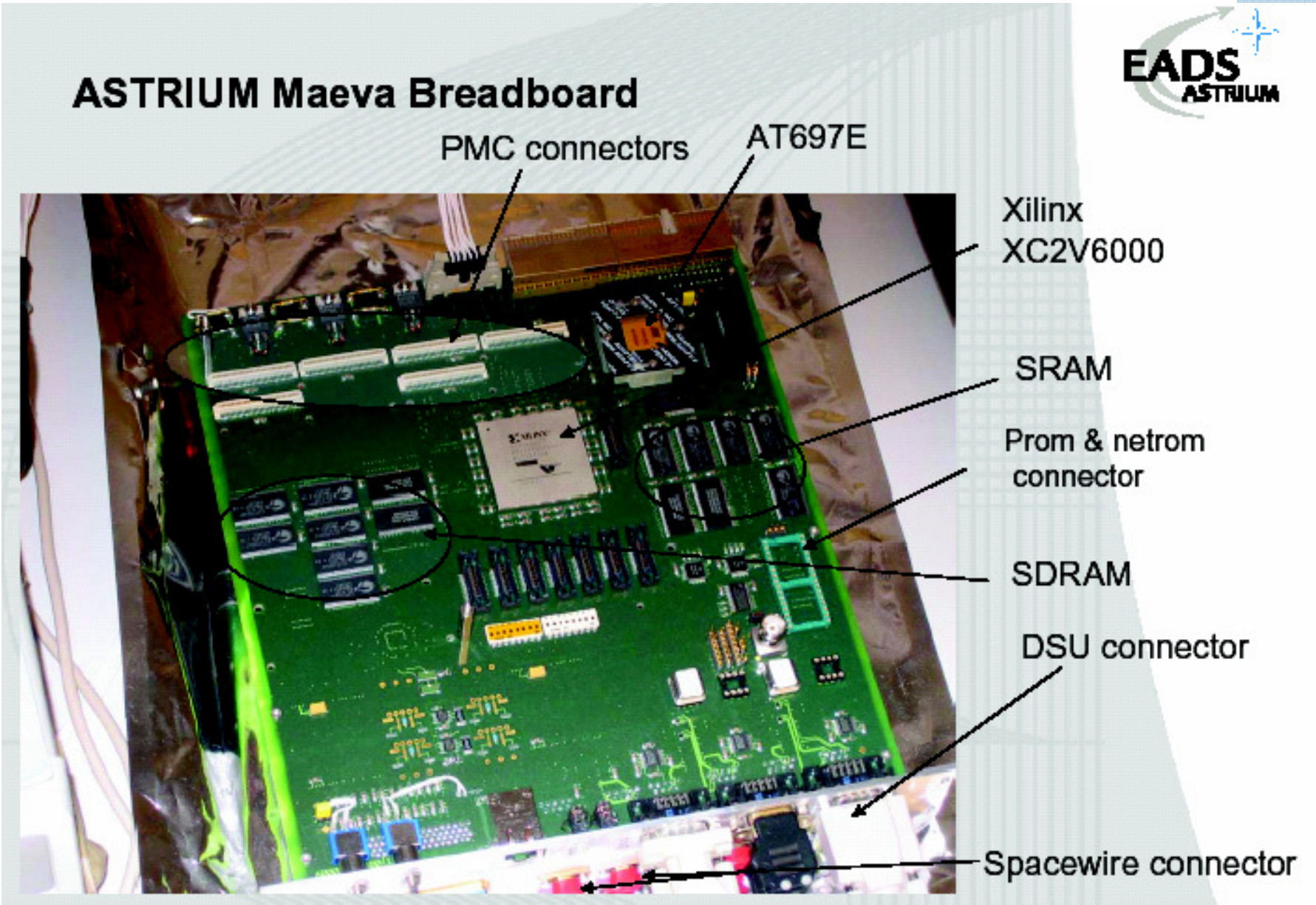
ATMEL validation results (2)

- Performance at 100MHz
  - 86 MIPS (Dhrystone 2.1)
  - 23 MFLOPs (Whetstone)
  - SDRAM interface speed impacted by the bus load
    - On AT697-EVAB (2 SRAM and 1 SDRAM banks) : 65 MHz maximum

Saab Ericsson space board



EADS Astrium board



Summary of the alpha customers validation

- Fully functional (no new bugs)
- Good power figures
- Answers the requirement of space community
- Issues to be solved for QML-V parts :
  - SDRAM timings
  - Correction of known bugs

Characterization results

- Characterisation performed
  - In full bias ranges : 3.0 V to 3.6V and 1.65 V to 1.95V
  - In full military temperature range : - 55°C to +125°C
- Parts fully functional in all the bias and temperature ranges
- DC and AC parameters in line with design expectations
  - Current consumptions, input leakages, output currents
  - Setup, hold, output delays
- Update of the datasheet done in February 06
  - See ATMEL web site http://www.atmel.com/products/radhard/

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Total dose test results (1)

- 20 parts used
  - 12 parts in static mode
  - 6 parts in dynamic mode (5 MHz)
  - 2 parts unbiased
- In accordance with MIL STD 883 method 1019.6
- Co60 source located near the Nantes factory

Total dose test results (2)

- Parts fully functional at 200 krad (Si)
- 3.3V I/O standby current increases after 100 krad (Si), and recovers after high temperature annealing
- These results allow to use these AT697E parts for space mission requiring a maximum of 60 krad (Si)

Single Event Effects test objectives

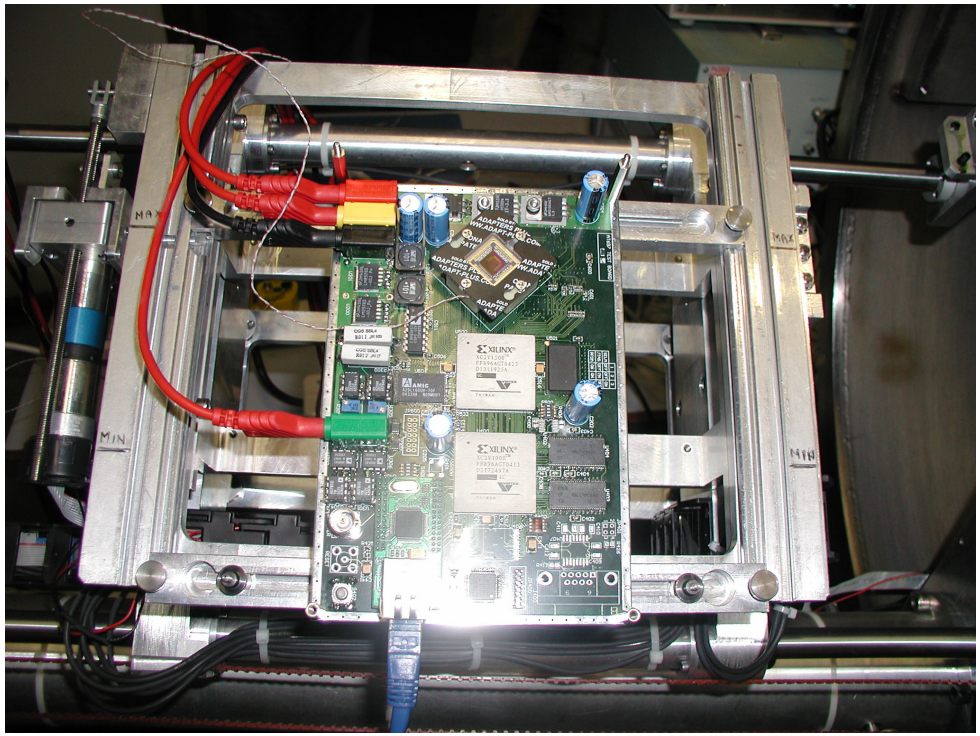
- Assess the SEU sensitivity of the AT697E processor
  - Check the implementation of EDAC and parity
- Assess the SET influence
  - Variation of the skew
  - Variation of the frequency
- Assess the SEL capability

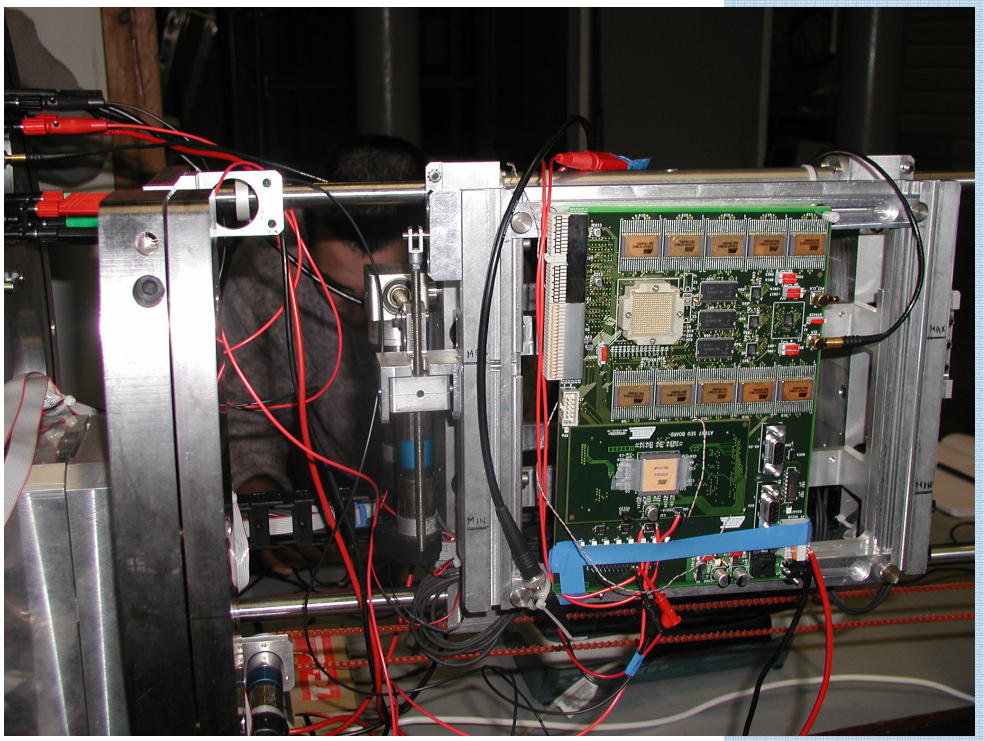
Single Event Effects test

- Four heavy ions test campaigns done, 9 parts used
- Heavy ions test done at UCL (Louvain, Belgium)
  - From July to December 2005
  - Use of a dedicated test board (in partnership with TIMA laboratory in Grenoble, France) and the ATMEL evaluation board
    - See next slide
- Different test programs used
  - Static tests to assess the memories SEU sensitivity and to confirm the appropriate behaviour of the EDAC and parity protections
  - Dynamic benchmarks
    - Matrix calculation
    - Bubble sort
    - PCI transfer
    - Orbit calculation program

SEE test set-up

- SEL conditions : max voltage, dynamic tests
- SEU/SET tests : min voltage, static and dynamic tests





Single Event Effects test results

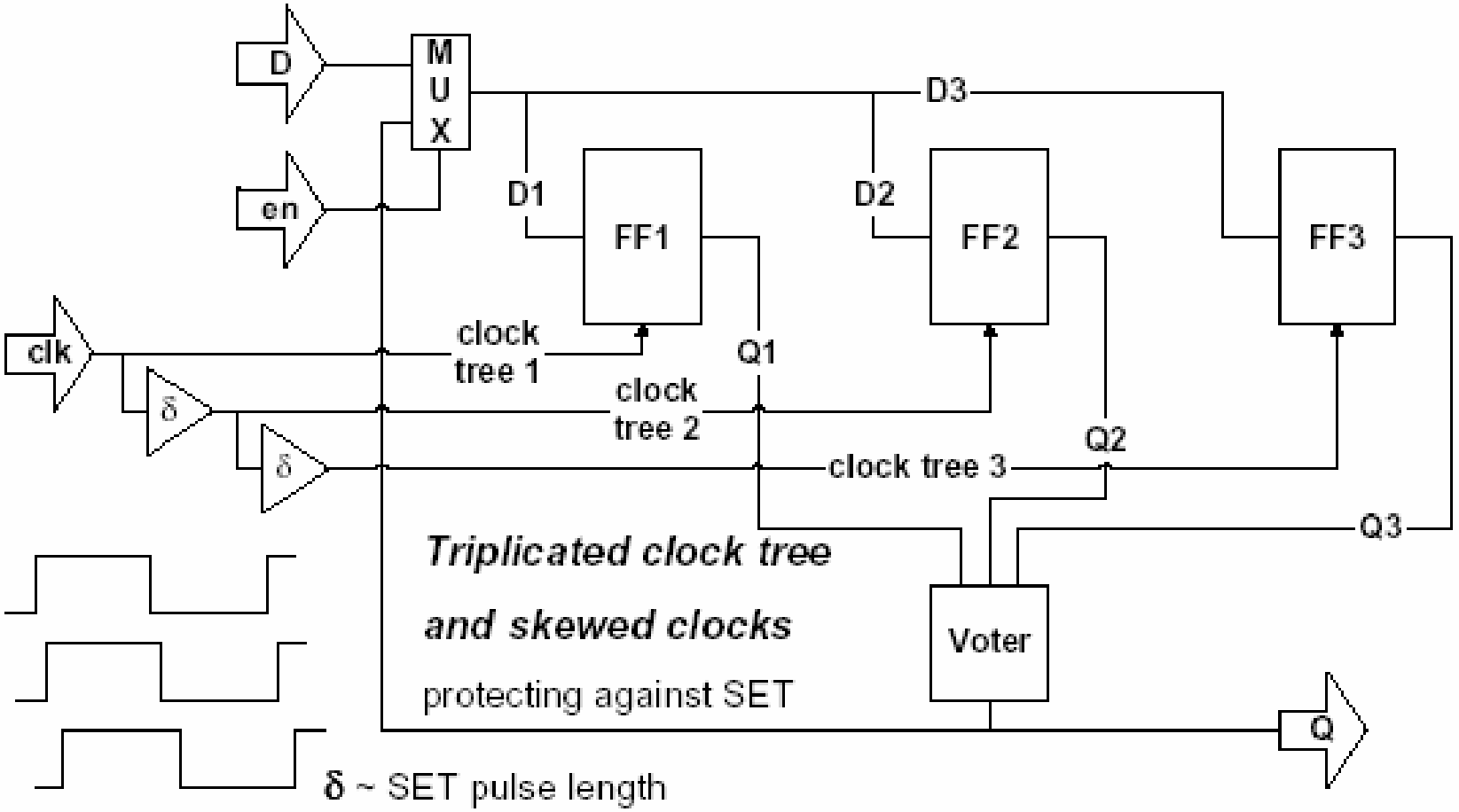
- Single Event Latchup
  - 3 parts used
  - No SEL at 70 MeV/mg/cm2 – max voltage – 25°C for a fluence of 1 E7 particles/cm2

- The static tests have confirmed the SEE test results of the ATC18RHA library (cross sections in cm2/bit)
  - the implementation of EDAC and parity is correct

LET (MeV/mg/cm^2)	SRAM ATC18RHA	Icache	Itag	Dcache
2.97	5 E-9	5.1 E-9	6.3 E-9	4.5 E-9
14.1	1.4 E-8	1.6 E-8	1.6 E-8	1.5 E-8
55.9	5 E-8	8.1 E-8	8.1 E-8	7.3 E-8

Protection against SET

- All FF are triplicated, with three separated clocks.
- The skew between the clocks can be the natural one or can be increased by an additional delay.



Error rate in space due to SEU/SET

- The SEU/SET error rate is good for space applications
  - The error rate decreases with the frequency in the same order of magnitude
  - No functional interrupt during all the test campaigns (no processor hang)
- Error rate using the sort test
  - uncorrectable errors (wrong calculation and traps)

Error rate per device per day versus orbit / MTBF (years)	AT697E used with maximum skew	AT697E used with natural skew
GEO	**1.3 E-5 / 211**	**2.4 E-5 / 114**
LEO 53° - 1000 km	**3.9 E-6 / 702**	**7.9 E-6 / 347**
LEO 98° - 852 km; Spot	**4.9 E-6 / 559**	**9.2 E-6 / 298**
LEO 98° - 600 km	**3.8 E-6 / 720**	**7.1 E-6 / 386**
LEO 51° - 450 km; ISS	**1.4 E-6 / 1956**	**2.6 E-6 / 1053**

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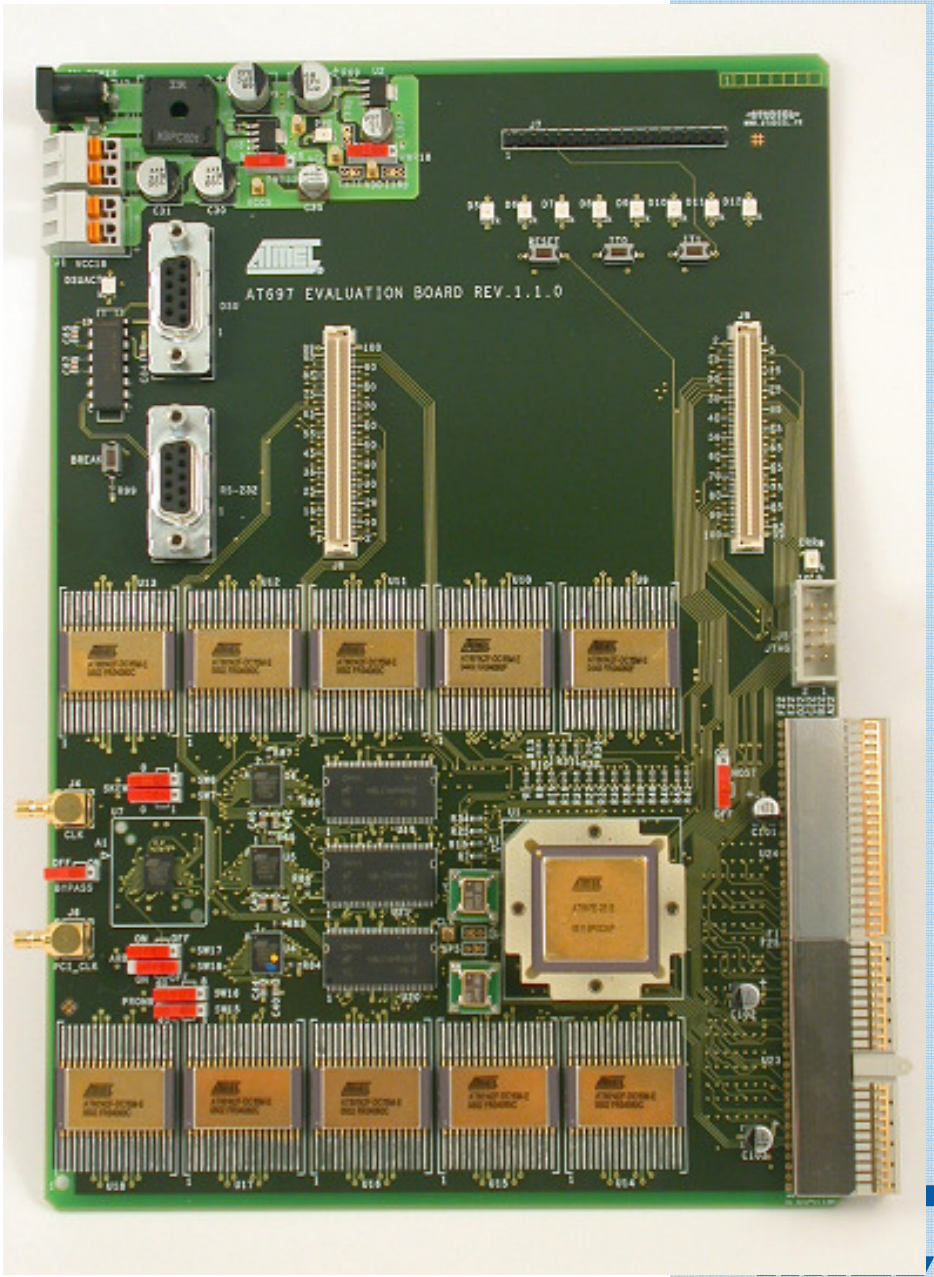
AT697 Development Platforms

- ATMEL Development Platforms
  - AT697-EVAB : ATMEL AT697 evaluation board
    - Hardware + Software Examples
    - Free compiler
    - One AT697E-2E-E part (engineering sample)
  - AT697-DKIT : ATMEL AT697 development kit
    - Hardware + Software Examples
    - Free compiler
    - One AT697E-2E-E part
    - Debug Monitor

ATMEL AT697 Compact PCI Evaluation board

- Compact PCI plug-in format
  - **6U format, 32 bit, 33MHz interface**
  - **Configurable for System and Peripheral slot operation**
- Processor
  - **Atmel AT697E, Rad-Hard 32 bit Sparc V8 Embedded Processor**
- On-board memory
  - **SRAM - 4Mbyte**
    - **2 AT60142 SRAM banks**
  - **FLASH - 2Mbyte**
  - **SDRAM - 64Mbyte**
- Interfaces
  - **Memory/Peripheral expansion connectors**
  - **Debug Support Unit interface**
  - **PIO expansion**
  - **On-board power regulation allows operation from PCI slot, or stand-alone with +5V supply.**

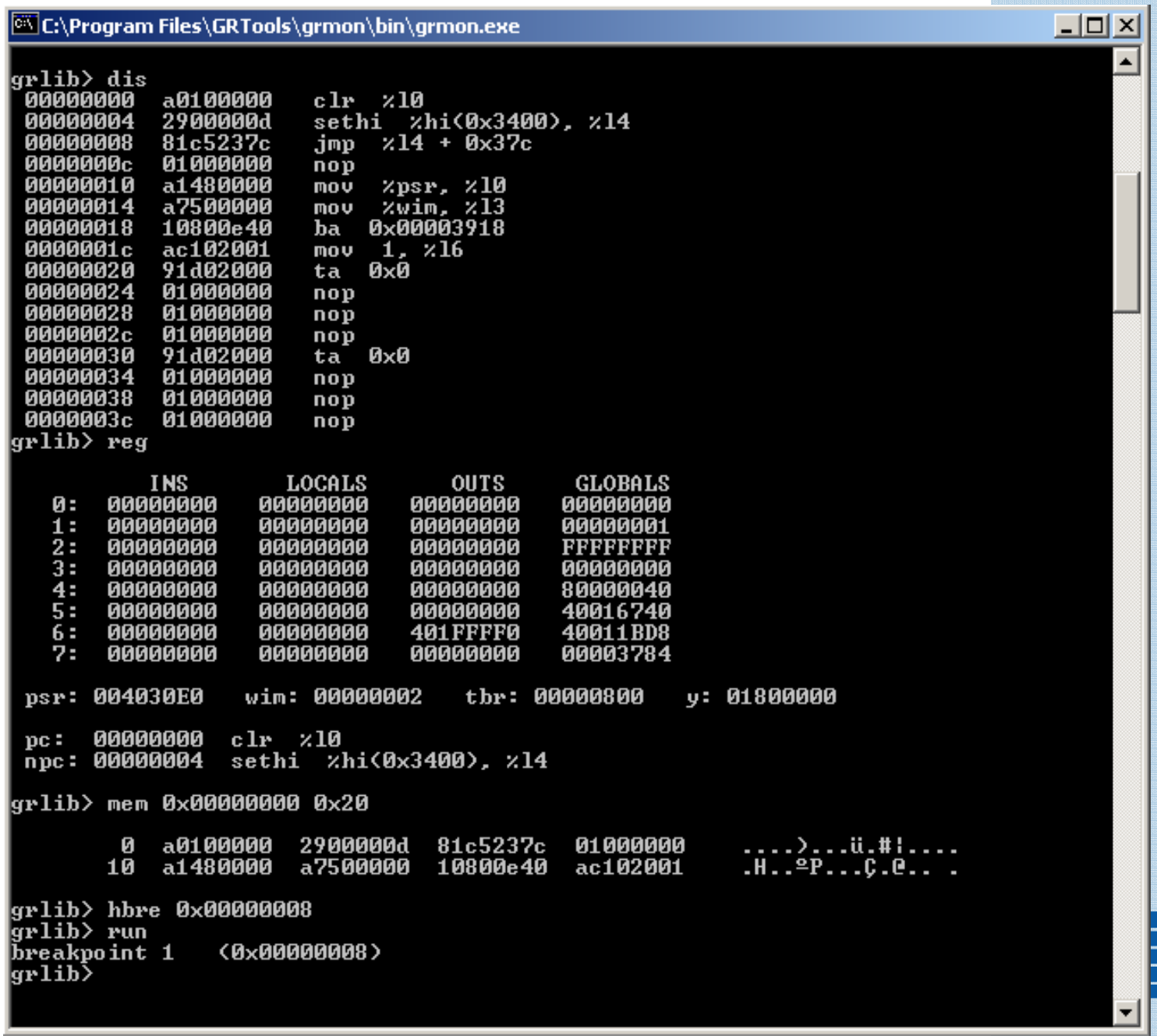


AT697 Software Development Tools

- Compiler
  - Bare-C Cross-compiler
  - RTEMS Cross-compiler
- Debugger
  - GRMON debug monitor
    target debug through serial DSU or PCI interface
- Simulator
  - TSIM simulator
- Real Time Operating Systems
  - RTEMS
  - VxWorks
  - eCOS
  - Snapgear Embedded Linux (uClinux)

GRMon Monitor

- Loader
  - Flash
  - RAM
- Debugger (Low level)
- Disassembler
- Trace
- …



Links / Documentation

- ATMEL
  - Documentation regularly updated on ATMEL web site
    - http://www.atmel.com/products/radhard/
    - Datasheet, errata sheet, evaluation board user manual
  - One dedicated Sparc Hotline
    - sparc-applab.hotline@nto.atmel.com
  - Radiation report available on demand

- Gaisler Research
  - www.gaisler.com

Presentation progress

- Initial objectives – design phase
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Summary results

- AT697E samples available since April 2005
- Validation, characterisation, radiation test results available since end 2005, and very positive :
  - AT697E is fully functional
    - over the whole bias and mil temp ranges
  - 86 MIPs / 23 MFLOPs at 100 MHz
  - 7 mW / MHz
  - Successfully tested up to 200 Krad (Si)
  - SEU/SET hardened processor
    - 1 uncorrectable error every 200 years in GEO orbit with max skew
  - No SEL at room temperature for a LET of 70 MeV/mg/cm2

150 MIPs/W

AT697E military quality grade version

- Some requests to use the current version for flight in some scientific missions
  - e.g. for ESA PROBA2 project
- AT697E lot qualification performed successfully
- AT697E-2E-MQ parts are available since August 2006
  - Screening equivalent to QML-Q quality flow
  - Include burn-in and life test

AT697E interest

- A number of early AT697E design starters
  - In Europe (~ 10)
  - In North America (~ 5)

- Near half of the technical questions received on the ATMEL Sparc hotline are AT697 related

The end

Thank you for your attention !