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Evaluation of a 10-bit 2.2 Gsps ADC for Space Applications

D. Bellin
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J. Bellefet (e2v)
C. Carmona (e2v)
F. Malou (CNES)
P. Ribeiro (TRAD)

Outline



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- e2v grenoble presentation
- Overview of 10-bit 2.2 Gsps AT84AS008 ADC
- Architecture and Process
- Package description
- Space Evaluation with CNES
 - Electrical characterization
 - ESD tests
 - Package tests (mechanical, thermal and reflow)
 - Quality and reliability tests
- Radiation tests
 - Total dose tests
 - Heavy ions tests
- Radiation assessment of AT84CS001 DEMUX (companion chip)
 - Total dose tests
 - SEL tests
- Conclusion

1- Overview of e2v Grenoble

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➤ Atmel Grenoble became **e2v grenoble** starting August 1st, 2006

□ Atmel motivation : to focus on its core technologies

□ e2v motivation :

→ very good strategic fit

→ will allow to extend markets with broader range of products

ATMEL
Grenoble



e2v grenoble

➤ In-house skills cover all aspects of:

□ Design

□ Electrical characterization

□ Package design / thermal modelling

□ Assembly

□ Test

□ Burn-in

□ All tasks required by space level production

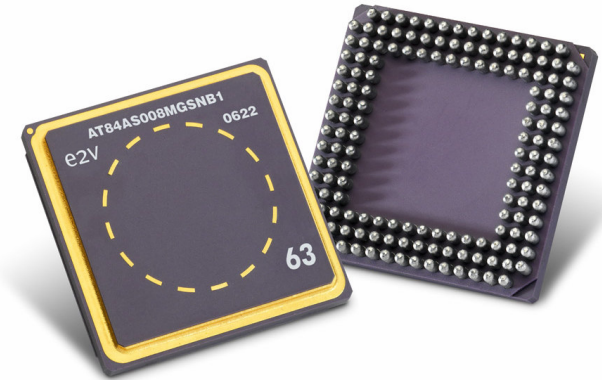


2- Overview of 10-bit 2.2 Gsps AT84AS008 ADC

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➤ 10-bit 2.2 Gsps ADC

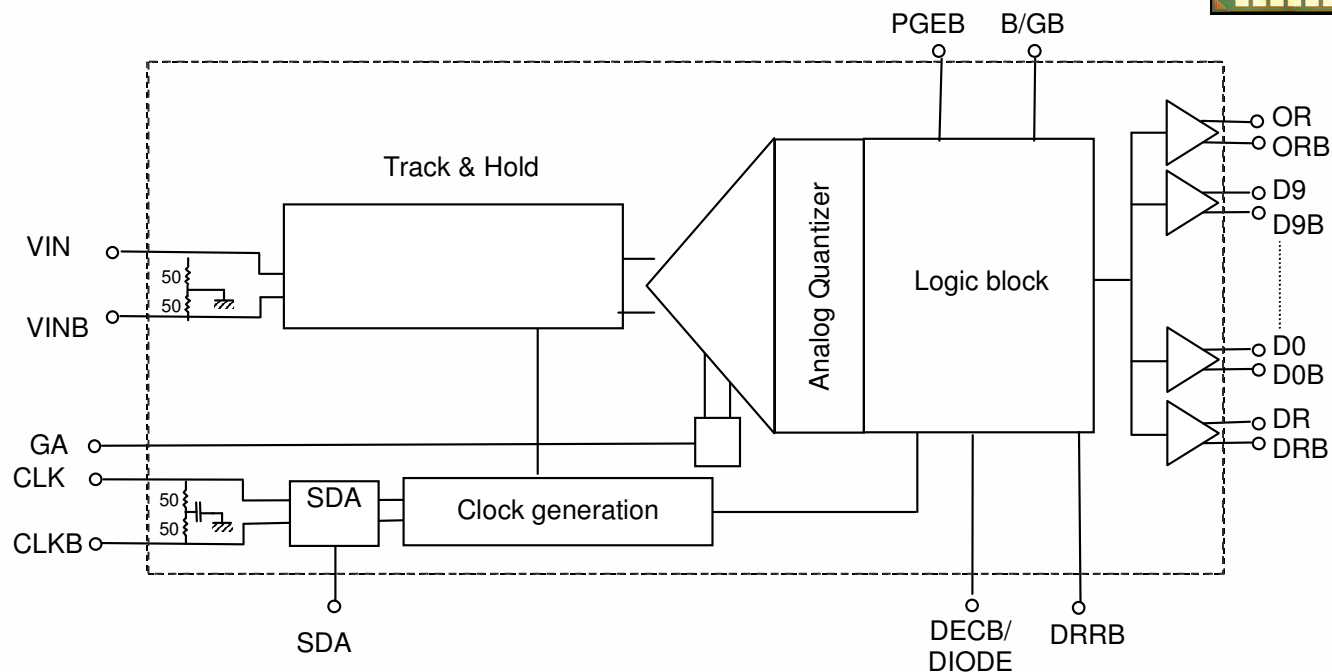
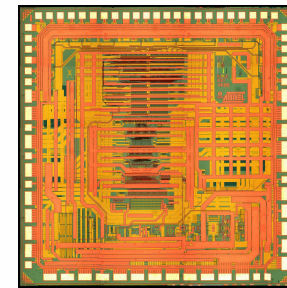
- ❑ 8 bit ENOB at 1.7 Gsps in 1st Nyquist
- ❑ 7.7 bit ENOB at 2.2 Gsps in 1st Nyquist
- ❑ SFDR = -54 dBc / SNR = 50 dB at 2.2 Gsps
- ❑ 3.3 GHz input bandwidth
 - ⇒ performances are flat over the full 1st Nyquist zone.
- ❑ Same features than previous TS83102G0B 10-bit 2 Gsps ADC:
 - AT84AS008 is fully pin-to-pin compatible with TS83102G0B ADC
 - Performance improvements are significant
 - ✓ better SNR and ENOB performances above $F_{in} = 1$ GHz
 - ✓ flatter spectrally 'pure' FFT response throughout 1st and 2nd Nyquist.



3- Architecture of AT84AS008 ADC

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- Track/Hold
- Analog quantizer (folding & interpolation)
- Regeneration of analog residues into logical levels
- Synchronization stage before output buffers
- Fully differential architecture

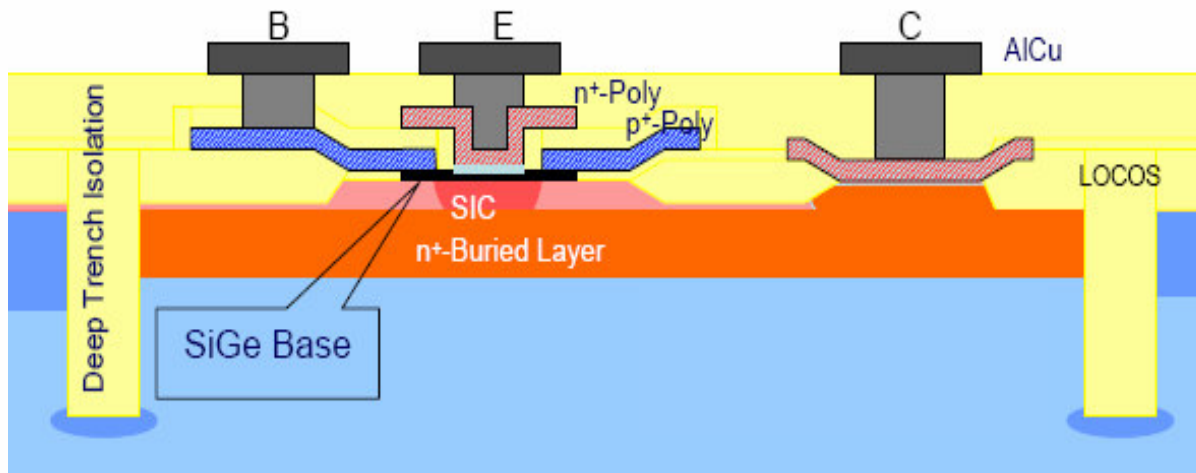
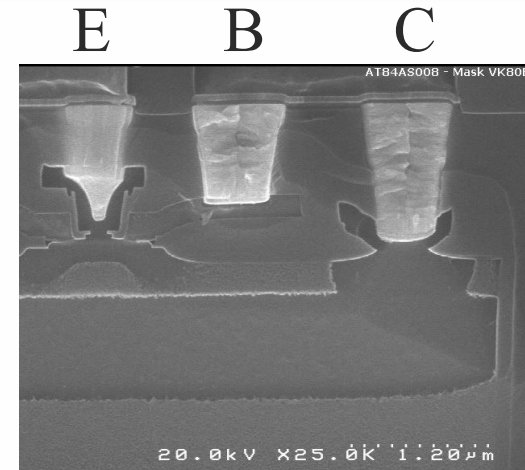


4- Process of AT84AS008 ADC

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➤ AT84AS008 is designed on a SiGe process

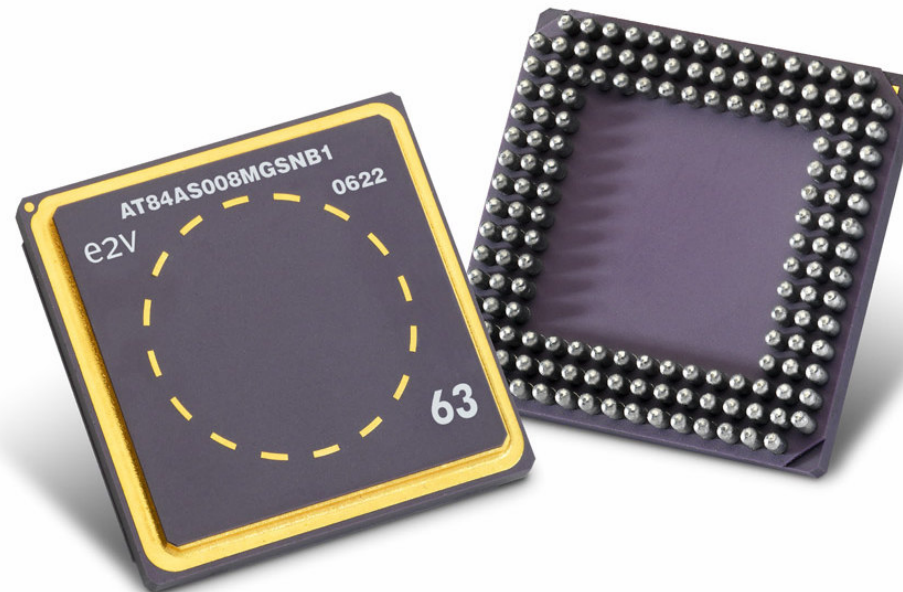
- ❑ INFINEON process (Germany)
- ❑ 75 GHz cut-off frequency
- ❑ High voltage NPN bipolar transistors
- ❑ 3 layers AlCu metallization
- ❑ Only vertical transistors and poly resistors to be rad tolerant
- ❑ Insulation concept: LOCOS and deep trench



5- Package description (1/4)

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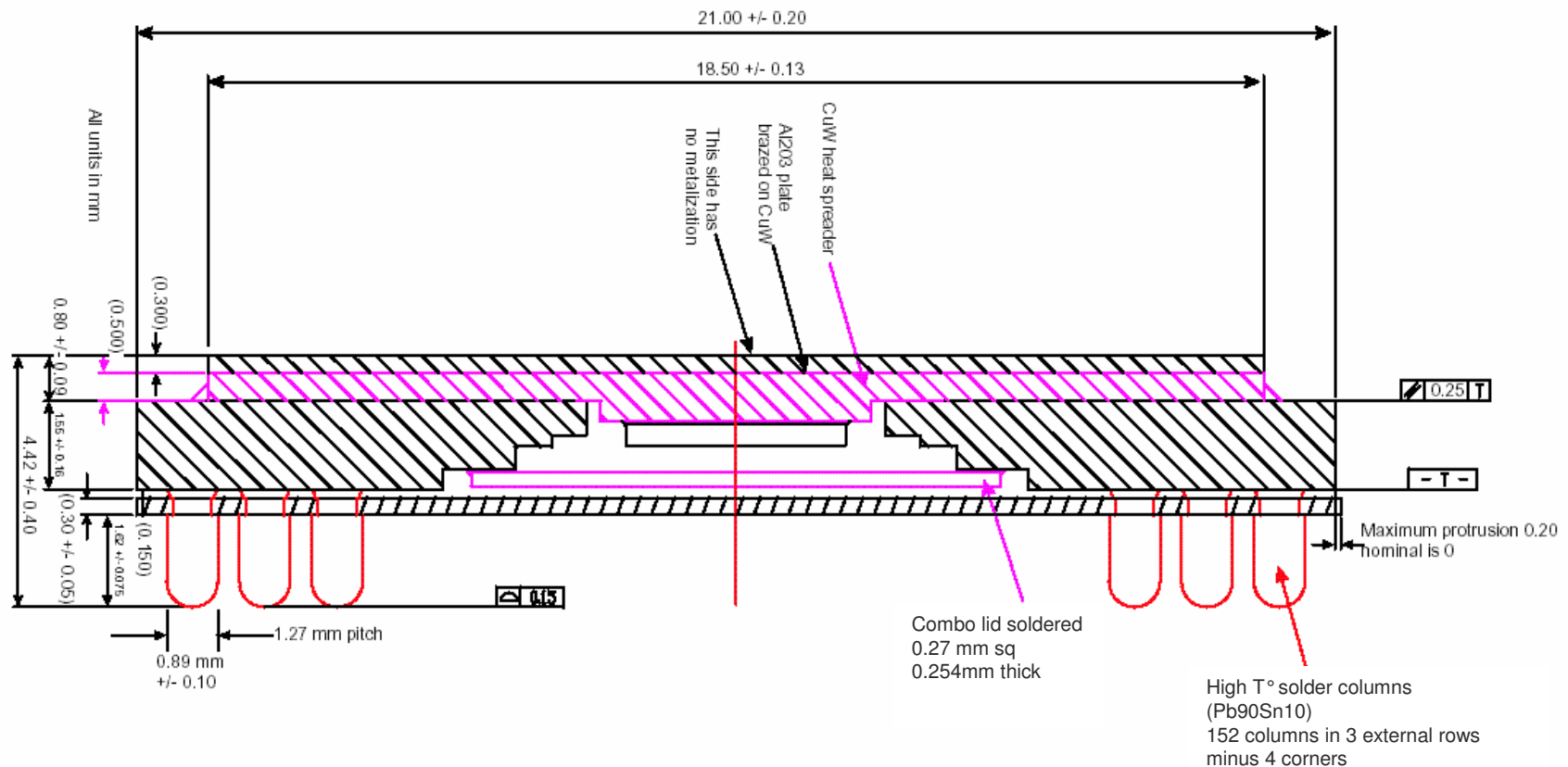
- High Reliability Hermetic Ceramic cavity down package (CI-CGA152)
- Solder Column Interposer (SCI) for good resistance to temperature cycling
- Column finish is Sn10Pb90
- Good thermal dissipation by columns



5- Package description (2/4)

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- The die is directly attached to the CuW heatspreader

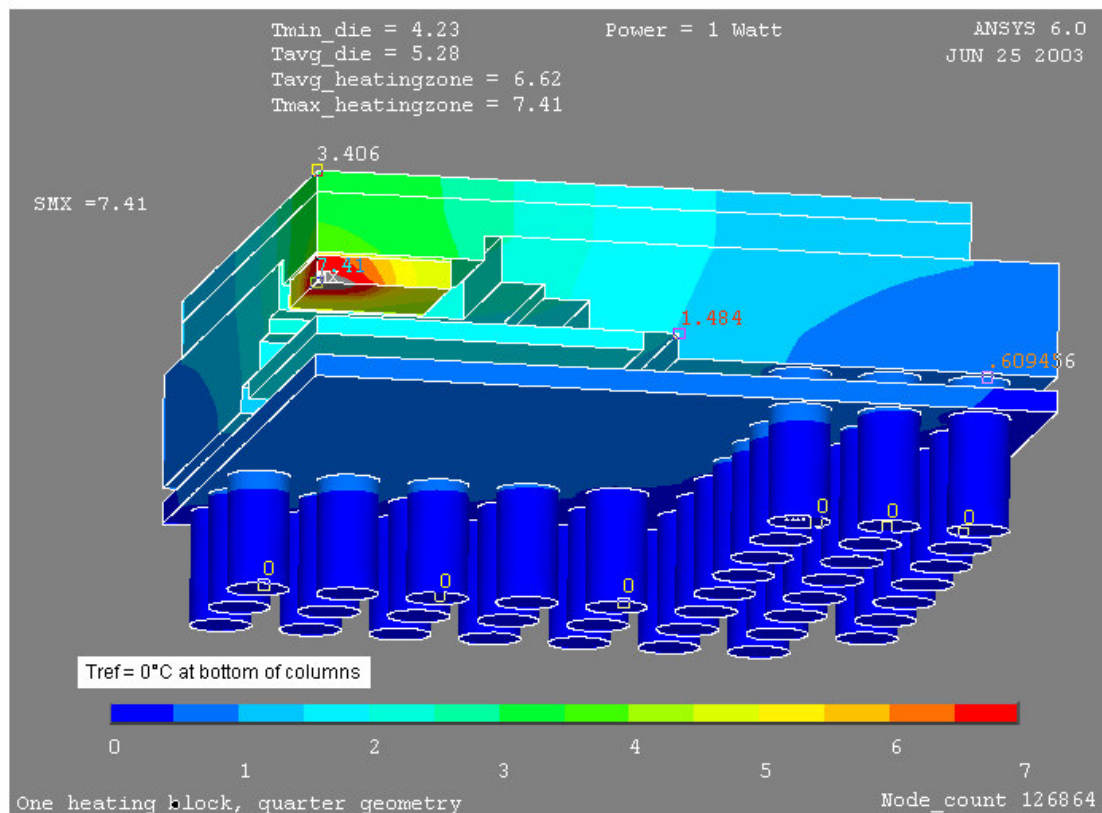


5- Package description (3/4)

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➤ Thermal simulation results of Rth from junction to bottom of columns

$$R_{th\ j - \text{bottom of columns}} = 7.4^{\circ}\text{C}/\text{W}$$



Hypothesis used for ANSYS simulations :

Body 21 x 21 mm 1.55 mm thick
glue 0.050 mm
Die 3.8 x 3.8 mm² 380 um thick
heating zone : 1.9 x 1.9 mm² 1 watt

Infinite heatsink at bottom of columns

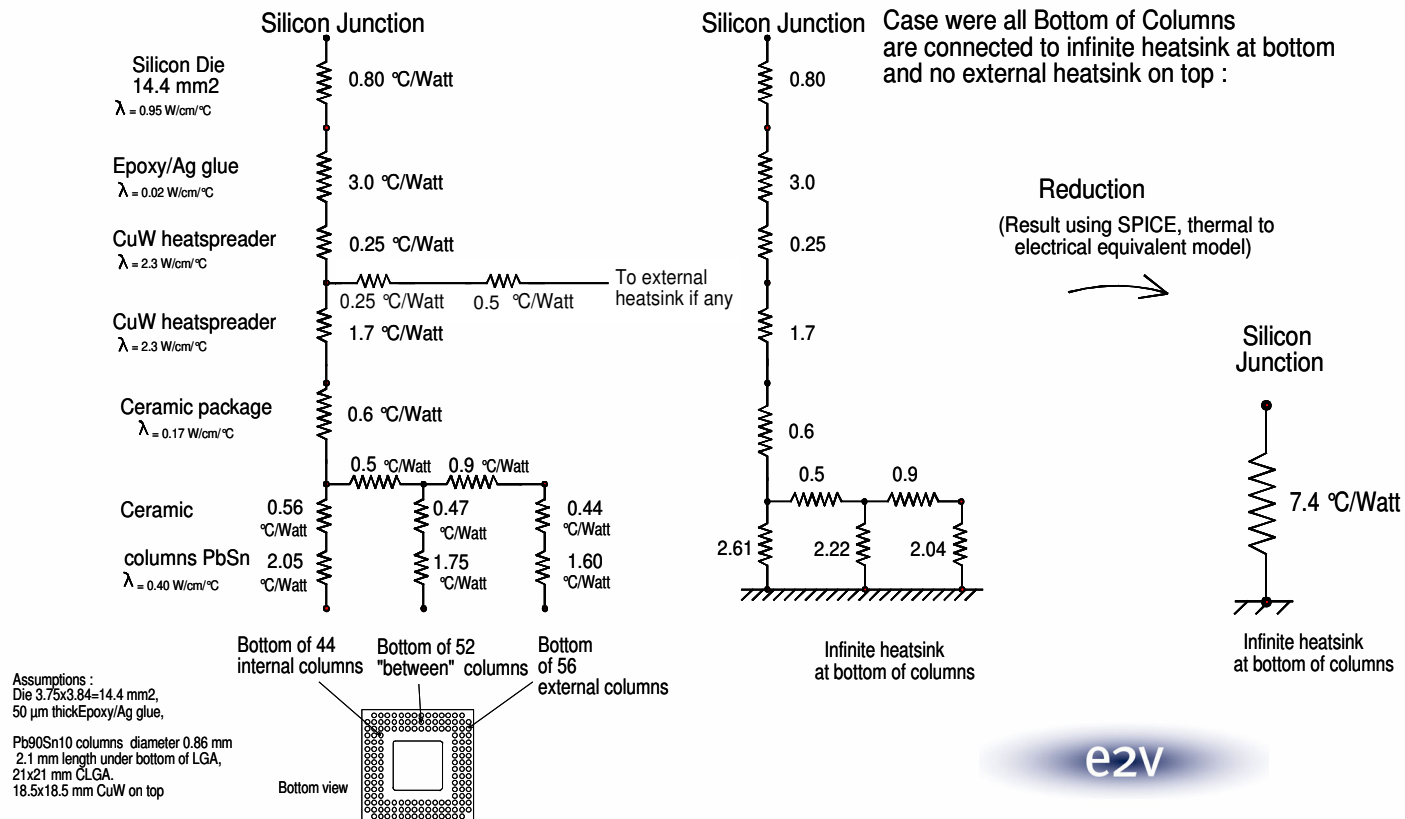
No external heatsink on top.

5- Package description (4/4)

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➤ Simplified thermal network of CI-CGA152 package

Typical values, with assumption of uniform power dissipation over 25% of die top surface.



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6- Space Evaluation with CNES

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- Evaluation according to ESCC no 226900 with CNES support.
- Parts were manufactured and screened according to ESCC no 9000 chart F3
- Complete evaluation test program to demonstrate the high reliability of the ADC for space applications
 - Electrical characterization
 - ESD tests
 - Package tests (mechanical, thermal tests and reflow simulation)
 - Quality (construction analysis) and reliability tests (life test)
 - Radiation assessment (refer to chap. 7)

6- Space Evaluation with CNES

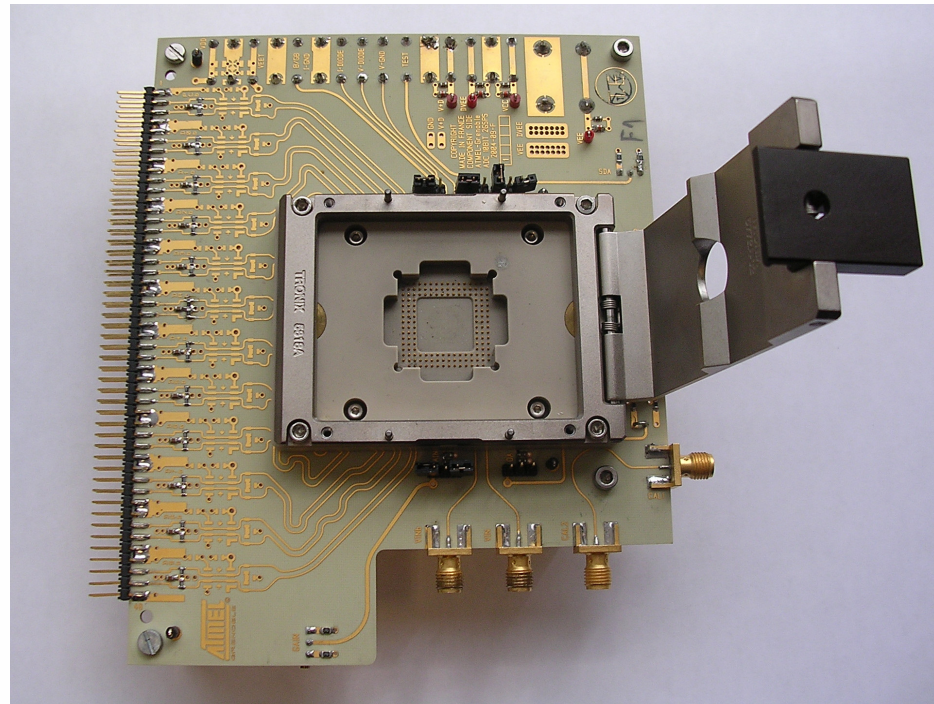
Electrical characterization (1/2)

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- Electrical characterization at full speed (2.2 Gsps, $F_{in} = 1.098\text{GHz}$ @-1dBFS)
 - measurement on 5 socketed parts
 - over power supply range
 - over military temperature range ($T_{case} = -55^{\circ}\text{C}$ to $T_j = 125^{\circ}\text{C}$)

 - Static parameters :
 - Power consumption
 - VOL/VOH
 - INL / DNL

 - Dynamic parameters (FFT)
 - SFDR, SINAD, ENOB, SNR and THD

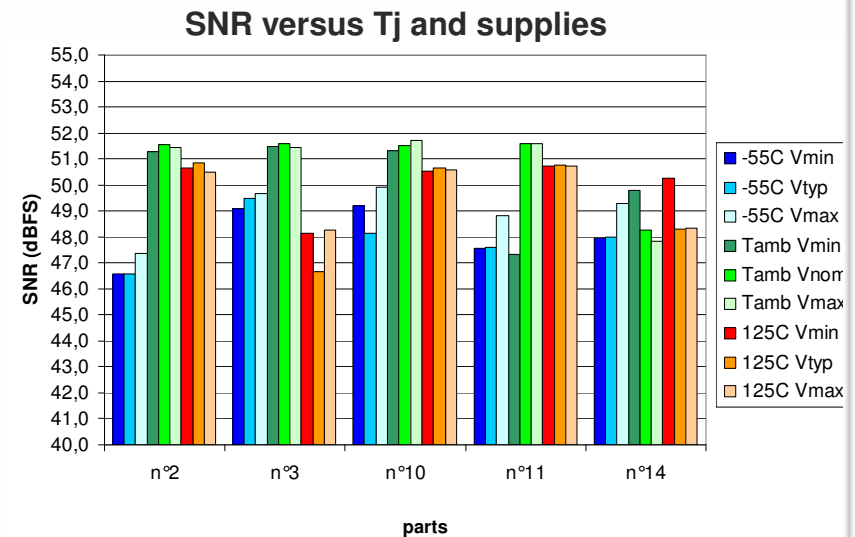
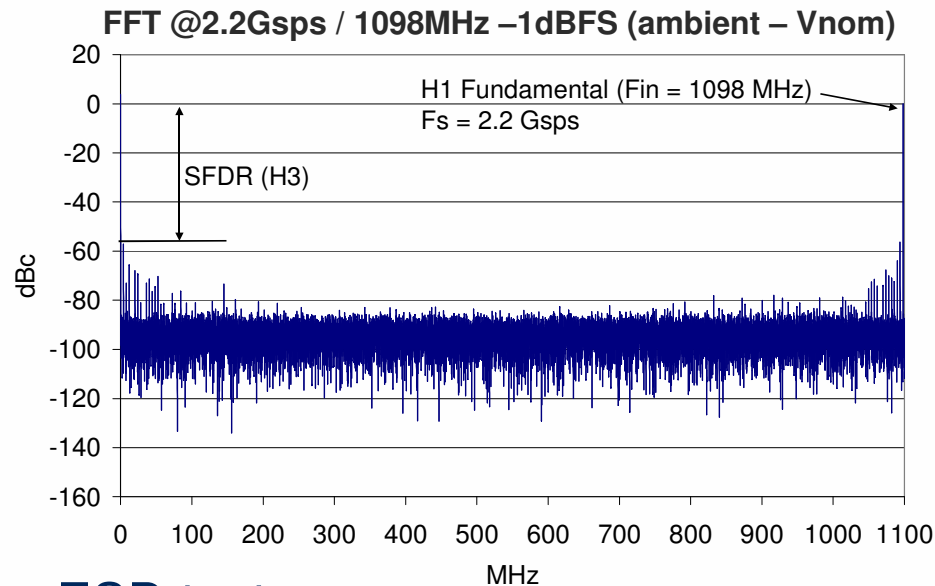


6- Space Evaluation with CNES

Electrical characterization & ESD tests

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➤ Electrical characterization



➤ ESD tests

- ❑ On 10 devices according to MIL STD 883 TM 3015
- ❑ All parts successfully passed 750 Volts stress
- ❑ ⇒ Device is compliant to ESD class 1

6- Space Evaluation with CNES

Package tests

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- Objective: find out the package robustness
 - ⇒ tests were pushed beyond ESCC no 226900 in term of number of cycles
- Mechanical tests
 - On 4 devices
 - 50 mechanical shocks cycles according to MIL-STD 883 TM 2002 cond. B
 - 120 vibrations cycles according to MIL-STD 883 TM 2007 Cond. A
- Thermal tests
 - On 4 devices
 - Temperature cycling : 500 cycles A/A according to MIL-STD 883 TM 1010 cond. C
 - Thermal shock : 100 cycles L/L according to MIL-STD 883 TM 1011 cond. C
- Reflow simulation (according to conditions Sn/Pb eutectic assembly)
 - On 2 devices
 - 5 reflow cycles according to J-STD-020C (peak 225°C)
- Conclusion of package tests : no electrical drift neither package damage
It confirms the package robustness

6- Space Evaluation with CNES

Endurance tests

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➤ Reliability test :

- 3000 hours endurance Life test at $T_j = 125^{\circ}\text{C}$
- On 20 devices running at 625 Ksps with maximum power supplies

- No electrical drift neither functional failure after 3000 hours
- \Rightarrow It demonstrates SiGe process high reliability

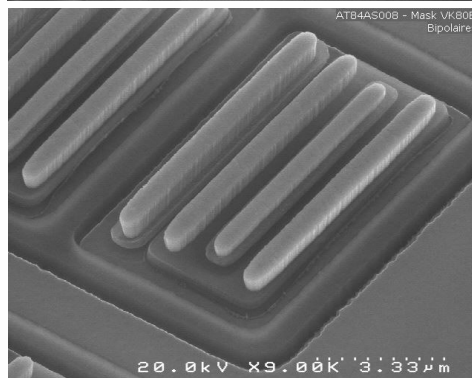
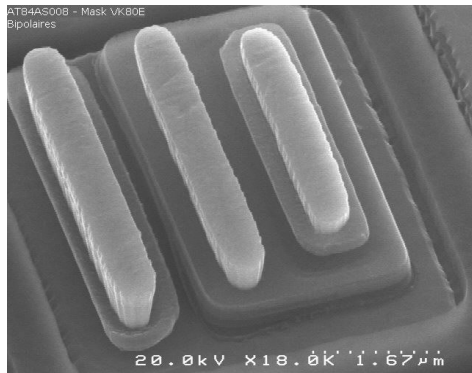
6- Space Evaluation with CNES

Quality tests

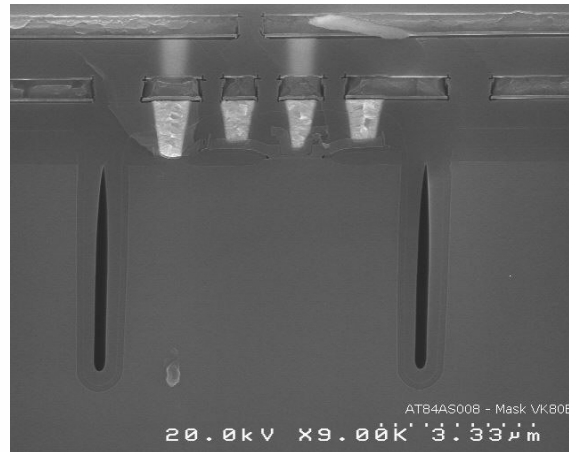
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➤ Quality tests

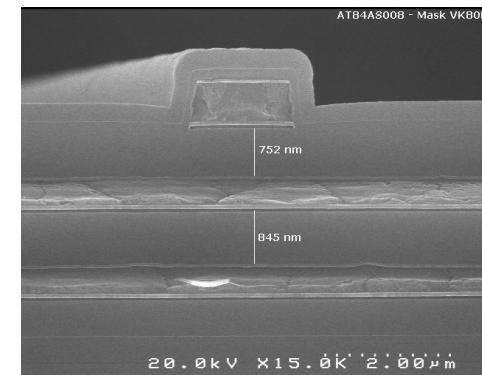
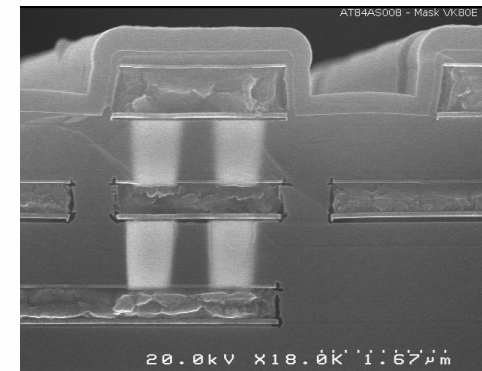
- SEM analysis of die
- #### Bipolar transistors



Deep trench



All metal layers with CMP planarisation

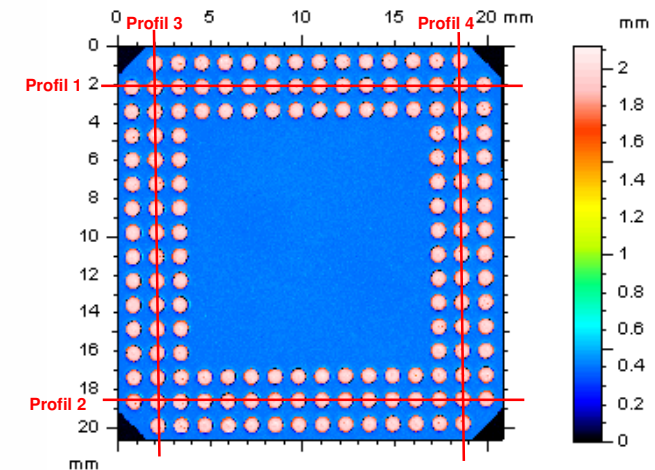
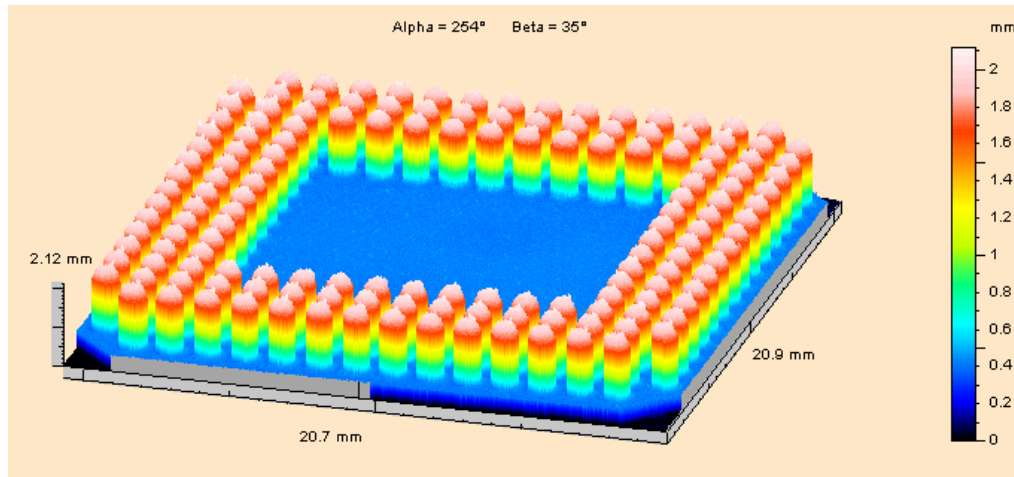


6- Space Evaluation with CNES

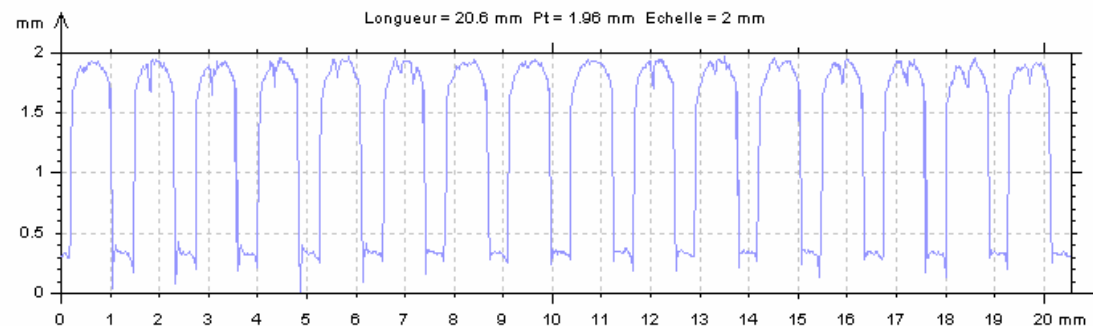
Quality tests

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- Quality tests
 - Back end construction analysis



Good coplanarity of columns



7- Radiation Tests

Total dose test of AT84AS008 ADC

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➤ Total dose tests

- ❑ Tests on 10 ADC AT84AS008 (6 parts ON / 4 parts OFF)
- ❑ 2 reference parts
- ❑ Low dose test (50 rad/hr)
- ❑ Co⁶⁰ source of the ONERA DESP (Toulouse – France)
- ❑ Test up to 150 Krad with intermediate measurements at 10, 25, 50 and 100 Krad(Si)
- ❑ 24 hours annealing at ambient and 168 hrs annealing at 100°C
- ❑ Tests performed by TRAD (Toulouse – France)

7- Radiation Tests

Total dose test of AT84AS008 ADC

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➤ Parameters monitored

PARAMETERS	SYMBOLS	TEST CONDITIONS (TA = 25°C)
High Output Voltage for D9 & D7	VOH _{d9} , VOH _{d7}	Vin = constant input level
Low Output Voltage for D9 & D7	VOL _{d9} , VOL _{d7}	Vin = constant input level
Swing Output Voltage for D9 & D7	Vdiff _{d9} , Vdiff _{d7}	Vdiff = VOH - VOL
Common Mode Output Voltage for D9 & D7	CM _{d9} , CM _{d7}	CM = (VOH + VOL)/2
Ivcc Supply current	Ivcc	
Ivplusd Supply current	Ivplusd	
Ivee Supply current	Ivee	
Idvee Supply Current	Idvee	
Power	P	$P = I_{vcc} \cdot 5 + I_{vee} \cdot 5 + I_{dvee} \cdot 2.2 + I_{plusd} \cdot 1.45$
Leakage current for VIN input	Ibias_vin+	Vin = 0V
Leakage current for VIN input	Ibias_vin-	Vin = 0V
Spurious Free Dynamic Range	SFDR	2Gsps Fin ~997 MHz @-1dBFS
Signal Noise Ratio	SNR	2Gsps Fin ~997 MHz @-1dBFS
Effective Number Of Bit	ENOB	2Gsps Fin ~997 MHz @-1dBFS
Signal to Noise And Distortion	SINAD	2Gsps Fin ~997 MHz @-1dBFS
Total Harmonic Distortion	THD	2Gsps Fin ~997 MHz @-1dBFS
Offset error	Offset_err	Vin = full scale (saturation)
Gain Error	Gain_err	Vin = full scale (saturation)
Differential Non Linearity min	DNL_min	Vin = full scale (saturation)
Differential Non Linearity max	DNL_max	Vin = full scale (saturation)
Differential Non Linearity rms	DNL_rms	Vin = full scale (saturation)
Integral Non Linearity min	INL_min	Vin = full scale (saturation)
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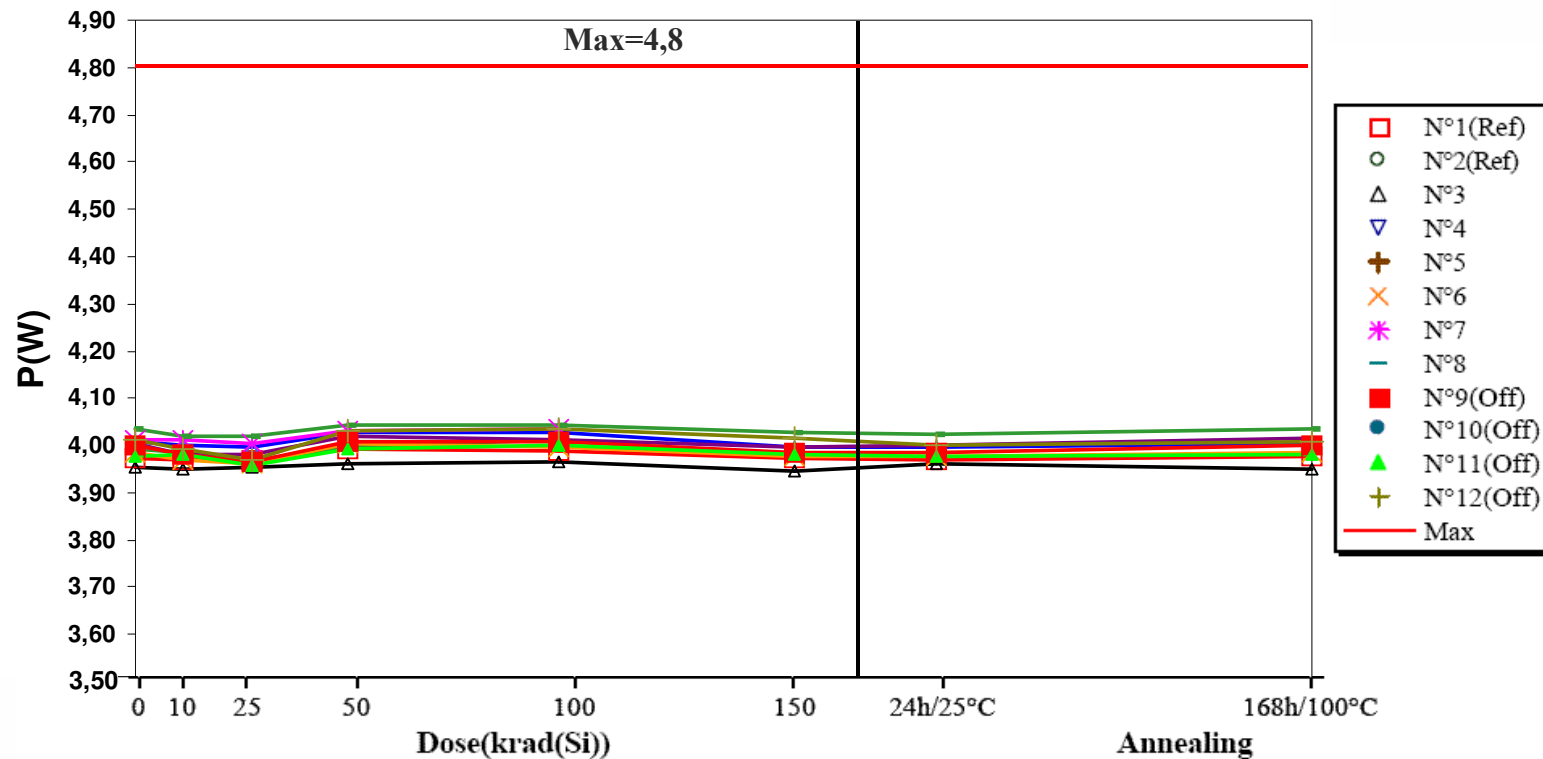
7- Radiation Tests

Total dose test of AT84AS008 ADC

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➤ Some test results versus TiD and annealing (1/3)

□ Power dissipation

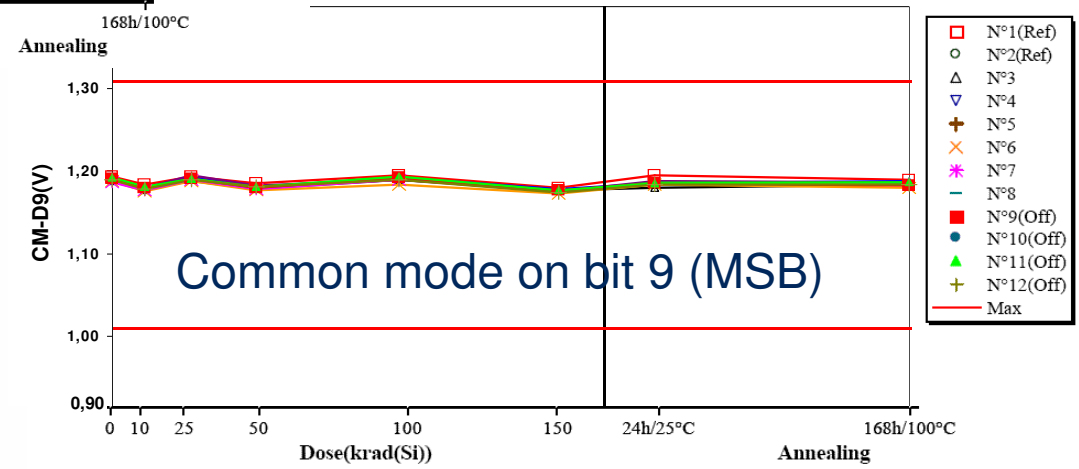
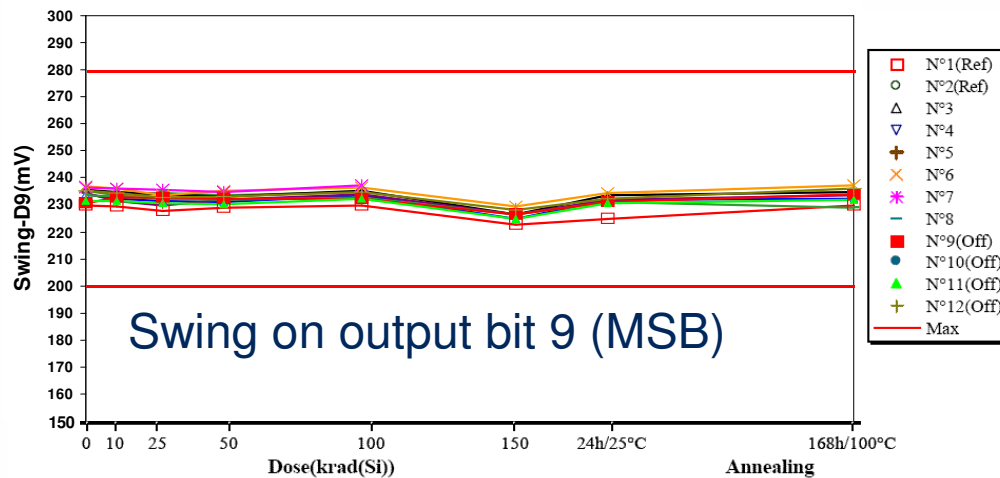


7- Radiation Tests

Total dose test of AT84AS008 ADC



➤ Some test results versus TiD and annealing (2/3)

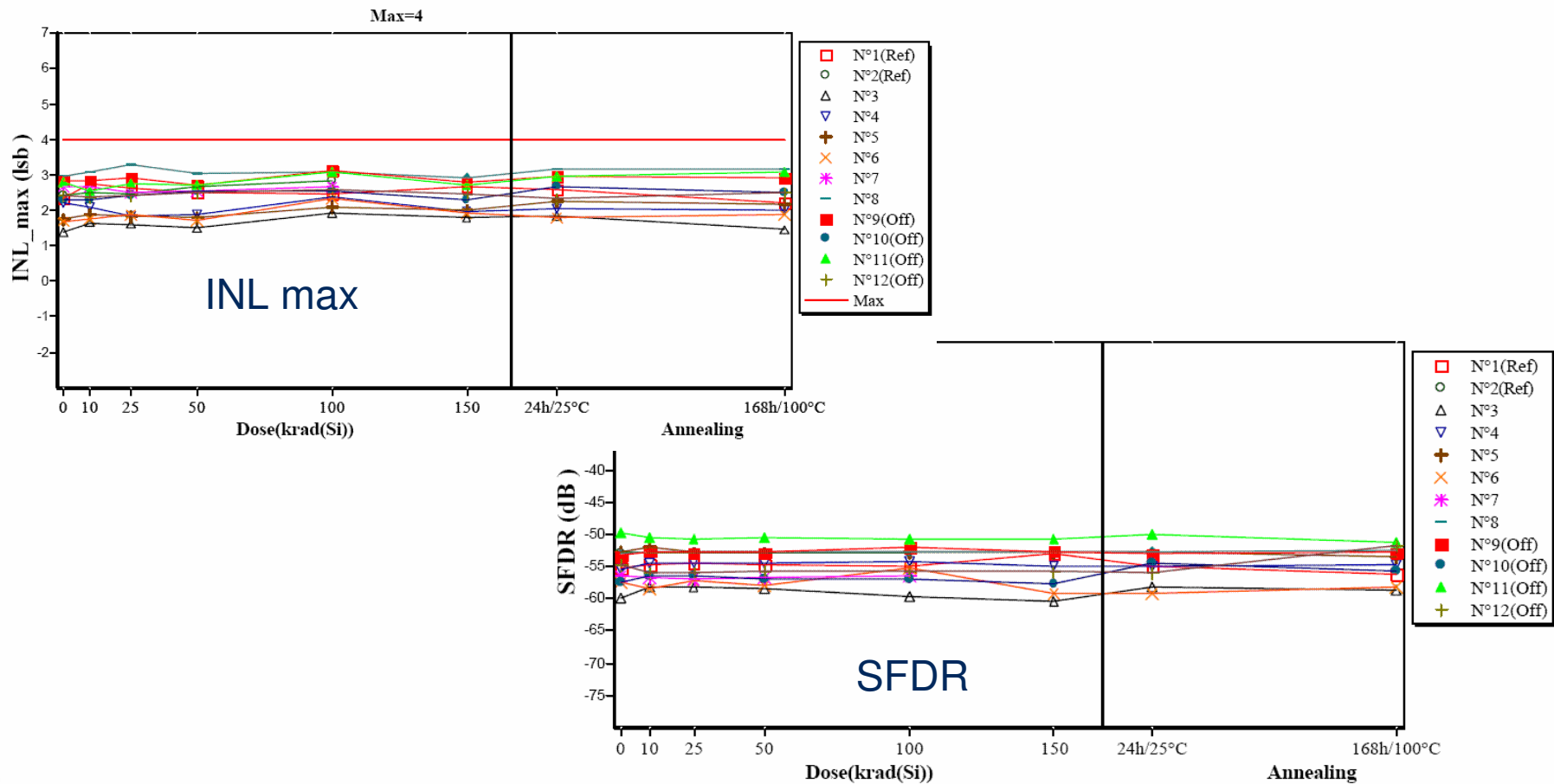


7- Radiation Tests

Total dose test of AT84AS008 ADC

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➤ Some test results versus TiD and annealing (3/3)



7- Radiation Tests

Total dose test of AT84AS008 ADC

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- Conclusion on total dose tests
 - Currents, voltages and dynamic performances are preserved at least at 150 Krad(Si)
 - AT84AS008 ADC can be considered as not sensitive to cumulated total dose of at least 150 Krad (Si)

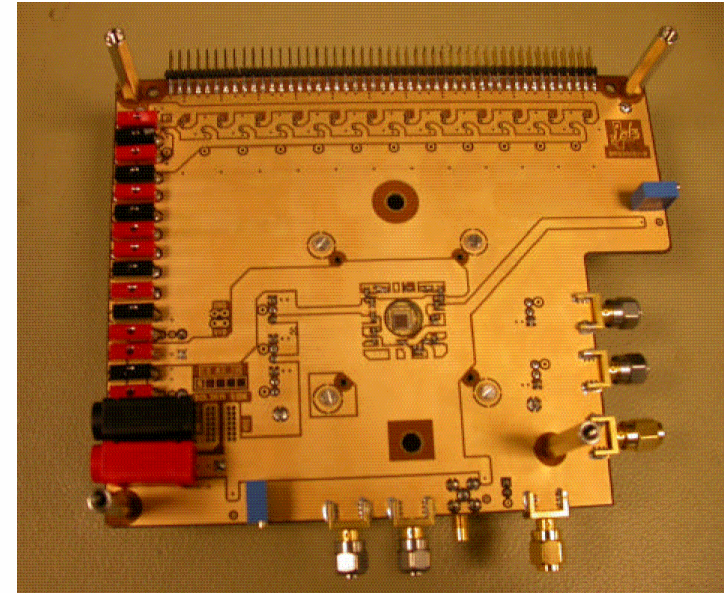
- Good Results can be explained by the following design rules used:
 - Fully bipolar process with only vertical insulated transistors:
 - no lateral active components
 - no PNP transistors
 - ⇒ it avoids leakage between the different transistors
 - Only oxide insulated polysilicon resistors (ie. no diffused resistors whose doping may be modified by radiations)
 - Strictly fully differential architectures which allows good rejection of common mode effects drift

7- Radiation Tests

Heavy ions tests

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- AT84AS008 Heavy ions tests
 - ❑ Tests performed on 2 parts soldered on evaluation boards (with a hole to provide direct access to the die)
 - ❑ Tests at UCL (Belgium)
 - ❑ By TRAD company (Toulouse – France)
- Irradiation cocktail used
 - ❑ Fluency up to 10^6 ions/cm² for SEU
 - ❑ Fluency of 10^7 ions/cm² for SEL detection



	Ion	Energy (MeV)	Range (μm)	LET ((MeV.cm ²)/mg)
Cocktail 1	⁴⁵⁹ Xe	459	43	55,9
	⁸⁴ Kr	316	43	34,0
	¹⁵⁰ Ar	150	42	14,1
	⁷⁸ Ne	78	45	5,9
	⁶² N	62	64	2,97

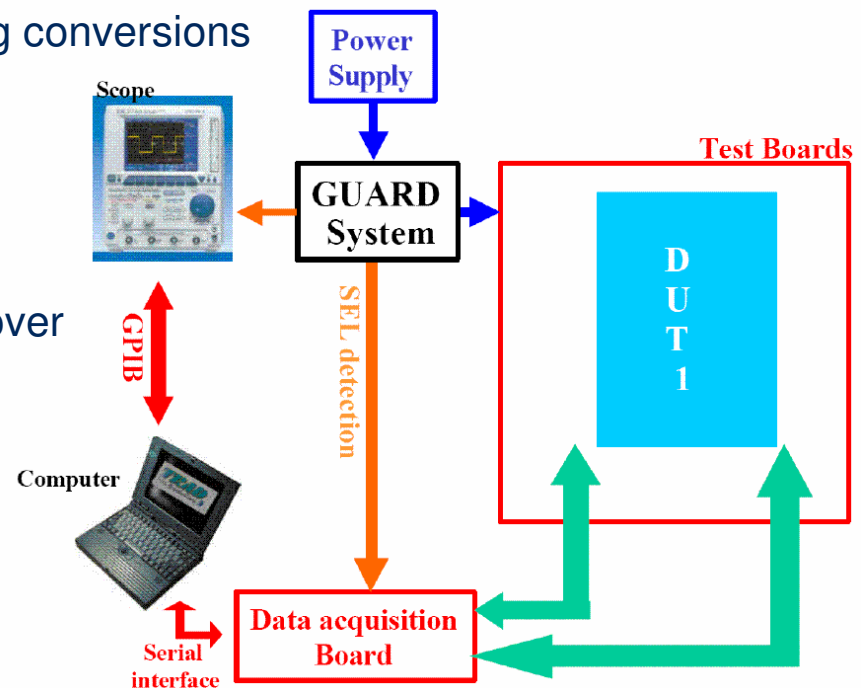
7- Radiation Tests

Heavy ions tests

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➤ Test procedure

- ❑ An acquisition board is connected to a Computer
- ❑ Events are detected in comparing DUT outputs to a reference ADC
- ❑ It counts the number of successive wrong conversions
 - 1 wrong conversion = SEU
 - successive wrong conversions
 - ✓ long Single Event Upset (SEU)
 - ✓ or Single Event Functional Interrupt (SEFI) if it does not recover
- ❑ Test is performed at 100 Msp
- ❑ Detection of Single Event Latchup (SEL)



7- Radiation Tests

Heavy ions tests

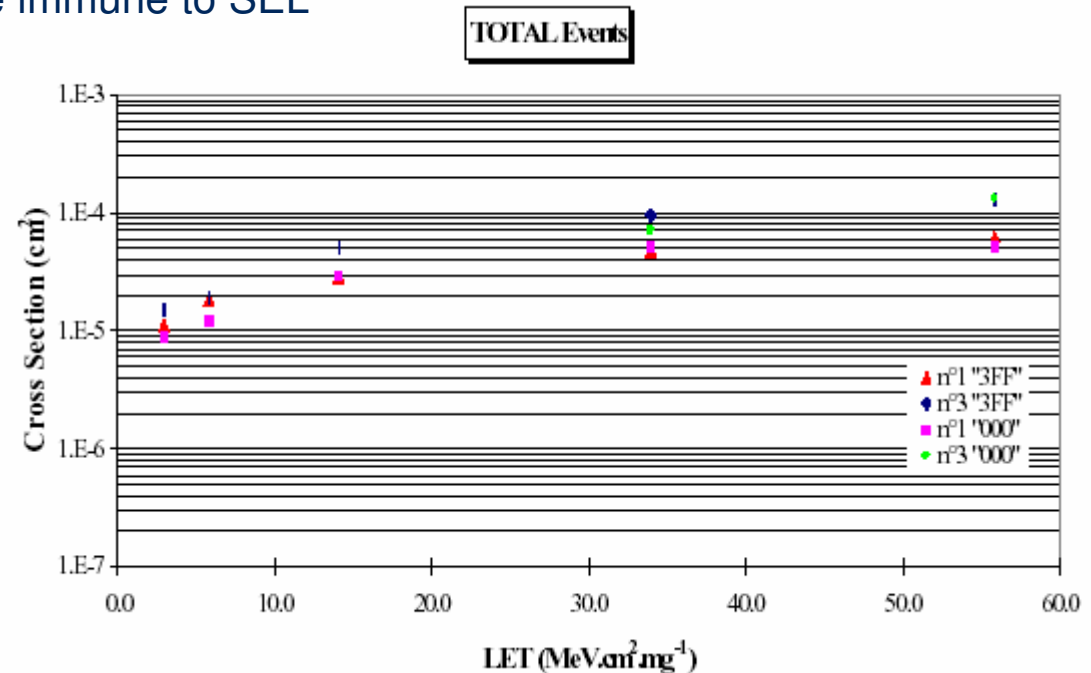
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➤ SEL test results

- ❑ No SEL at a LET of 55.9 MeV.cm²/mg with a fluence of 9.00 E6 particles/cm²
- ❑ AT84AS008 ADC is therefore immune to SEL

➤ SEU test results

- ❑ SEU were monitored for 2 output codes:
 - 000
 - 3FF
- ❑ Same results for the 2 codes
- ❑ No SEFI was detected
- ❑ Only SEU and long SEU with a maximum of 15 successive wrong conversion errors at a LET of 55.9 MeV cm²/mg



7- Radiation Tests

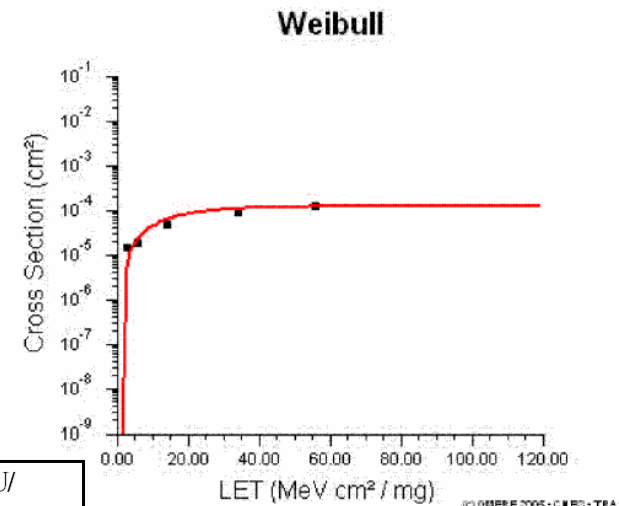
Heavy ions tests

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➤ Calculation Rate

□ Results were computed using OMERE 3.0 free software developed by TRAD: “OMERE 2.0: A TOOLKIT FOR SPACE ENVIRONMENT”, P. F. Peyrard, T. Beutier et al., RADECS 2003, Noordwijk, Hollande”.

- LET threshold = $1.49 \text{ MeV.cm}^2.\text{mg}^{-1}$
- Saturation cross section is $1.29\text{E-}4 \text{ cm}^2$



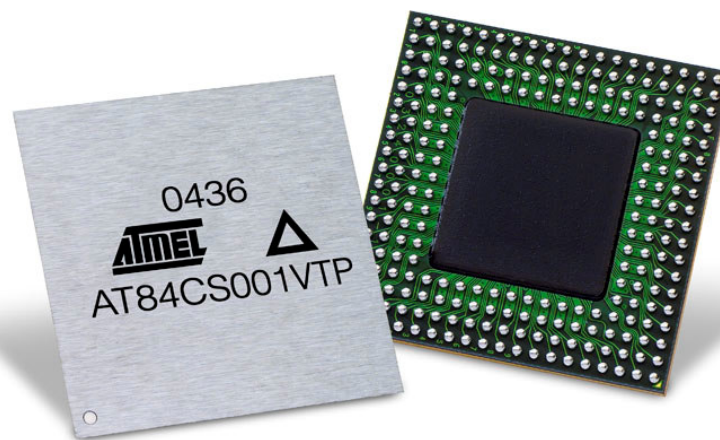
Project	Altitude Km	Inclination deg	CREME 86 m =	SEU/ Cell.day	SEU/ Device.day
Geostationary	35870	0	3	3.42E-4	3.42E-3
SPOT	852	98	3	1.108E-4	1.108E-3
LEO-1	600	98	3	1.036E-4	1.036E-3
LEO-2	1000	53	3	4.98E-5	4.98E-4
Inmarsat-P	10300	45	3	1.962E-4	1.962E-3

8- Radiation Tests on DEMUX AT84CS001

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➤ DEMUX AT84CS001

- ❑ Companion chip of ADC AT84AS008
- ❑ 10-bit 2.2 Gbps 1:4 DEMUX
- ❑ Si BiCMOS process ($F_t=25\text{GHz}$) but only bipolar transistors are used
- ❑ EBGA240 package (industrial temperature range)
- ❑ In the frame of ADC evaluation, it was decided to evaluate the radiation behavior of this DEMUX (that could be introduced in a spatial version with hermetic package)



8- Radiation Tests on DEMUX AT84CS001

Total dose test

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➤ Total dose tests

- ❑ Tests on 10 DEMUX AT84CS001 (6 parts ON / 4 parts OFF)
- ❑ 1 reference part
- ❑ Low dose test (50 rad/hr)
- ❑ Co⁶⁰ source of the ONERA DESP (Toulouse – France)
- ❑ Test up to 150 Krad with intermediate measurements at 10, 25, 50 and 100 Krad(Si)
- ❑ 24 hours annealing at ambient and 168 hrs annealing at 100°C
- ❑ Tests performed by TRAD (Toulouse – France)

- ❑ Intermediate measurements were performed using a AT84AS008 ADC driving the DEMUX at 2 Gbps

8- Radiation Tests on DEMUX AT84CS001

Total dose test

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➤ Parameters monitored

PARAMETERS	SYMBOLS	TEST CONDITIONS (TA = 25°C)
High Output Voltage for A9, B9, C9 & D9	VOH _{A9} , VOH _{B9} VOH _{C9} , VOH _{D9}	Vin = constant input level
Low Output Voltage for A9, B9, C9 & D9	VOL _{A9} , VOL _{B9} VOL _{C9} , VOL _{D9}	Vin = constant input level
Swing Output Voltage for A9, B9, C9 & D9	Vdiff _{A9} , Vdiff _{B9} Vdiff _{C9} , Vdiff _{D9}	Vdiff = VOH - VOL
Common Mode Output Voltage for A9, B9, C9 & D9	CM _{A9} , CM _{B9} , CM _{C9} , CM _{D9}	CM = (VOH + VOL)/2
Ivcc Supply current	Ivcc	
Ivplused Supply current	Ivplused	
Power	P	P = Ivcc*3.3+Ivplused*2.5
Leakage current for I0 and I9 inputs	I0, I0b, I9, I9b	Vin = 0V
Spurious Free Dynamic Range	SFDR ⁽¹⁾	2Gsps Fin ~997 MHz @-1dBFS
Signal Noise Ratio	SNR ⁽¹⁾	2Gsps Fin ~997 MHz @-1dBFS
Effective Number Of Bit	ENOB ⁽¹⁾	2Gsps Fin ~997 MHz @-1dBFS
Signal to Noise And Distortion	SINAD ⁽¹⁾	2Gsps Fin ~997 MHz @-1dBFS
Total Harmonic Distortion	THD ⁽¹⁾	2Gsps Fin ~997 MHz @-1dBFS
Offset error	Offset_err ⁽¹⁾	Vin = full scale (saturation)
Gain Error	Gain_err ⁽¹⁾	Vin = full scale (saturation)
Differential Non Linearity min	DNL_min ⁽¹⁾	Vin = full scale (saturation)
Differential Non Linearity max	DNL_max ⁽¹⁾	Vin = full scale (saturation)
Differential Non Linearity rms	DNL_rms ⁽¹⁾	Vin = full scale (saturation)
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Integral Non Linearity max	INL_max ⁽¹⁾	Vin = full scale (saturation)
Integral Non Linearity rms	INL_rms ⁽¹⁾	Vin = full scale (saturation)

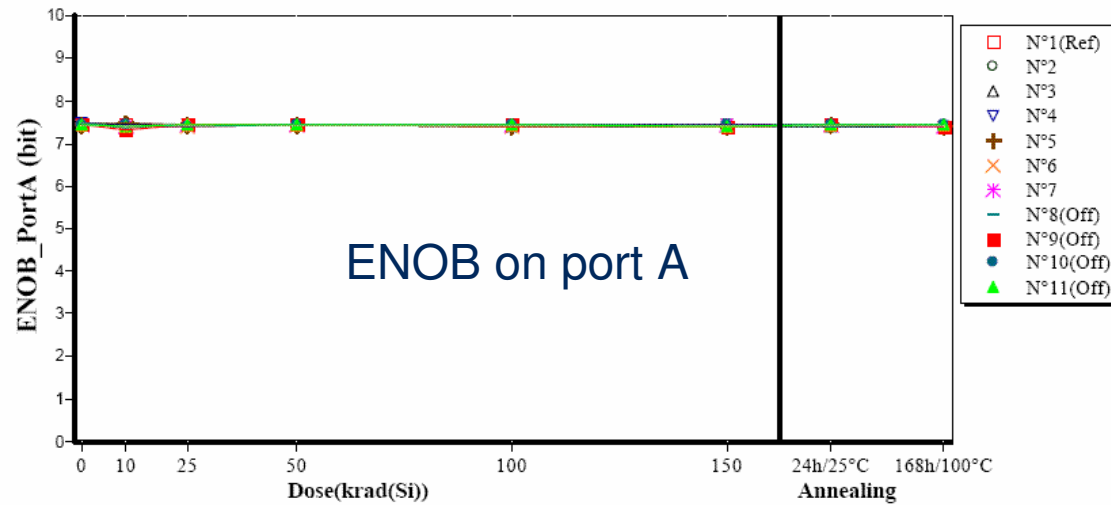
(1) Measurements were performed on each port (A, B, C and D).

8- Radiation Tests on DEMUX AT84CS001

Total dose test

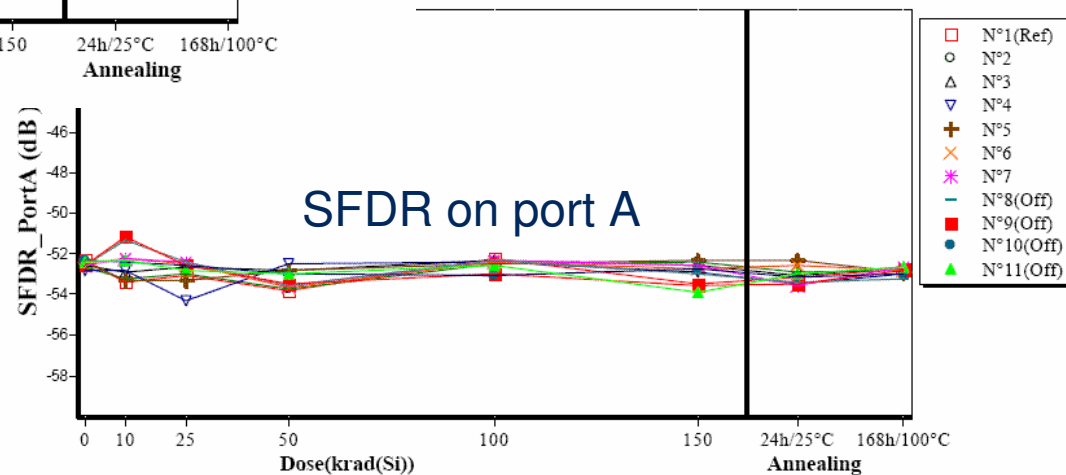
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➤ Some test results versus TiD and annealing



➤ Conclusion

- DEMUX AT84CS001 is not affected by a total dose of at least 150 Krad (Si)



8- Radiation Tests on DEMUX AT84CS001

Single Event Latchup test

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➤ Single Event Latchup test

- To confirm it is SEL immune. (BiCMOS process, but only bipolar transistor are used)
- Tests performed on 2 delidded parts at UCL (Belgium)
- Tests performed by TRAD company (Toulouse – France)

- The test principle is the same than for AT84AS008 ADC

Ion	DUT energy (MeV)	Range ($\mu\text{m Si}$)	LET ($\text{MeV.cm}^2.\text{mg}^{-1}$)
$^{132}\text{Xe}^{26+}$	459	43	55.9
$^{83}\text{Kr}^{25+}$	756	92	32.4

□ Conclusion :

- No SEL was detected for these two ions.
- The AT84CS001 is Latchup free at a LET of $55.9 \text{ MeV.cm}^2.\text{mg}^{-1}$

Conclusion

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- AT84AS008 ADC **successfully passed the CNES space evaluation** in terms of:
 - radiation tolerance
 - reliability
 - quality and assembly process

- The innovative architecture leads to **unprecedented dynamic performance** at a sampling rate of **2.2 GHz** and over the full military temperature range

- These **performances are preserved** with a total dose of at least **150 Krad (Si)**

- This confirms e2v position as a European partner **for high-speed data converters in space applications.**