Astrium Space Transportation
Competence Centre

MEMSRAD
ESA_QEC1008T_C

Technical Note – TN4
Part 1

RADIATION TEST REPORT
MEMS Type 1
Colibrys Accelerometers

ESA_QEC1008T_C

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TITLE MEMSRAD: MEMS Sensitivity to Space Radiation

MEMS Type 1: Radiation test Results on Colibrys Accelerometers

ABSTRACT

This document constitutes the detailed report of the Radiation testing on MEMS Type 1: Colibrys Accelerometers. This report covers the tasks of different WPs: 4000.1, 4000.2, 5000.1& 5000.21 related to Accelerometers. These works are done by following Consortium members: Infoduc, EADS-IW and Astrium ST.

KEYWORDS

MEMS, Sensors, Radiation, Space, Guidelines, Accelerometers, TID, Heavy Ions

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ABSTRACT

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TITLE: MEMSRAD

MEMS Type 1: Radiation test Results on Colibrys Accelerometers

This document constitutes the detailed report of the Radiation testing on MEMS Type1: Colibrys Accelerometers.

This report covers the tasks of different WPs: 4000.1, 4000.2, 5000.1& 5000.21 related to Total Dose (TID) and Heavy Ion testing:

- Radiation testing preparations & Campaigns
- Exploitation of results
- Results analysis

Proton testing is planned on 12th & 13th of December 2008 at PSI, Villigen, Switzerland. The next edition of the document will include the results of Proton Testing.

Section Manager TE612

V. FORMOND

Summary

1. INTRODUCTION:

This document gives the result of the Total Ionizing Dose tests performed on MS8002 accelerometers manufactured by Colibrys. The aim of this test was to verify that test guidelines that are applied to prepare the radiation test plan and the test procedure are well adapted to MEMS devices.
In the first chapter a brief description of the Device Under Test (DUT) is given and the main aspects of the test plan are recalled.
In the second Chapter On Line Measurements results are detailed.
In the third chapter Post radiation and post annealing results of measurement performed by EADS-IW are given.
Finally results are discussed and the need to complementary experiments is presented.

2. APPLICABLE DOCUMENTS

[1] Statement of Work – MEMSRAD: MEMS sensitivity to space radiation, appendix to AO/1-5056/06/NL/CP, ref: TEC-QCT/2005SSOW09/LM/NS, issue 1, rev.5, 17th January 2006.
[2] Technical Proposal by Astrium ST – ref TE 060 195 Issue 1, rev 0, 02/05/2006
[3] Test Plan for MEMS type 1 by Astrium ST – ref TE624 n° 149152, 3rd December 2007

3. DUT DESCRIPTION AND RADIATION TEST PLAN

3.1 DUT DESCRIPTION

The MS-Accelerometer MS8000 is based on MEMS capacitive technology.
The sensor is independent from the electronics. Three electronic chips are used:
a temperature sensor, an analog ASIC called Interface Circuit in the block diagram, a microcontroller.
The accelerometer output signal "Vout" is a ratiometric analogue voltage as described hereafter:

Vout= Bias +(Scale factor*Acceleration)

Where the parameters are defined as follows:

Bias(V) is the output voltage at 0g acceleration
Scale factor (V/g) is the sensor sensitivity
Acceleration (g) is the applied acceleration in the sensitive axis Z.

Calibration registers:
The microcontroller loads calibration registers at RESET when the power supply is applied.

3.1.1 Block Diagram

The block diagram of the accelerometer is given in figure 1

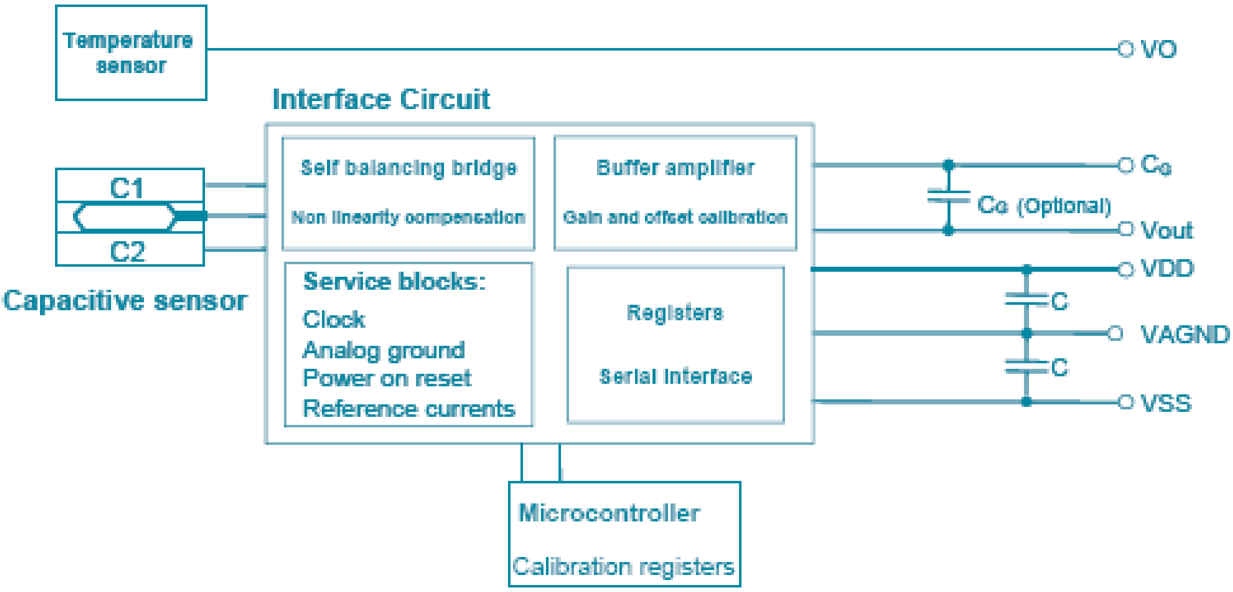


Figure 1: Block Diagram of MS8002 Accelerometer from Colibrys

3.1.2 Evaluation board

The devices were mounted by colibrys on a standard evaluation board. The evaluation board is shown in fig 2 and its schematic is given in figure 3.

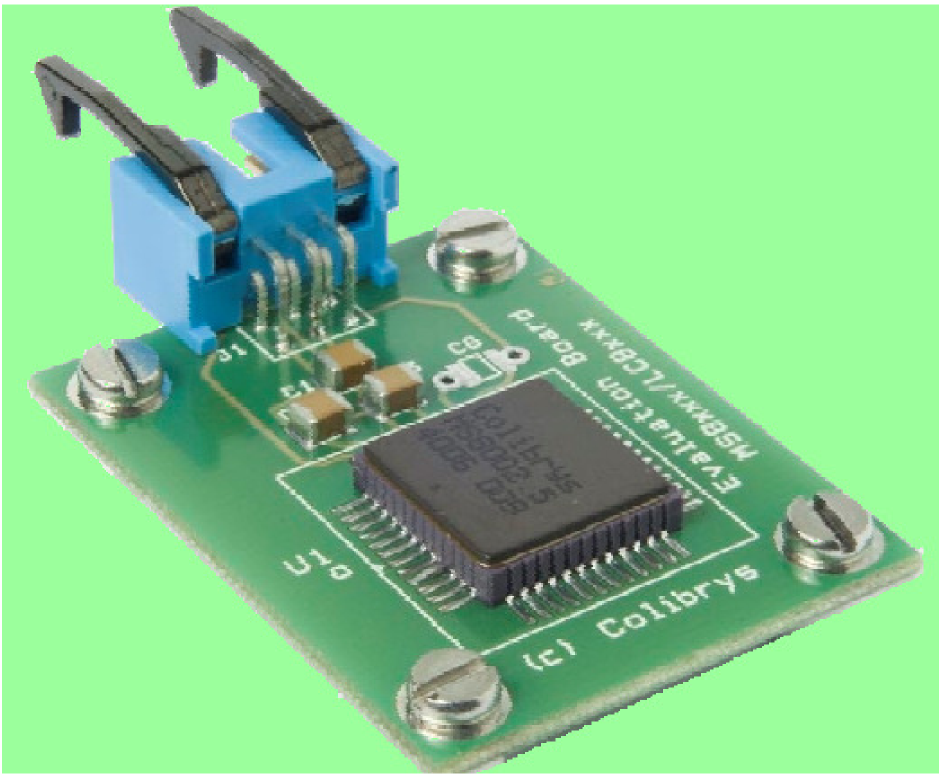


Fig 2 Evaluation Board

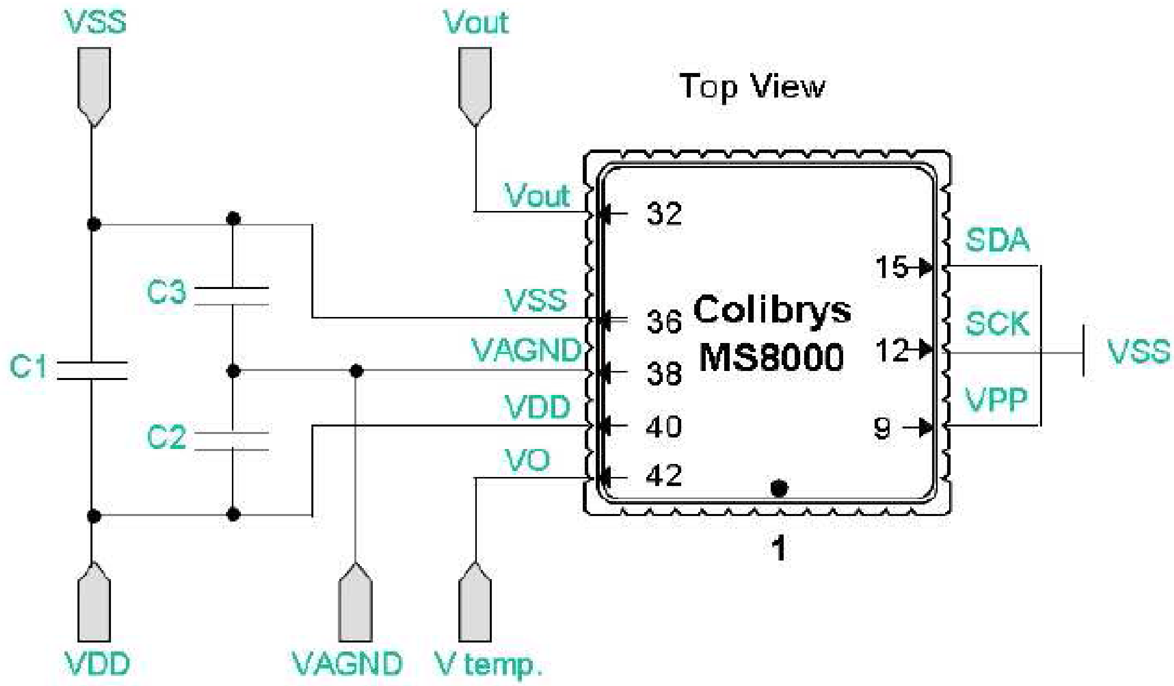


Fig3: Evaluation board schematic C1=C2=C3=1µF

3.2 RADIATION TEST PLAN:

In the radiation test plan the following steps are required:

- Obtaining accelerometers with uniform characteristics and traceability of the electronic components
- Initial detailed parameter measurements
- Repartition of the devices in two lots for low dose rate and high dose rate tests
- Irradiation and on line measurements
- Post-irradiation and post-annealing detailed measurements

3.2.1 List of irradiated devices

The following list gives the reference of the samples irradiated

Sensor	Dose Rate	Total Dose	Comments
C6025-001	<360Rad/h	5	on 0g
C6025-008	<360Rad/h	10	on 0g
C6025-013	<360Rad/h	20	on 0g
C6025-018	<360Rad/h	50	on 0g
C6025-038	<360Rad/h	50	on 0g
C6025-041	<360Rad/h	50	on 1g
C6025-045	<360Rad/h	50	on 1g
C6025-047	<360Rad/h	50	on 1g
C6025-051	<360Rad/h	50	on 1g
C6025-056	<360kRad/h	50	off 1g
C6025-058	3.6kRad/h	5	on 0g
C6025-089	3.6kRad/h	10	on 0g
C6025-103	3.6kRad/h	20	on 0g
C6025-112	3.6kRad/h	50	on 0g
C6025-141	3.6kRad/h	50	on 0g
C6025-149	3.6kRad/h	50	on 1g
C6025-211	3.6kRad/h	50	on 1g
C6025-212	3.6kRad/h	50	on 1g
C6025-224	3.6kRad/h	50	on 1g
C6025-225	3.6kRad/h	50	off 1g

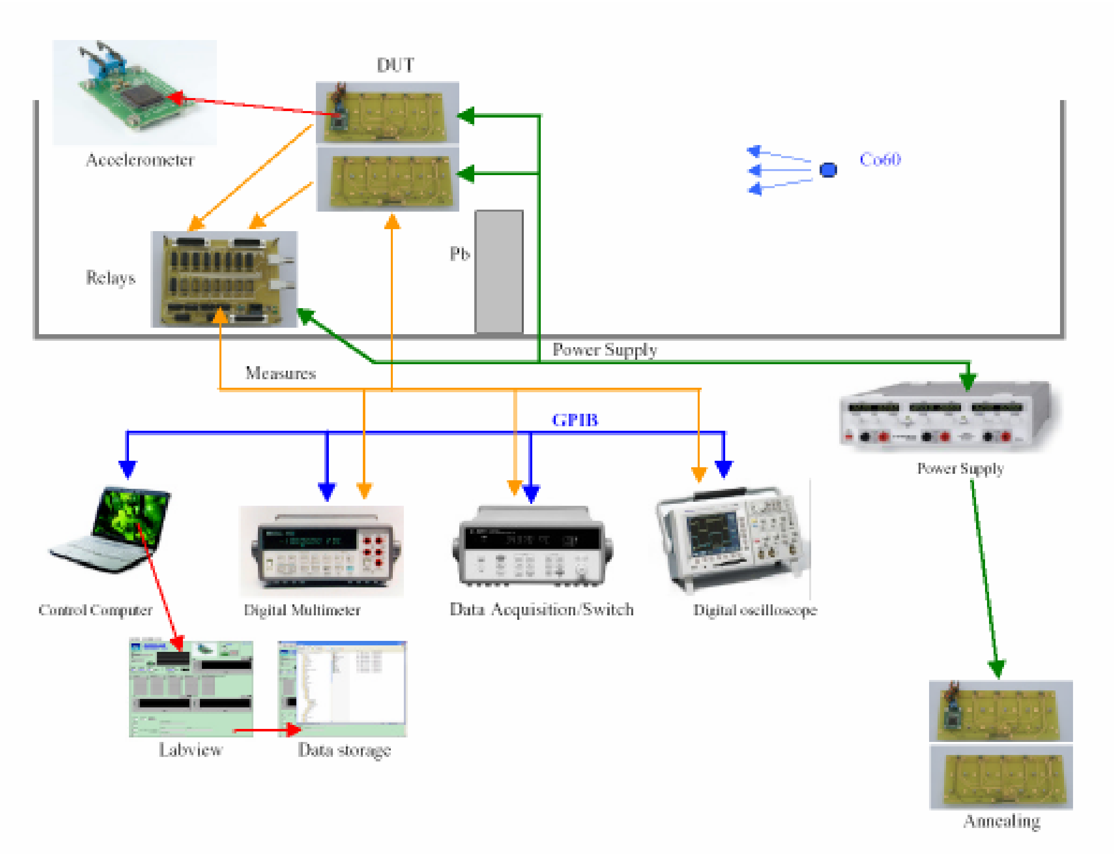
3.2.2 Pre-radiation examination results

Some pre-irradiation test results of the MS8002 accelerometers are given in Appendix 1
The measurements were performed by EADS-IW.
Detailed results are given in Appendix 1.
For each parameter the worse devices were identified.
Devices were chosen in lot C6025. In this lot, N°001 is the worst for velocity random walk, N°008 is the worst for bias, non linearity and bias drift.

4. ON LINE MEASUREMENTS RADIATION RESULTS:

4.1 ON-LINE TEST SET-UP

The On-line test set-up is described below. The principal apparatus are
Data acquisition switch:
Digital Multimeter:
Power Supply:



4.2 LOW DOSE RATE EXPERIMENT:

The low dose rate experiment is performed at a dose rate of 300 rad/h (0,083 rad/s):

The 10 devices configuration under radiation is given below:

Number	1	2	3	4	5	6	7	8	9	10
Power State	ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF
G value	0	0	0	0	0	1	1	1	1	1
Max dose (krad)	5	11	21	53	53	53	53	53	53	53
Ref Number	001	008	013	018	038	041	045	047	051	056

The parameters followed during irradiation are:

- The power supply current at VD=5V
- The output voltage: devices are in 0g or 1g configuration,
- The temperature output
- Output voltage peak-peak noise

4.2.1 Power supply current:

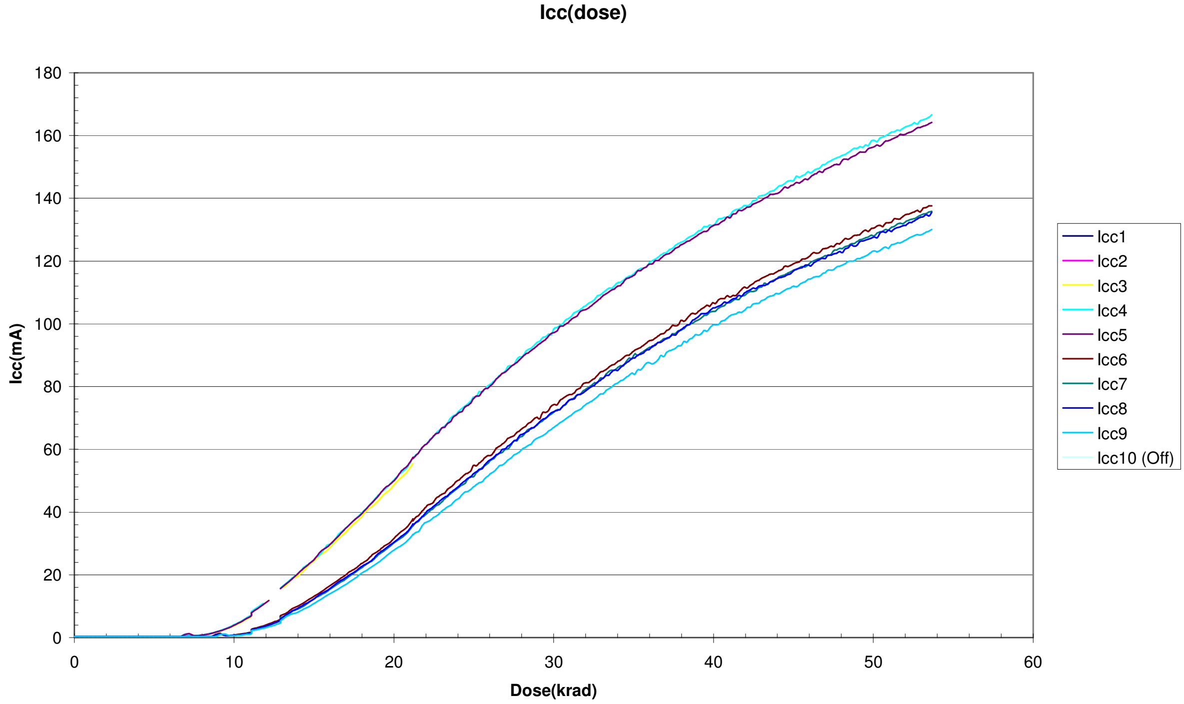
The power supply current is measured for each device during irradiation excepted for device N°10 that is in off state with no bias voltage.
The power supply is generally a good indicator of the sensitivity of electronic devices to ionizing irradiation.
A rapid increase of the supply current is observed.
The table below gives values for I supply values expressed in mA at some typical doses expressed in krad:

Number	1	2	3	4	5	6	7	8	9	10
Initial	0,292	0,300	0,296	0,296	0,288	0,298	0,288	0,300	0,292	0,302
5	0,308	0,317	0,313	0,323	0,310	0,317	0,313	0,315	0,313	0,306
11		7,196	6,800	7,263	7,028	1,809	1,593	1,539	1,219	0,308
15			24,790	25,210	25,210	13,320	12,580	12,580	11,090	
21			55,420	57,330	57,440	37,800	35,720	36,150	32,860	0,370
30				98,520	97,250	74,320	71,980	72,090	67,100	
50				166,6	164,2	137,64	135,84	135,52	130,05	0,959

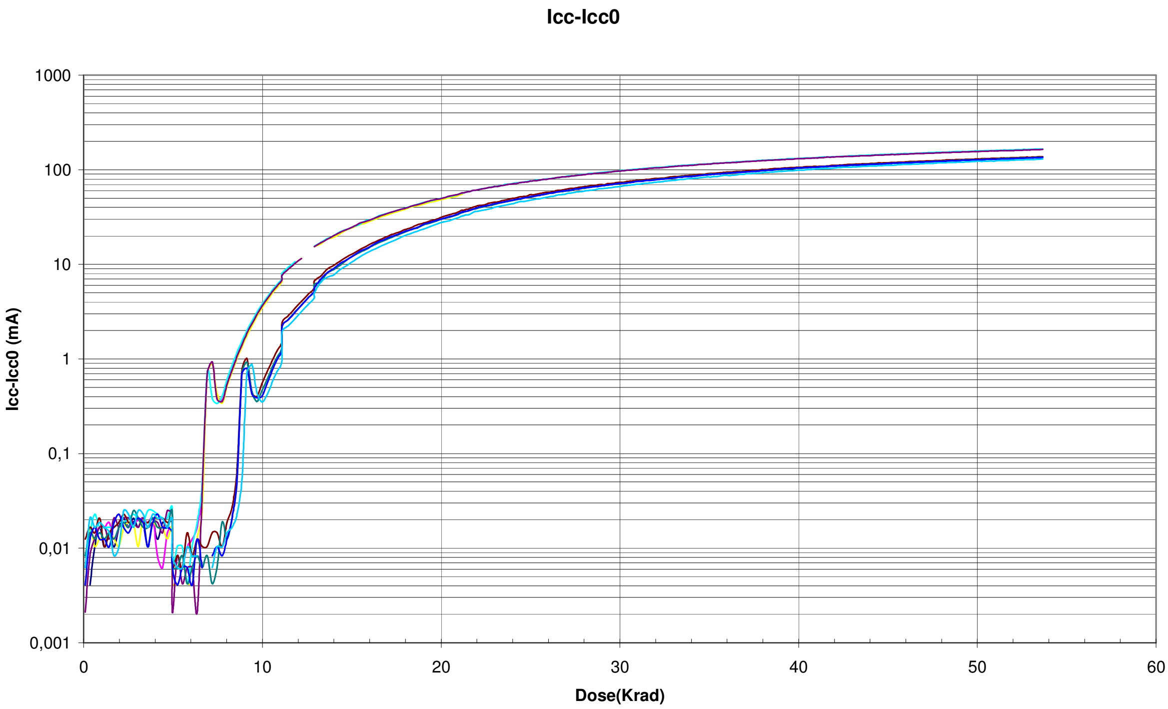
A dramatic increase of the power supply value is observed. The effect becomes important after a dose of 7krad.
The dose that gives an increase by a factor of 10 of the power supply current are given below.

Number	1	2	3	4	5	6	7	8	9	10
Dose for I_{supp0}X10		9,5	9,7	9,6	9,6	11,4	11,5	11,5	11,9	>50

The population behaviour is homogeneous and the influence of the bias state (power supply applied or not) under irradiation is clearly seen. The OFF device is much less sensitive. The value of the acceleration applied to the sensitive axis gives a second order effect. Devices 6 to 9 with 1g applied are less sensitive than devices 2 to 5 with 0 g applied.



The same curve but with a logarithmic scale is given below showing the influence of the acceleration applied. The dose threshold for which the supply current increases is 6 and 8krad.



4.2.2 Output voltages:

The output voltage is related to the acceleration applied to the sensitive axis by the relation

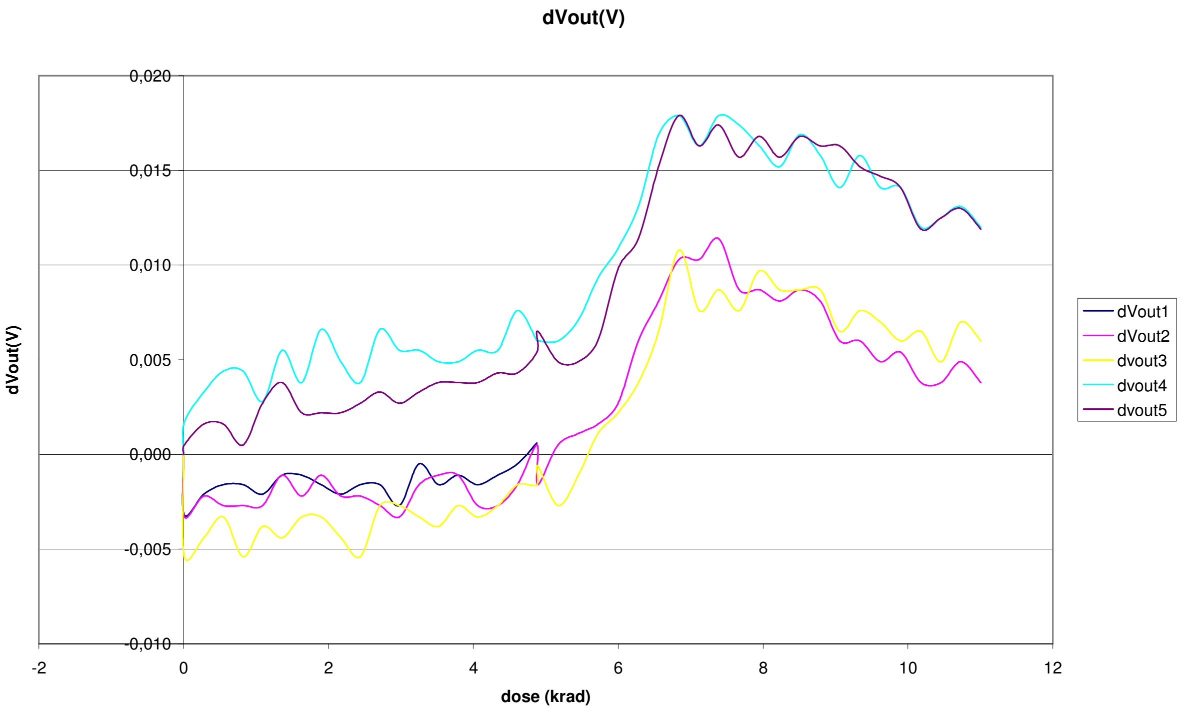
Vout= Bias+(Scale factor*Acceleration)

For devices 1 to 5, in 0g position the output is the at the analog ground level in the middle between Vdd and Vss that means 2.5V for VDD=5V and VSS=0V.

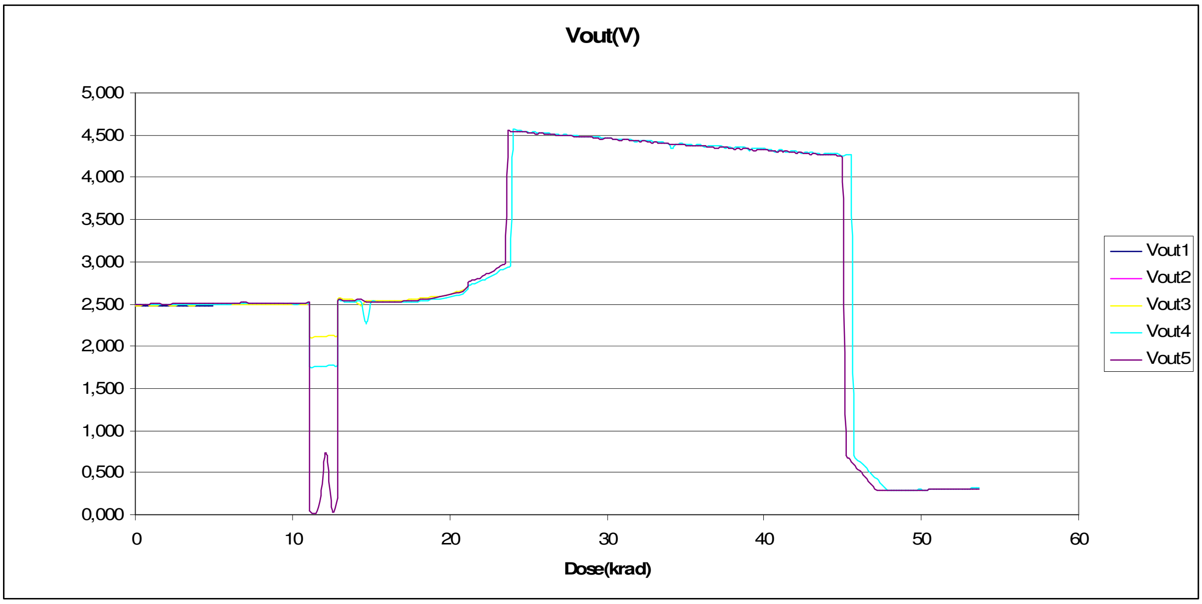
For devices 6 to 9 in 1g position the initial output value is near 3.5V.

0g Position:

At low dose D<11 krad the variation is less than 20mg.



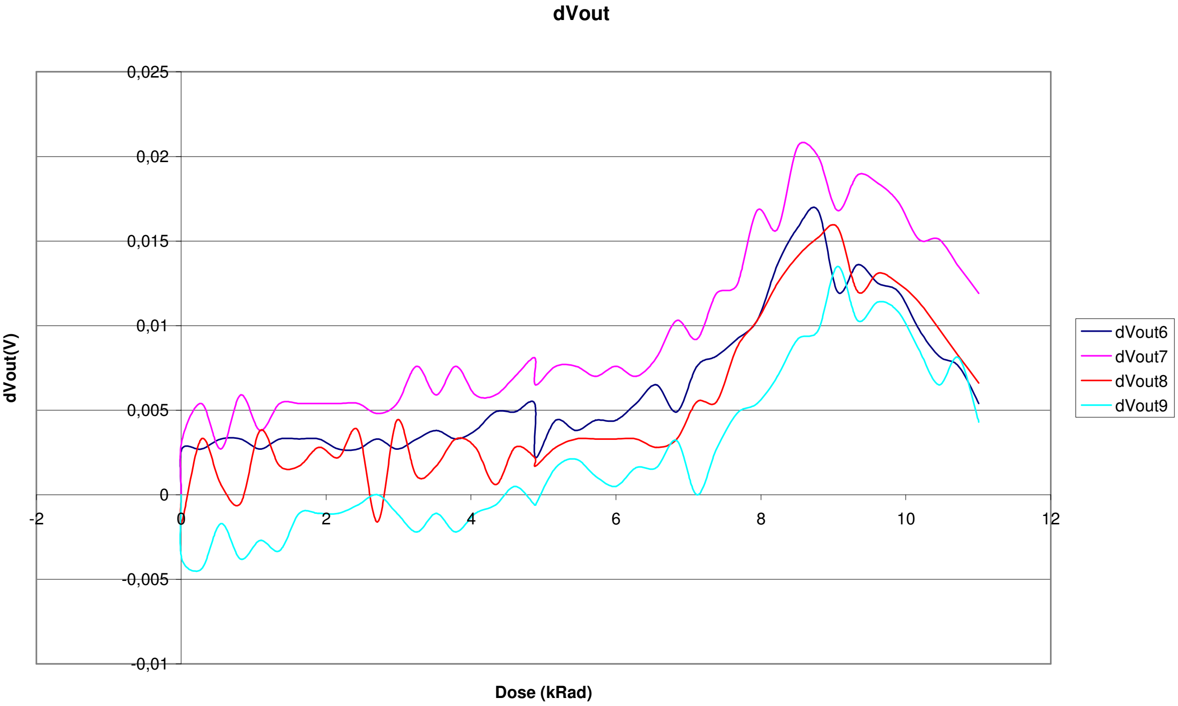
At high dose the behaviour is more complex as shown below.



After the step 11krad, the behaviour is erratic: the output switches to 0V or 1.7V. After 23 krad the output switches to the maximum positive output and at 45krad the output switches to 0.3V.
This behaviour can be related to damage in the sensor or damage in the electronic circuits.
A more detailed investigation is needed to explain this behaviour.

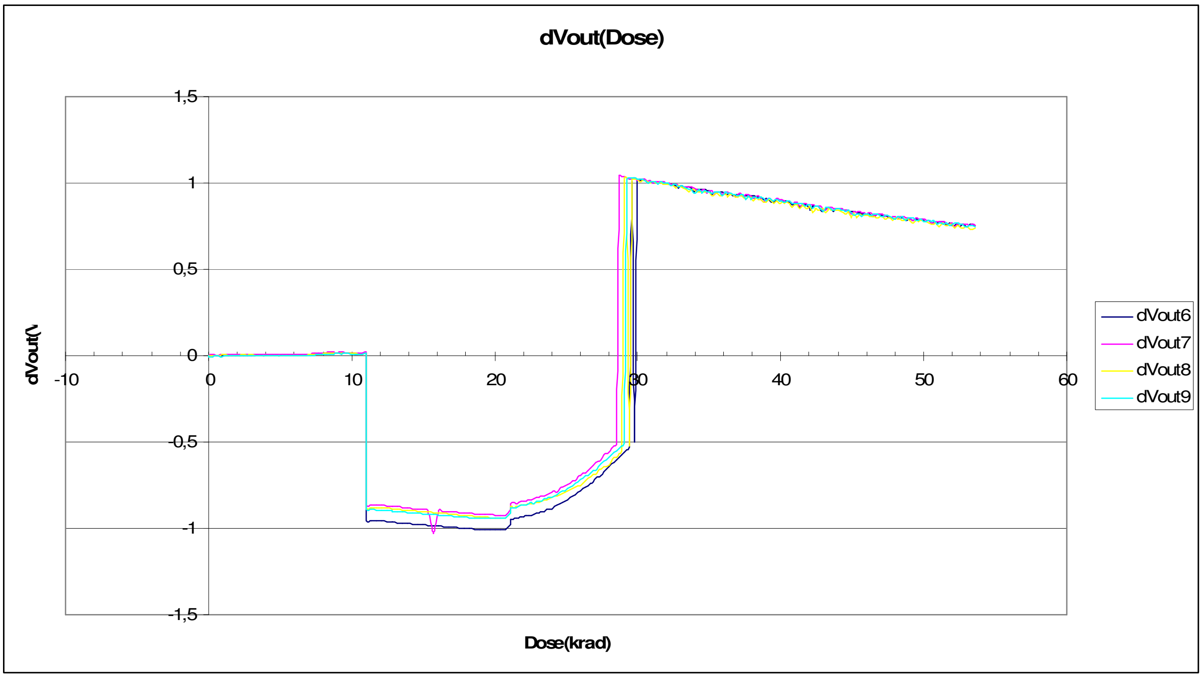
1g position

The behaviour of devices 6 7 8 9 in 1g position is given below.
For doses lower than 11krad the variation of the output is less than 20mV (about 20mg).



Some variation (>10mV) is observed when I supply increases for doses>8krad.
After the second step of 11krad, when irradiation begins again a strong variation is observed for the 4 devices. The output value switches near 2.5V that corresponds to 0g.

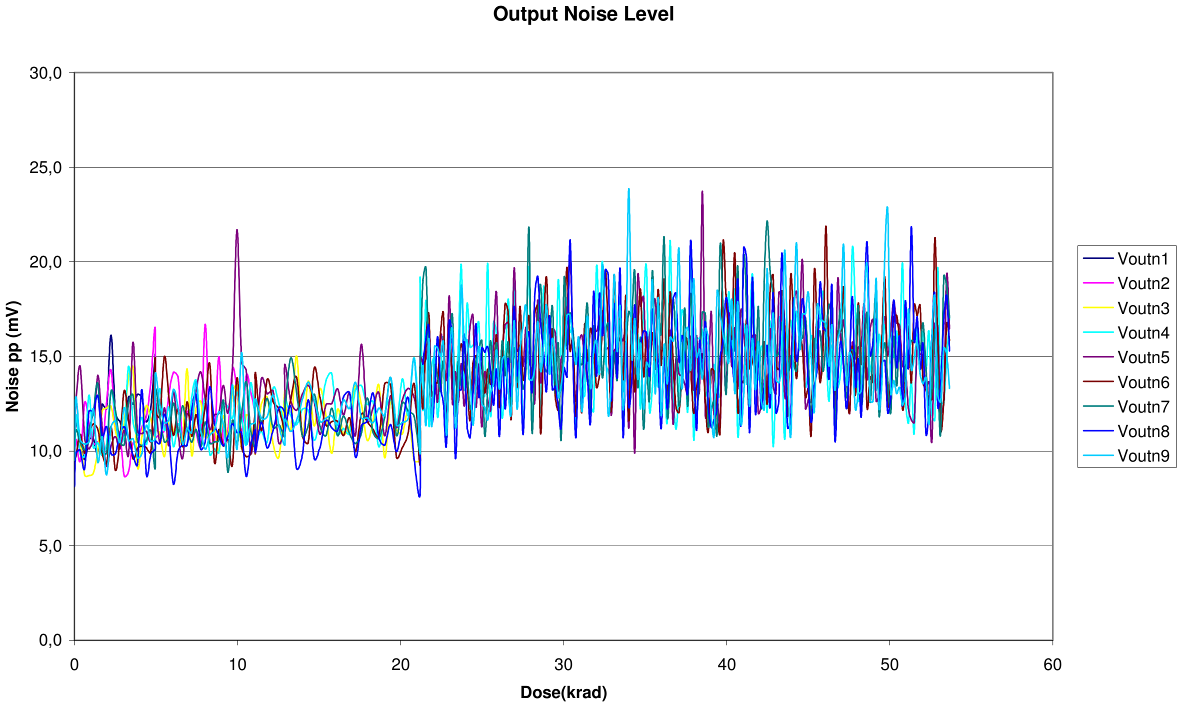
After the step 20 krad the output value tends to recover toward the initial value and finally all devices switch to 4.5V that represents the positive saturation value.
The sudden variation after 11 krad (the end of the second irradiation step) need to be explained.



4.2.3 Output voltage noise:

The output voltage noise is measured with an oscilloscope. Peak-peak values are recorded for a sweep rate of 1ms/cm.

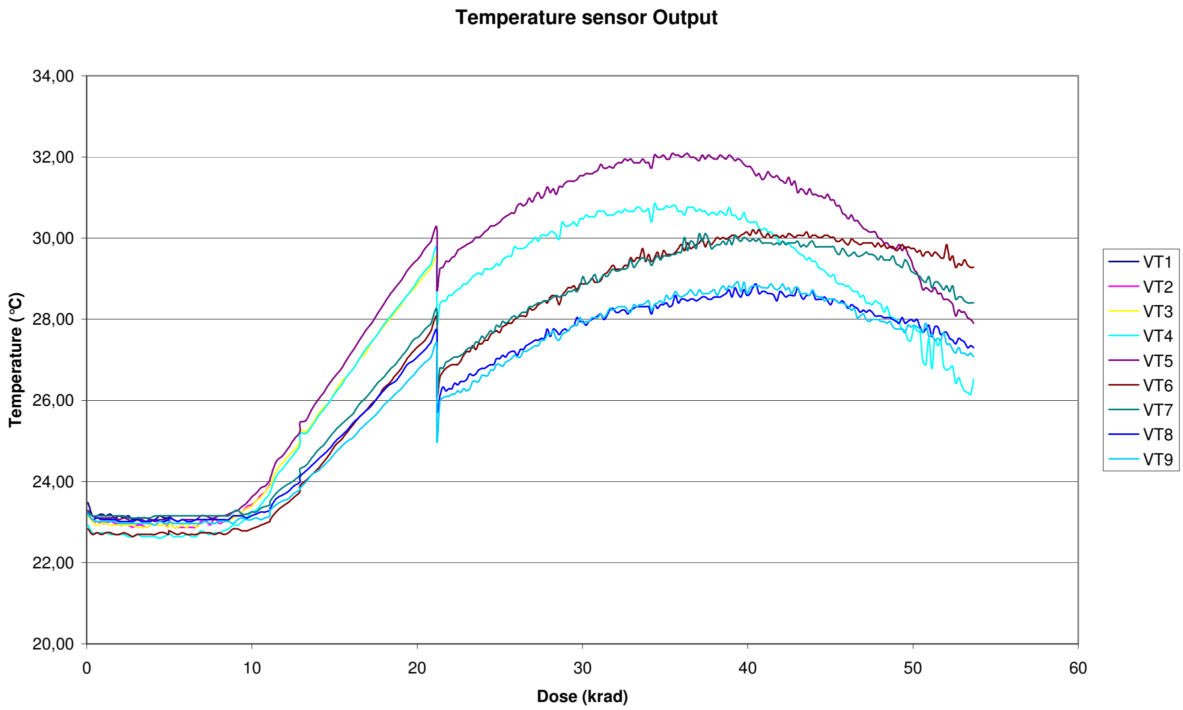
During experiment some controls are performed at other sweep rate to verify the absence of high frequency noise.



A slight increase is observed after 20krad. But at this dose level most of the devices have limited functionality.

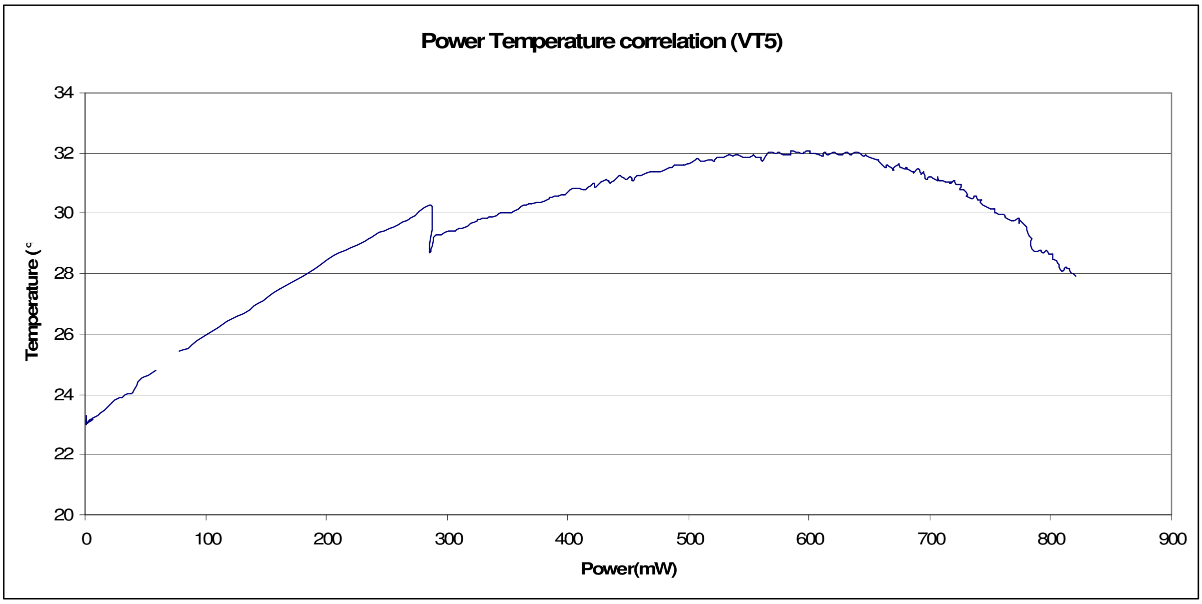
4.2.4 Temperature sensor output:

Output Voltage at 20°C Typ: 1.632 V
Sensitivity Typ: -11.77 mV/°C
Long term stability Max -0.03°C to +0.09° C (1000h @ 150°C)
Accuracy +- 5°C (From -40°C to 125°C)
.
The apparent measured temperature is given below.



The temperature is rising during irradiation after 10 krad. This is well correlated with the increase in power dissipated in the device at low to medium dose.
A maximum of the sensor output value is obtained between 30 and 40 krad
The observed response is the result of the variation of the temperature due to the increase of power dissipated in the device Pdiss= I supply.* VSupply and the variation of the output value (at a given temperature) due to radiation effects on the temperature sensor and associated electronic.

To tray to separate the two factors the dissipated power in each device is also calculated and the variation of the calculated temperature as a function of dissipated power is shown below for device VT5. In the calculation of the dissipated power, Vdd is assumed to remain constant. This was not verified during the experiment. Some correction of VD value at device level in the order of 0.2 V due to ohmic voltage drop in the 15m supply wire should probably needed to enhance accuracy.



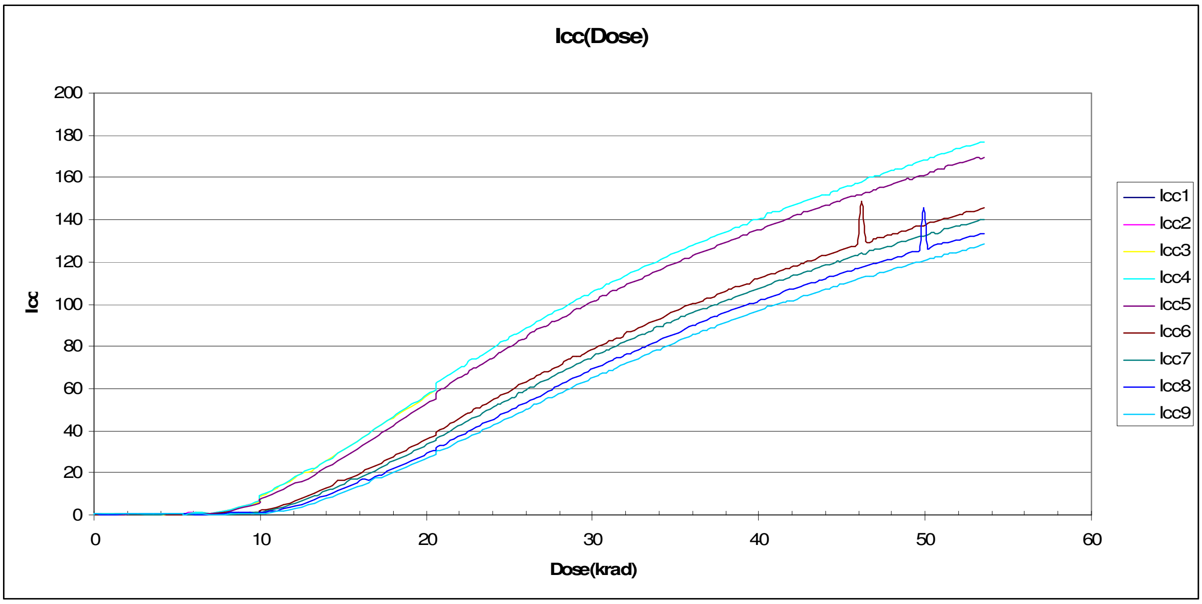
At low dose the temperature increase is proportional to the power dissipated in the device. But as total dose increases, the coefficient dT/dP decreases and becomes negative showing a strong degradation of the temperature sensor.
An independent measurement of the temperature of the package gives the following results:

4.3 HIGH DOSE RATE EXPERIMENT

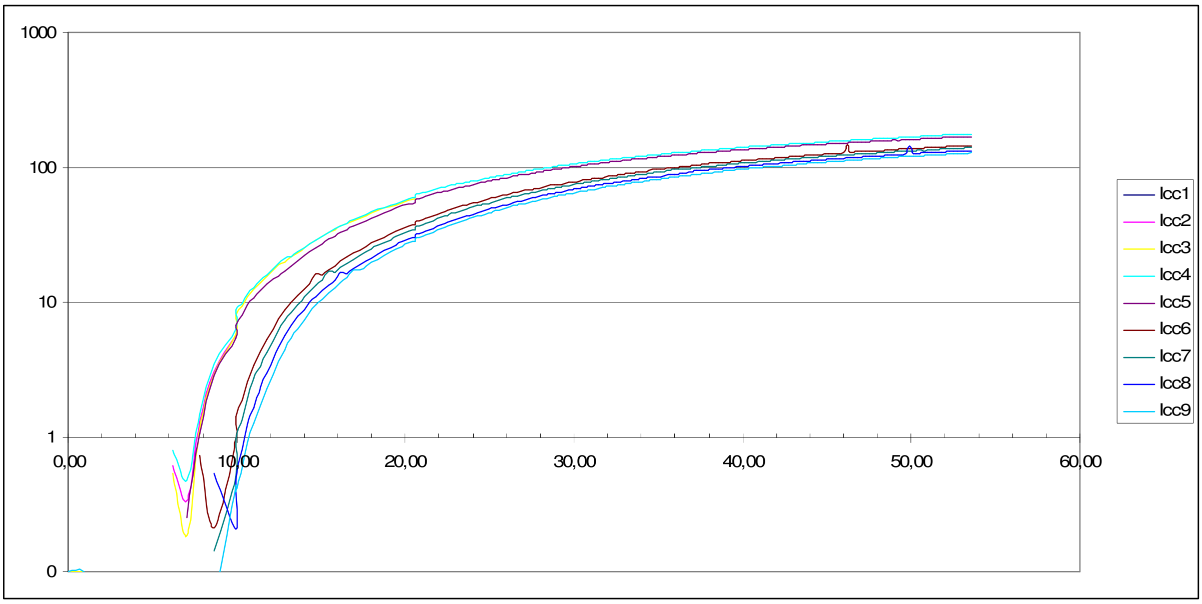
The dose rate is 3,6krad/h, roughly a decade higher than the dose rate applied during the low dose rate experiment.
The list of the devices and conditions are given below

Number	1	2	3	4	5	6	7	8	9	10
Power State	ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF
G value	0	0	0	0	0	1	1	1	1	1
Max dose (krad)	5.3	10	20.5	53	53	53	53	53	53	53
Ref	058	089	103	112	141	149	211	212	224	225

4.3.1 Power Supply Current

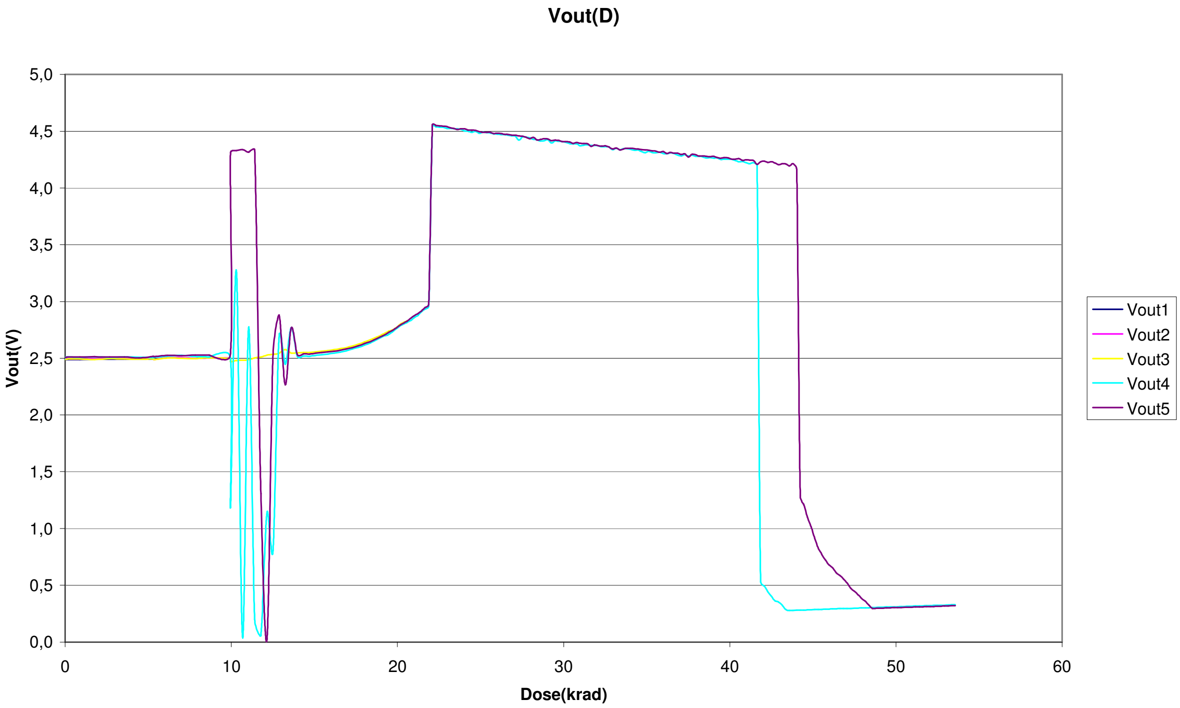


As it was observed for the low dose rate experiment, two different behaviours are clearly identified related to the 1g or 0g state.
The power supply current variation Icc (Dose) - Icc (0) is given below with a log scale.
The fast increase begins at 7 and 9 krad, 1krad higher than at low dose rate.



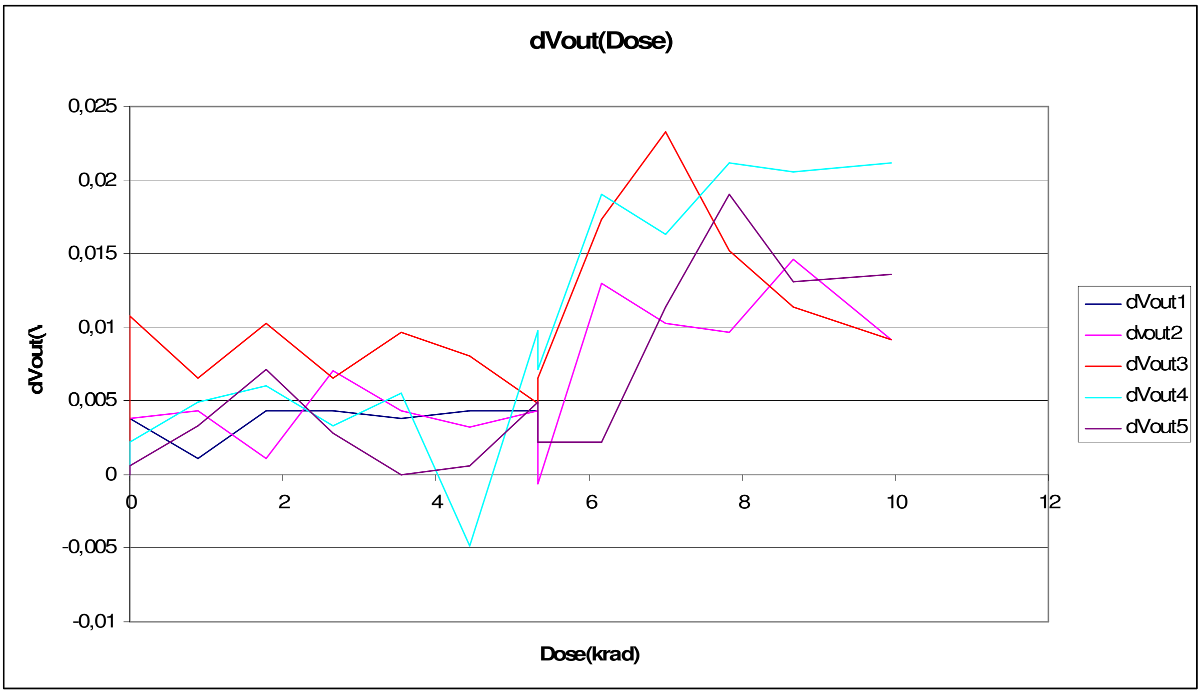
4.3.2 Output Voltage:

4.3.2.1 0g applied during irradiation



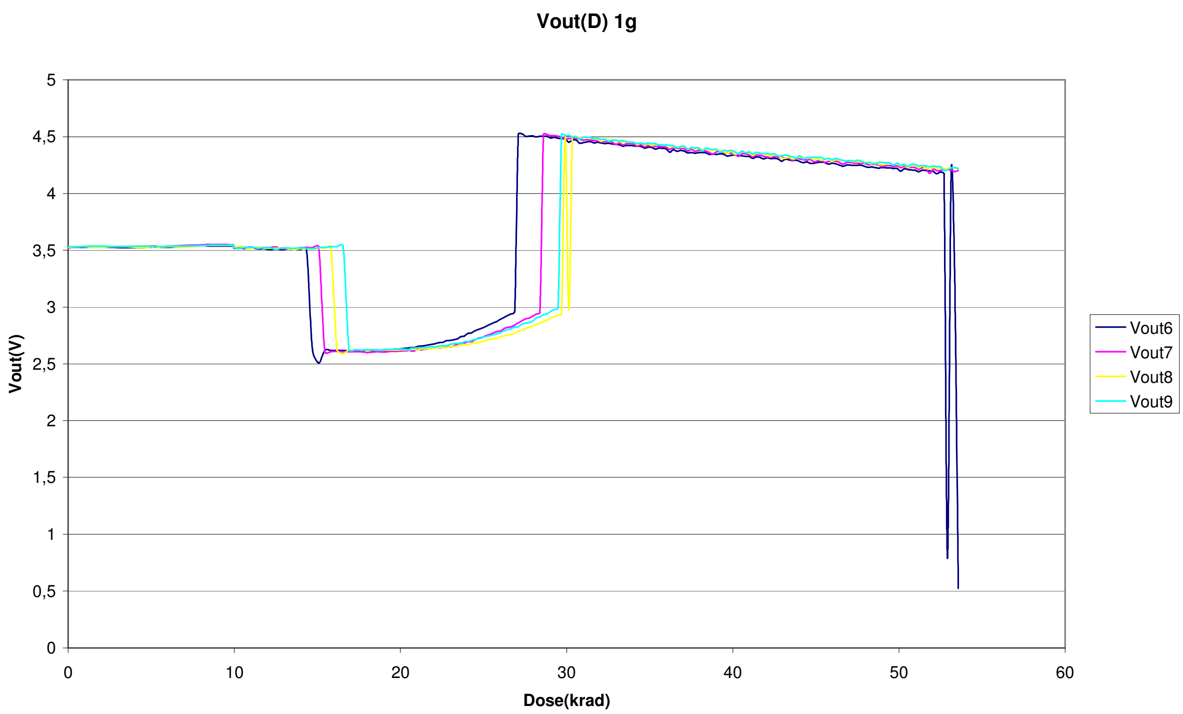
A complex behaviour of the output level is again observed. At the beginning of the third step instabilities are observed. For increasing dose, saturations to maximum high output level are followed by a switch to low output level between 40 and 50krad.
When the output of the device is in positive saturation, the output voltage decreases from 4.5V to 4.25V.
The origin of the instabilities is not clear. We need to check further if these instabilities are related or not to the testing procedure applied between two radiation steps.

For low doses (before the beginning of instabilities) the relative output variation is given below.



The stability of the measurement is better than 10mg at doses lower than 4 krad. The variation reaches +25 mg when the power supply current begins to increase after 5 krad.

4.3.2.2 1g applied during irradiation



The initial output value of 3.5V (1g acceleration) switches abruptly to 2.5V (0g acceleration) between 13 and 16 krad and then switches to the saturated positive value of 4.5V between 27 and 31krad. Finally a switch to 0.5V occurs at D>50 krad.

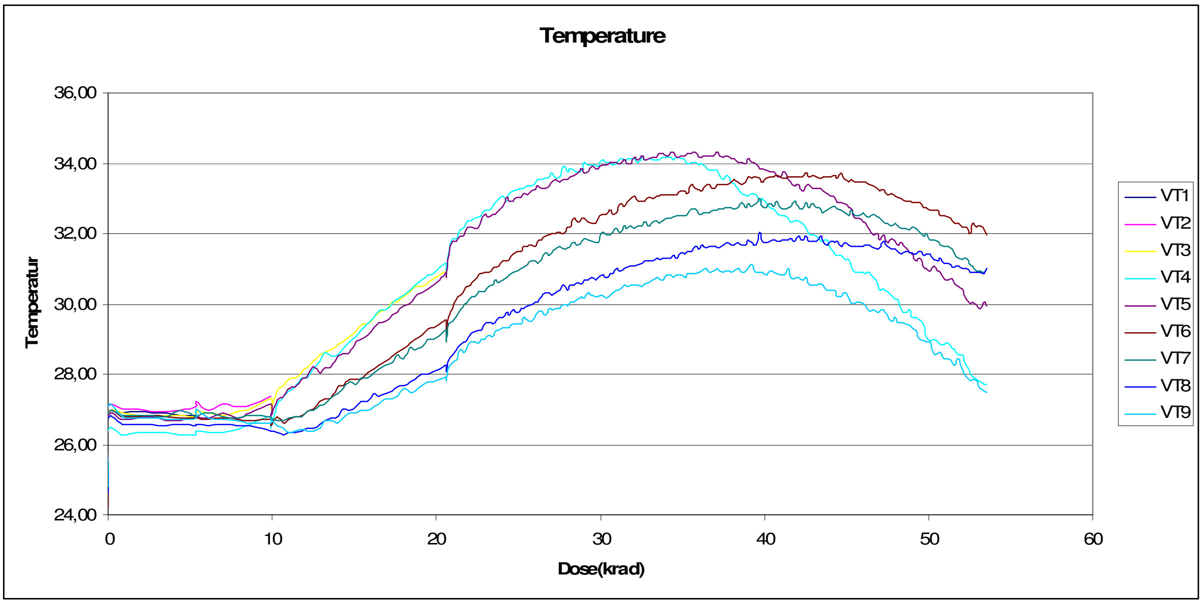
The behaviour is different from the 0g applied configuration at doses between 10 and 20 krad. But the origin of this different behaviour may come either from the sensor or from the ASIC.

For low doses (before the beginning of instabilities) the relative output variation is given below.

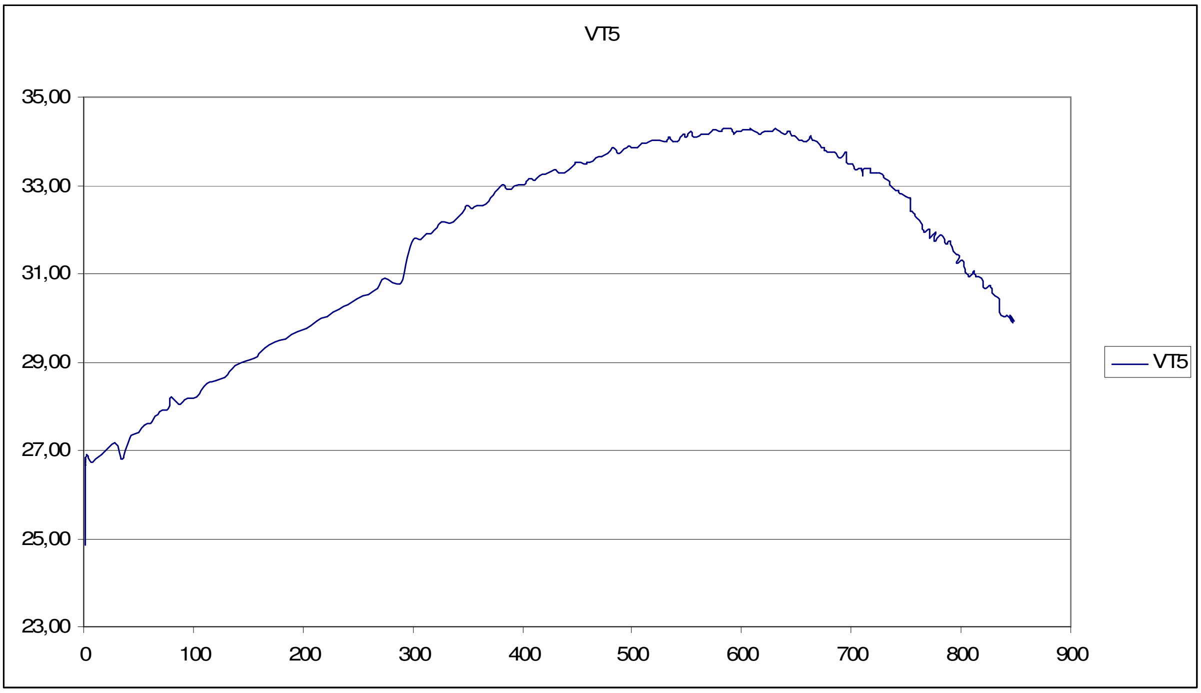
The variation of the output value does not exceed 25mg for doses lower than 10krad.
This variation is of the same order of values observed for 0g applied acceleration.
So the contributions of bias or scale factor can’t be separated by this measurement.

4.3.3 Temperature

The temperature is calculated by applying the equation already applied in the low dose rate section: Temp= 23+ (1,632-Vout)/11.77E-3



The temperature increases with dose till 35krad and then decreases.
The correlation with the dissipated power is given below for Sample N°5



At low dose the calculated output temperature follows the increase of dissipated power, reaches a maximum and then decreases.
The initial slope is about 15°C/W. When total dose increases the apparent slope diminishes and finally becomes negative. As indicated for low dose rate experiment some correction to the calculated dissipated power, due to ohmic voltage drop is probably needed, but the conclusions are unchanged.

5. POST RADIATION AND POST ANNEALING MEASUREMENTS:

After irradiation the devices have been stored during few days at room temperature under bias. Then they have been sent to EADS for post-irradiation measurement. There they have been stored without bias during few days.
Then the devices have been measured again by EADS, following the same procedure used for pre-irradiation measurements. An annealing was performed during of 168h at a temperature of 100°C without bias.

5.1 DEVICES IRRADIATED AT LOW DOSE RATE:

Number	1	2	3	4	5	6	7	8	9	10
Power State	ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF
G value	0	0	0	0	0	1	1	1	1	1
Max dose (krad)	5	11	21	53	53	53	53	53	53	53
Ref Number	001	008	013	018	038	041	045	047	051	056
Icc End Irrad(mA)	0.308	7.19	55.42	166.6	164.2	137.6	135.6	135.5	130	0.959
Icc EADS	0.30	7.0	52	182	171	144	141	141	135	1.5
Icc Post annealing	0.3	4	36	78	77	62	68	67	66	1.4

After Irradiation Icc values at EADS-IW are greater than Icc values obtained at the end of on-line measurements. This apparent “reverse annealing” behaviour is in fact due to a difference in applied voltage of a few hundred of mV due to voltage drop in the 15m length power wires used during irradiation.
After Annealing the Icc values have decreased but most of the devices remain non functional.
The increase of the power supply current of the device N°056 without power supply during irradiation is low but this device present a very low sensitivity to acceleration input of the order of 0.1 V/g. This sensitivity is of same order of magnitude as other devices under bias irradiated at 53 krad.

5.2 DEVICES IRRADIATED AT HIGH DOSE RATE:

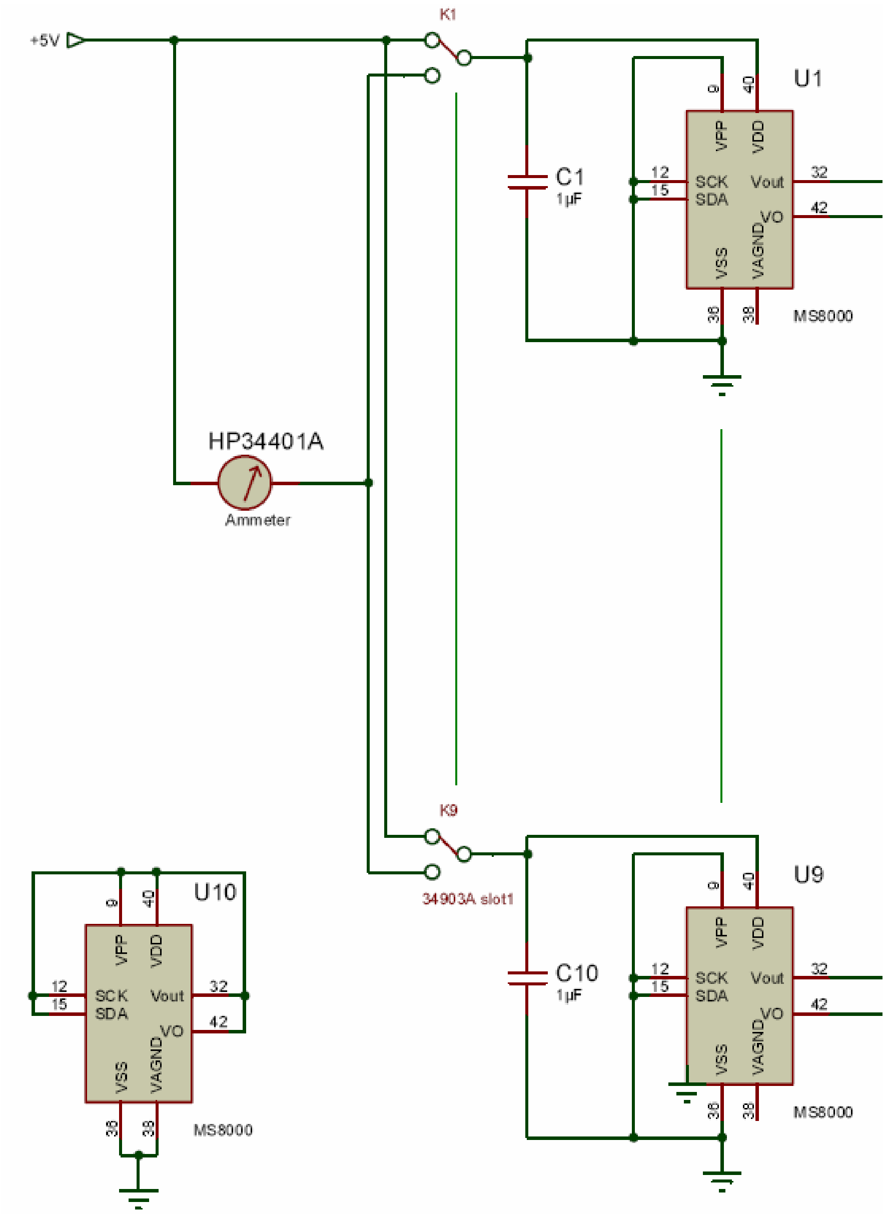
Number	1	2	3	4	5	6	7	8	9	10
Power State	ON	ON	ON	ON	ON	ON	ON	ON	ON	OFF
G value	0	0	0	0	0	1	1	1	1	1
Max dose (krad)	5.3	10	20.5	53	53	53	53	53	53	53
Ref Number	058	089	103	112	141	149	211	212	224	225
Icc End Irrad(mA)	0.311	5.97	59.1	176.8	169.6	145.5	139.9	133.6	128.2	1.54
Icc EADS	0.3	6	56	180	173	148	141	133	128	1.5
Icc Post annealing	0.3	3.5	35	73	72	70	62	56	59	1.4

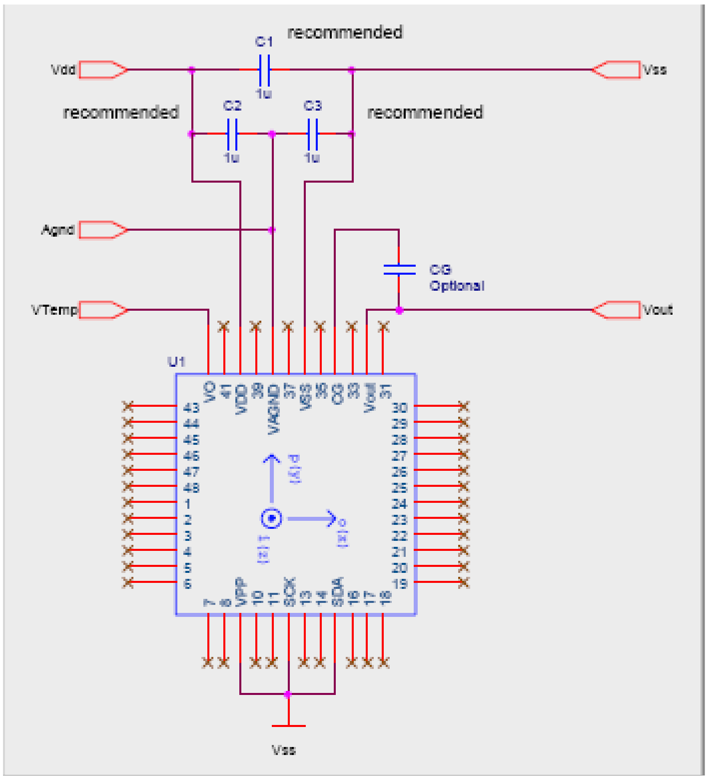
After Irradiation Icc values at EADS-IW are very close to Icc values obtained at the end of on-line measurements. Some Icc values are slightly greater of a few percent. This apparent “reverse annealing” behaviour is in fact due to a difference in applied voltage of a few hundred of mV due to voltage drop in the 15m length power wires used during irradiation.
After Annealing the Icc values have decreased but most of the devices remain non functional.

The increase of the power supply current of the device N°225 without power supply during irradiation is low but this device present a very low sensitivity to acceleration input of the order of 0.1 V/g. This sensitivity is of same order of magnitude as other devices under bias irradiated at 53 krad.

5.3 POWER SUPPLY CURRENT MEASUREMENT PROCEDURE.

The power supply current measurement procedure uses a switching matrix Ref HP34903 that incorporates an ammeter ref HP34401A between the external power supply and the DUT.
First a switch K1 between +5V and Vdd is open and then the switch between the Ammeter and Vdd is closed allowing a measurement of current. During the time interval when the first switch is open and the ammeter switch is not closed, the power supply current is supplied by decoupling capacitors (effective value 1.5 µF).


+5V
K1
U1
C1
1µF
VPP
VDD
SCK
SDA
Vout
VO
VSS
VAGND
MS8000
HP34401A
Ammeter
K9
34903A slot1
U9
C10
1µF
MS8000
U10
MS8000



The decoupling capacitor effective value is C= C1+ C2*C3/ (C2+C3)= 1.5 µF

The voltage decrease rate is dV/dt = Icc/C. To perform a detailed calculation of the Vsupply (t) variation a model of Icc (Vsupply) should be used.
To obtain only orders of magnitude of the decay rate we consider Icc(Vdd)=Cste.

For initial power supply current values of 0.4 mA,   the voltage drop rate is dV/dt = 0.4 E-3/1.5E-6= 0,26V/ms.
The voltage drop from Vdd=5V to Vdd=2.5V will need at least 10 ms. It must be checked with the timing sequence if the power supply value drops below the voltage threshold that induces an automatic reset procedure at power-up.
As indicated by the manufacturer Colibrys
"At every power-up, the microcontroller transfers the calibration parameters to the ASIC and then goes in a sleep mode. During this initialization phase, which takes less than 35ms, the current consumption goes up to 1400 µA (max. 1500 µA) @ 5V and at room temperature. Then, the normal operating current consumption remains less than 400µA under the same conditions".

For increasing doses, the power supply current increases strongly and, for example at Icc=100mA, dV/dt= 0.1/1.5E-6= 6.6 E5 V/s, so in less than 10µs the power supply voltage is reduced to less than 1V. So a reset procedure takes place at each power supply current measurement when the ammeter is connected.
A separate experiment on the microcontroller would be needed to verify its behaviour during the automatic reset and reload.

5.4 SENSOR BEHAVIOUR

When analyzing the output voltage results, information on the behaviour of the capacitive sensor are obtained only when the associated electronics remain functional and keep the measurement precision.

Post-irradiation measurement indicates that at D=5krad no parameter variation of the accelerometer are measured.

To obtain more information on the sensor behaviour, separate irradiation of the sensor and the electronics should be needed.
This can be obtained in two ways:

- Work on the sensor alone with application of nominal excitation voltage during irradiation and then perform measurements on a specific test bench
- Irradiate only the sensor part with a collimated X-Rays beam and use the non-irradiated electronics for measurements.

To obtain further information from the irradiated and annealed devices, a characterization of the sensor alone would need to open the package, extract the sensor and put it with a new electronics. But this procedure presents some risks for the sensor.
An alternate procedure would be to open the package, remove the electronics and put new electronics. This second procedure is safer for the sensor.

5.5 IMPLICATIONS FOR RADIATION TEST PROCEDURES GUIDELINES

This TID experiment has clearly shown the difficulty to explain the observed behaviour under radiation of a system when the behaviour of the separate parts is not known.
The electronics seems the most sensitive part because the signature (the power supply current increases with dose) is the usually observed behaviour in irradiated electronics.
It must de distinguished between radiation evaluation and radiation qualification of MEMS.
During evaluation, separation of the contribution of sensors and electronics is an important issue in order to obtain possible radiation hardening.
On line measurements appear to be very important and bring a lot of information.
The test procedure will be generally more complicated than with pure electronic devices because some variation of input mechanical parameters or sensor inputs will be needed to check parameters such as linearity, offset, saturation level, frequency response,…
During qualification a global test, as was performed in this TID test, is a correct approach. But worse case conditions must be identified before the qualification or different positions (sensor input) must be applied during irradiation on a sufficient number of devices..

6. CONCLUSIONS:

Total Induced Dose (TID) irradiation of MEMS accelerometers manufactured by Colibrys has been performed at low and high dose rates at ESA-ESTEC Co60 facility.

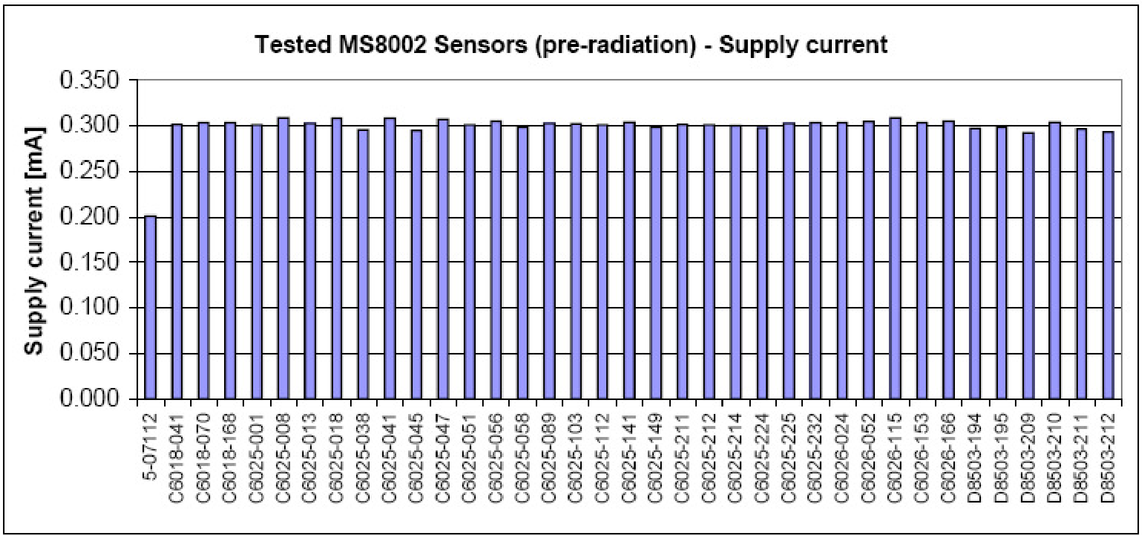
A strong increase of the power supply current begins between 6 and 7 krad followed by functional failure between 10 and 20 krad. No important ELDRS effects were observed.

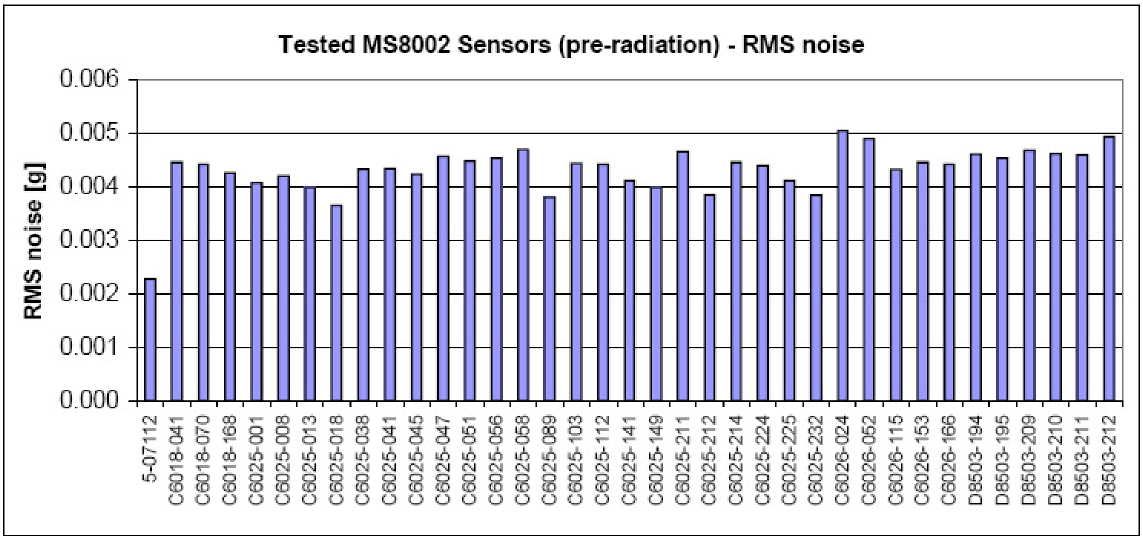
Power supply decreases after annealing at 100℃. The CMOS ASIC and CMOS microcontroller are probably the most sensitive parts. No precise information could be obtained on the behaviour of the sensor for D>10krad.

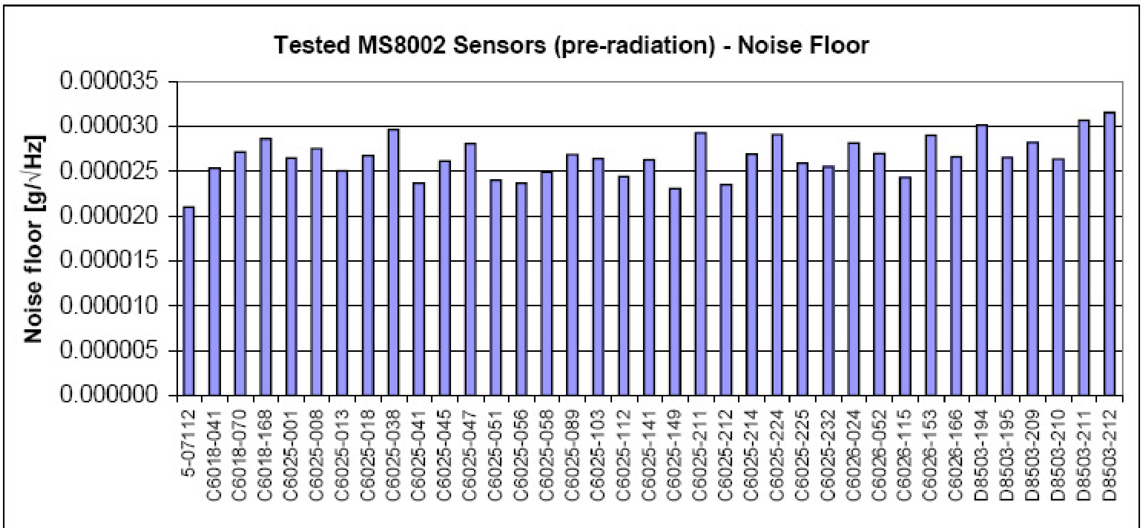
APPENDIX1 : PREIRRADIATION MEASUREMENTS

Pre-irradiation detailed measurements were performed by EADS-IW.
Results are grouped below.
Supply current is very uniform at 0.3mA for all the devices of the different lots except 5-07112
RMS Noise is around 4 E-3 g
Noise floor is around 2.5 E-6 g/sqrt(Hz)
Cut-off frequency presents some variation (distribution of values between 500 and 800 Hz)
Velocity random walk: devices C6025-001 and C6025-225 are the worse devices (more than 2 times the mean value
Bias instability: C6025-212 followed by C6025-232 and C6025-153 are the worse devices
Bias: The worse devices are C6025-008, C6025-062 D8503-194
Non Linearity: the worse devices are C6025-008, C6025-058, D8503-212
Bias drift: The worse devices are C6025-008, C6025-232

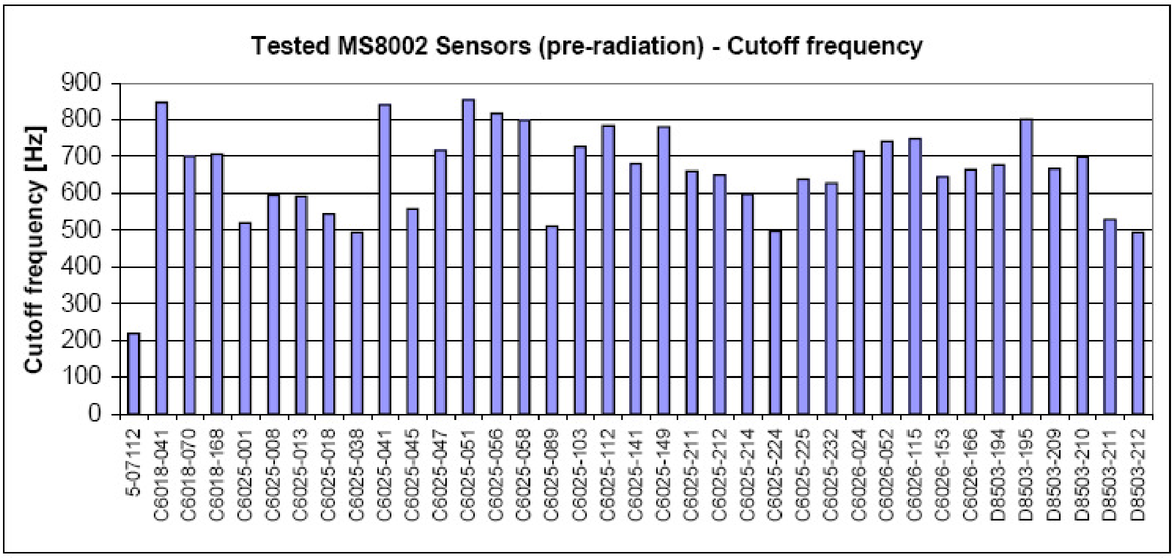
MS8002 Test Results (pre-radiation)

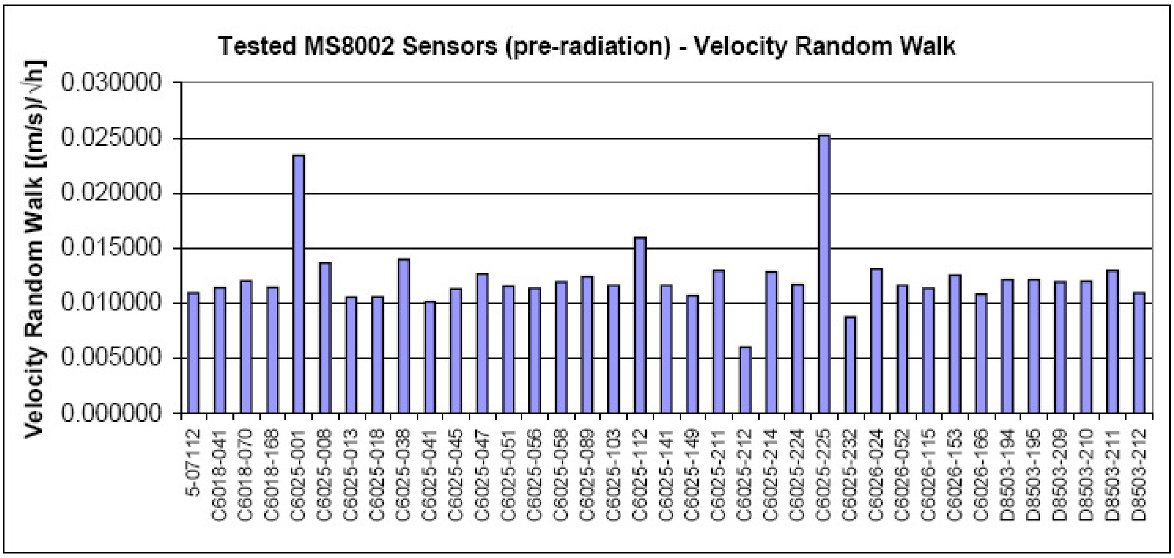


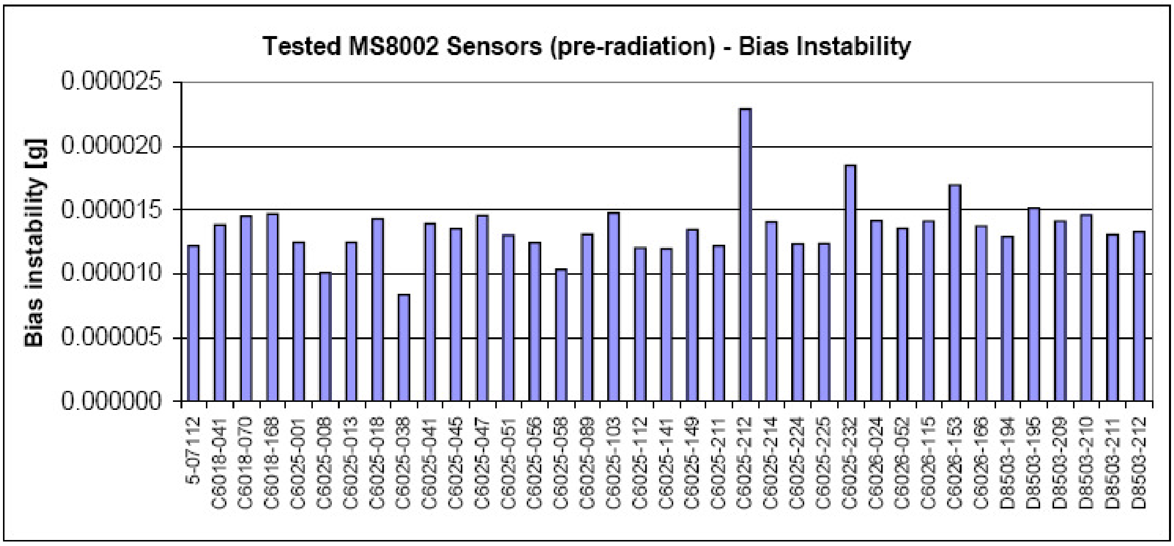




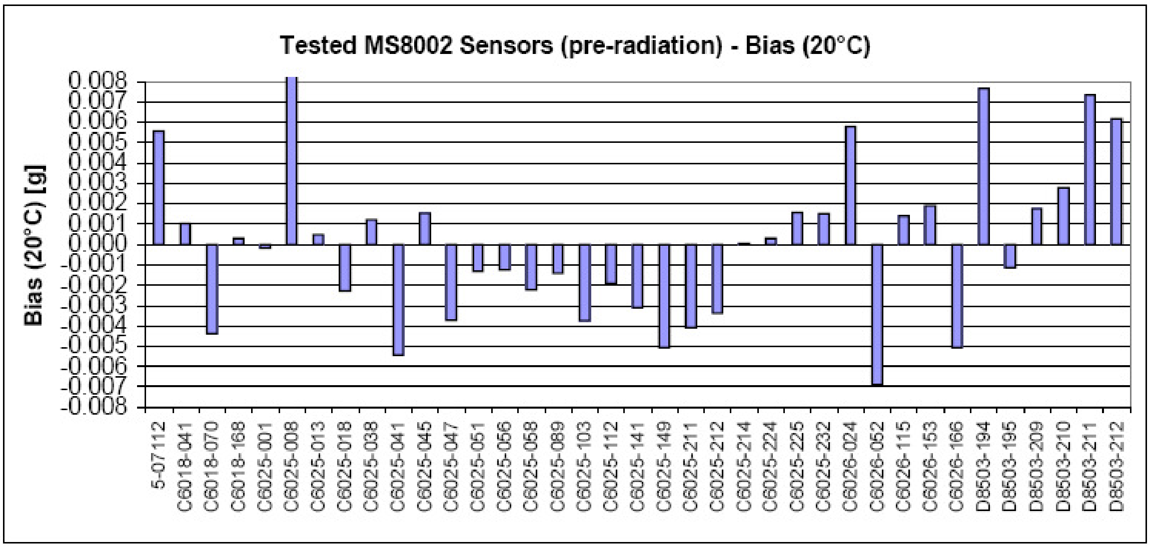
MS8002 Test Results (pre-radiation)

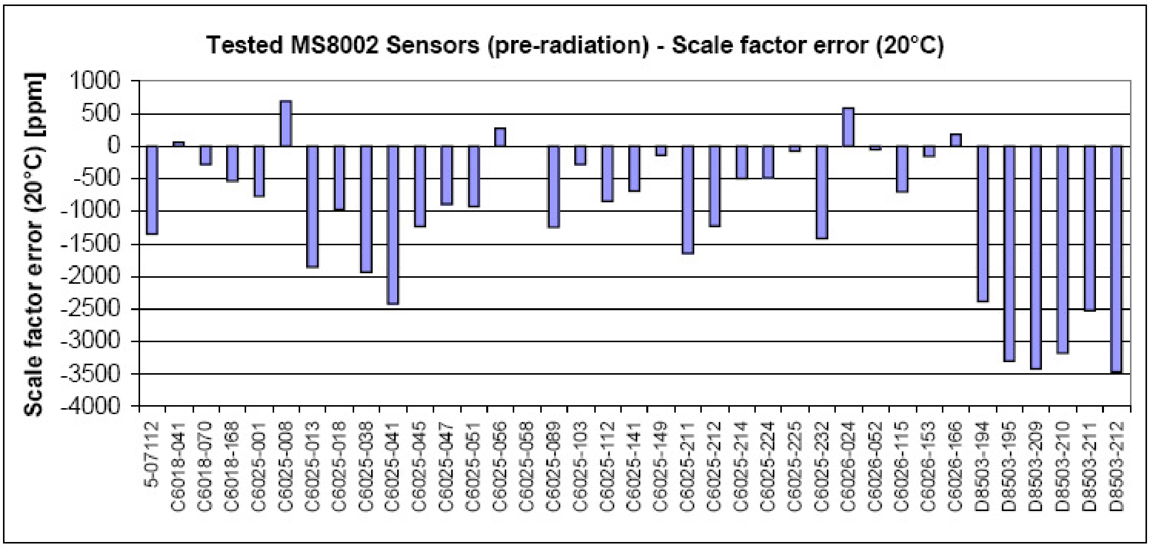


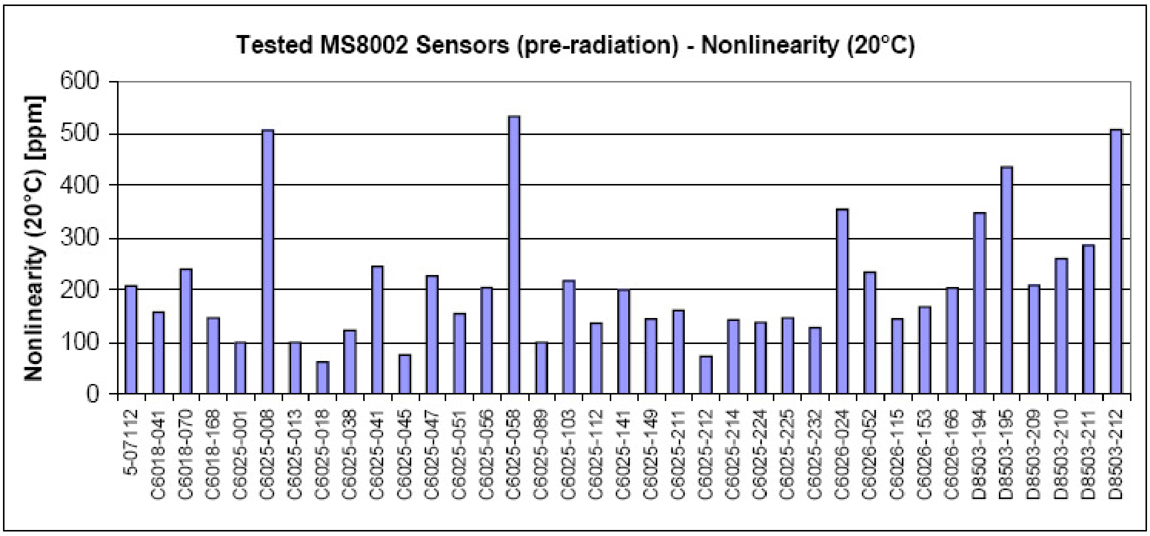




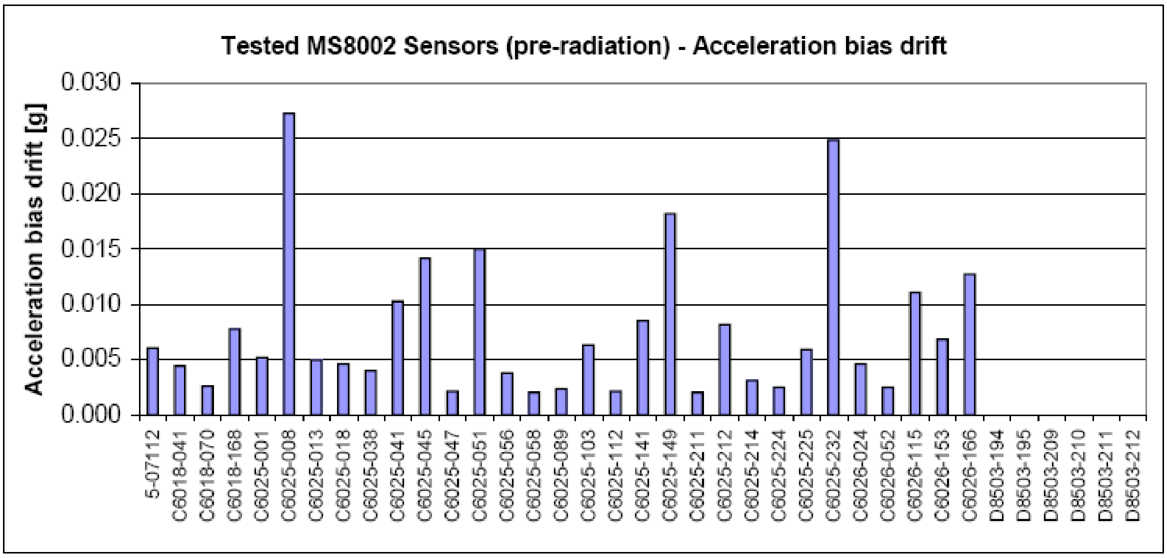
MS8002 Test Results (pre-radiation)

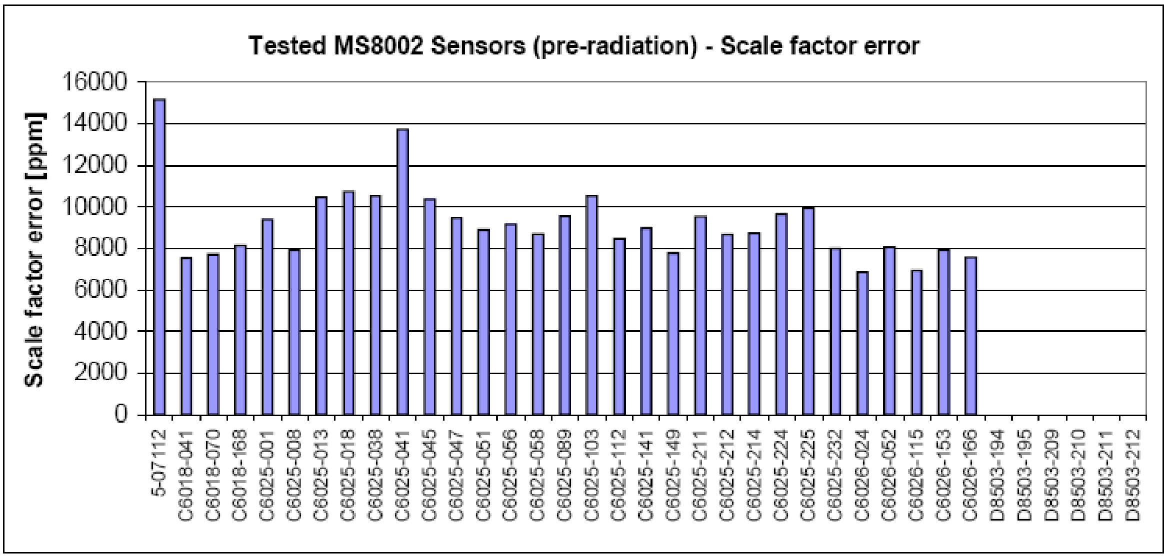






MS8002 Test Results (pre-radiation)





APPENDIX2: POST-IRRADIATION AND POST ANNEALING MEASUREMENTS:

The following measurement results reports are issued from EADS-IW test report on Post-irradiation and post annealing measurements.

Test Report (MEMSRAD)
Post-radiation (TID) examination results for the accelerometers MS8002 from Colibrys

Sensors measured – MS8002- (TID irradiated)

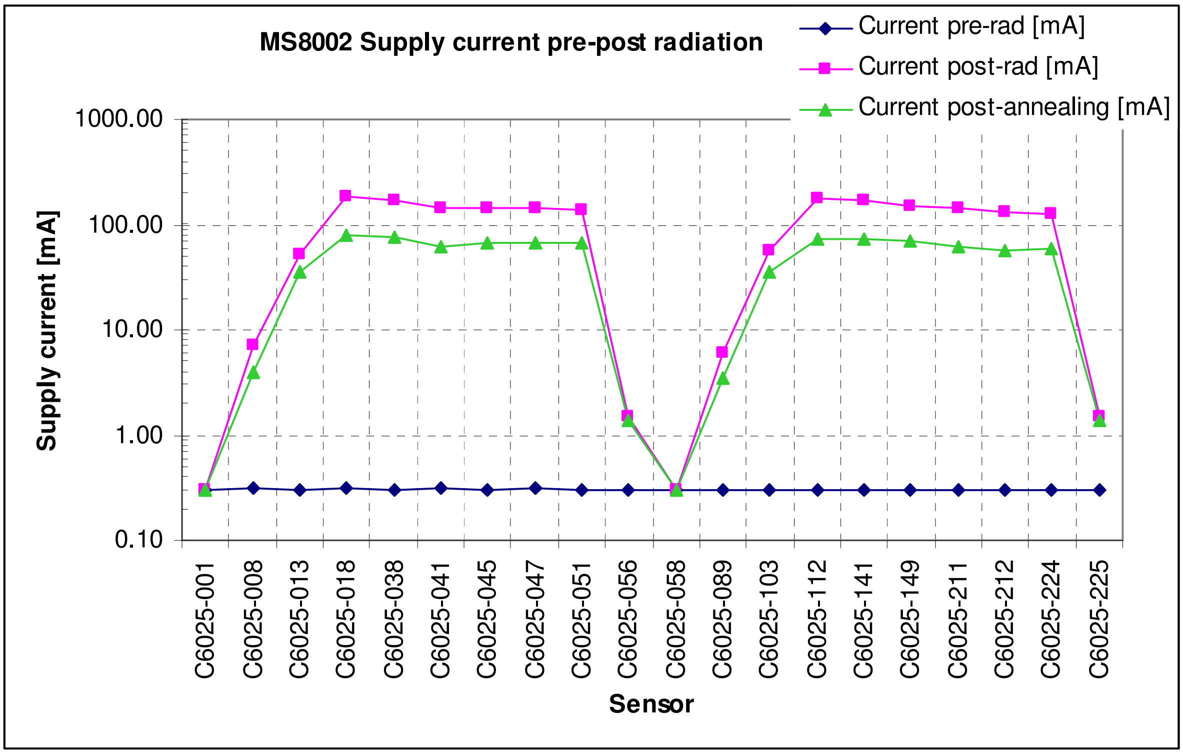
Sensor	Dose Rate	Total Dose	Comments
C6025-001	<360Rad/h	5	on 0g
C6025-008	<360Rad/h	10	on 0g
C6025-013	<360Rad/h	20	on 0g
C6025-018	<360Rad/h	50	on 0g
C6025-038	<360Rad/h	50	on 0g
C6025-041	<360Rad/h	50	on 1g
C6025-045	<360Rad/h	50	on 1g
C6025-047	<360Rad/h	50	on 1g
C6025-051	<360Rad/h	50	on 1g
C6025-056	<360kRad/h	50	off 1g
C6025-058	3.6kRad/h	5	on 0g
C6025-089	3.6kRad/h	10	on 0g
C6025-103	3.6kRad/h	20	on 0g
C6025-112	3.6kRad/h	50	on 0g
C6025-141	3.6kRad/h	50	on 0g
C6025-149	3.6kRad/h	50	on 1g
C6025-211	3.6kRad/h	50	on 1g
C6025-212	3.6kRad/h	50	on 1g
C6025-224	3.6kRad/h	50	on 1g
C6025-225	3.6kRad/h	50	off 1g

Tests performed before annealing	
Supply current	At room temperature
Noise	RMS noise and PSD at room temperature
Allan-variance	-
Bias, scale factor and nonlinearity	At Room temperature

Tests performed after annealing	
Supply current	At room temperature
Noise	RMS noise and PSD at room temperature
Allan-variance	15h at room temperature, sensor 001, 008, 058, 089
Bias, scale factor and nonlinearity over temperature	All At Room temperature, sensor 001, 008, 058, 089 from -30℃ to 70℃

Supply Current: pre-radiation, post-radiation and after annealing (T=100°C, t=168h)

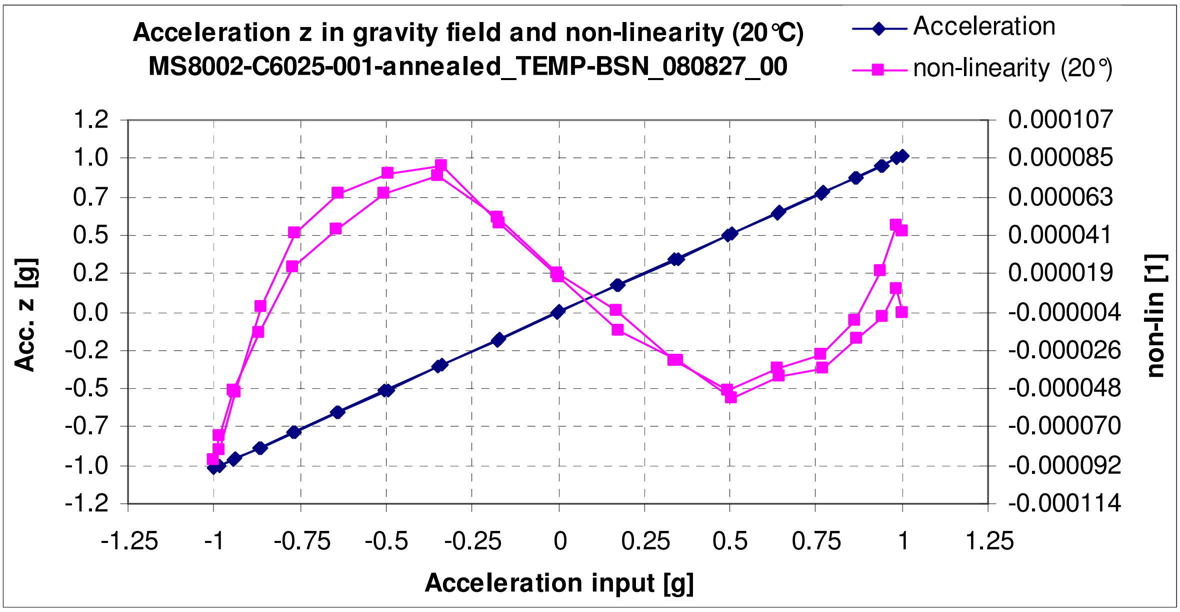
Sensor	Current pre-rad [mA]	Current post-rad [mA]	Current post-annealing [mA]	Total Dose [kRad]
C6025-001	0.3009	0.3	0.3	5.0
C6025-008	0.3087	7.0	4.0	10.0
C6025-013	0.3029	52.0	36.0	20.0
C6025-018	0.3085	182.0	78.0	50.0
C6025-038	0.2955	171.0	77.0	50.0
C6025-041	0.3080	144.0	62.0	50.0
C6025-045	0.2946	141.0	68.0	50.0
C6025-047	0.3071	141.0	67.0	50.0
C6025-051	0.3005	135.0	66.0	50.0
C6025-056	0.3050	1.5	1.4	50.0
C6025-058	0.2984	0.3	0.3	5.0
C6025-089	0.3024	6.0	3.5	10.0
C6025-103	0.3020	56.0	35.0	20.0
C6025-112	0.3009	180.0	73.0	50.0
C6025-141	0.3041	173.0	72.0	50.0
C6025-149	0.2980	148.0	70.0	50.0
C6025-211	0.3013	141.0	62.0	50.0
C6025-212	0.3007	133.0	56.0	50.0
C6025-224	0.3003	128.0	59.0	50.0
C6025-225	0.2977	1.5	1.4	50.0



Supply current before and after TID

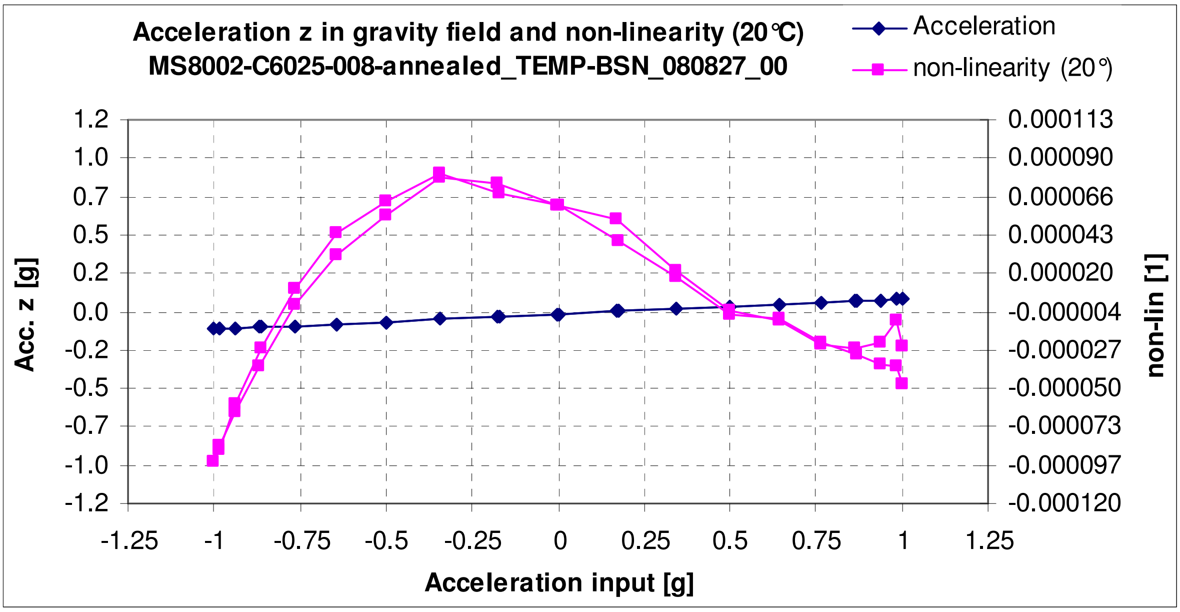
- Current before radiation: about 300uA
- Until 5 kRad: no change of Isupply
- from10 kRad: rapid current increasing with radiation
- in case of unbiased sensors: Isupply: 1.5mA

Bias, scale factor and nonlinearity at room temperature, after annealing



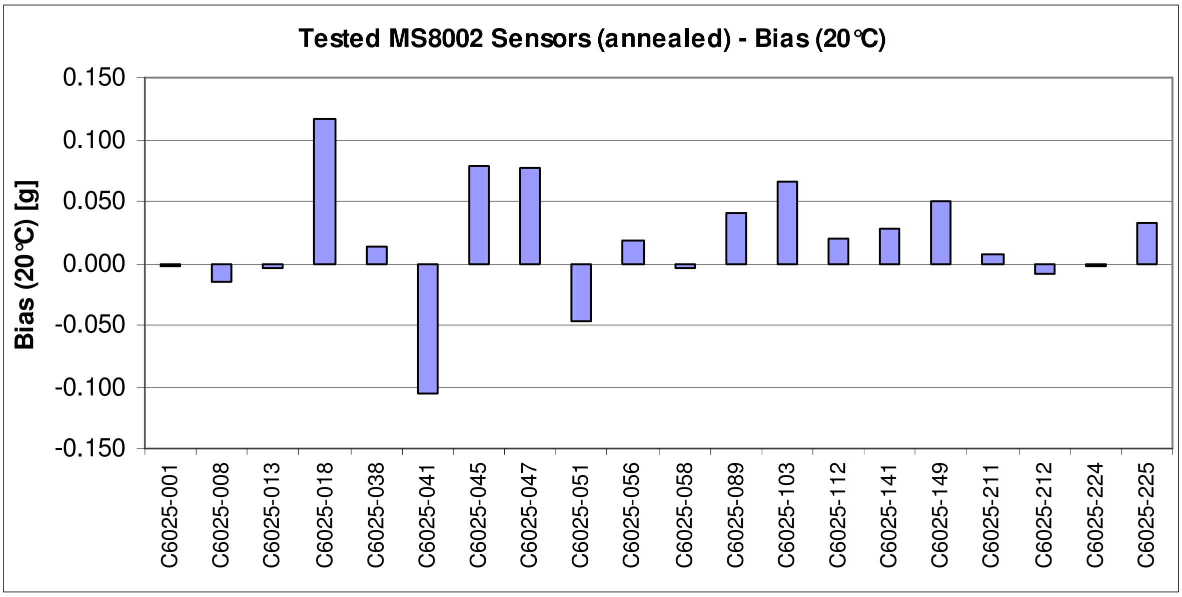
Sensor 001, typical behavior, similar to pre-radiation test

This behavior is only shown from sensor 001 and 058 after TID radiation. All other sensors show very less sensitivity to acceleration like sensor 008.

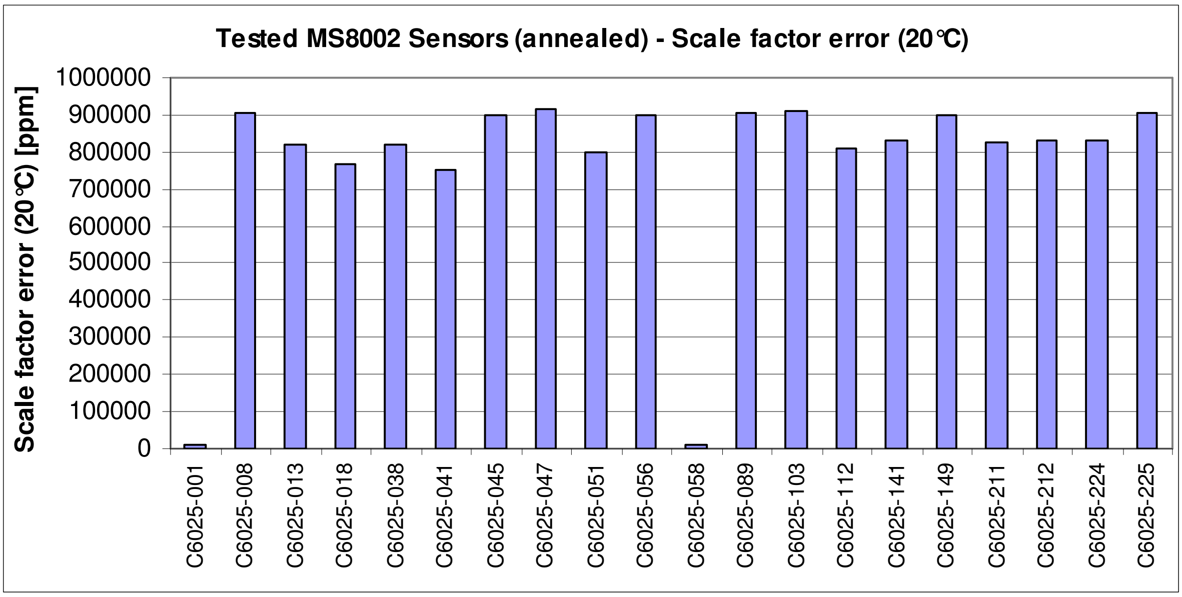


Sensor 008, typical behavior

The sensitivity of all other sensors is in the range of 0.1 instead of 1. Only the two sensors with total dose of 5kRad are working properly.



Bias of all tested sensors after annealing, at room temperature



Scale factor error of all tested sensors after annealing, at room temperature

Remark: a scale factor error of 900000 ppm means, that the scale-factor-error is 90% or the scale-factor is only 10%.

Comparison of parameters pre-radiation, post-radiation and after annealing

This measurement was done with the 4 Sensors: 001, 008, 058 and 089.

MS8002 Test Results (pre/post-radiation)

Sensor	Current [mA]	RMS noise [g]	Noise floor [g/?Hz]	Cutoff frequency [Hz]	Velocity Random Walk [(m/s)/?h]	Acc. Quantization Noise, Bias instability [g]	Bias (20°C) [g]	Scale factor error (20°C) [ppm]	Non linearity (20°C) [ppm]	Offset max [g]	Offset min [g]	Acceleration bias drift [g]	Scale factor error max [ppm]	Scale factor error min [ppm]	Scale factor error [ppm]
C6025-001	0.3009	0.004075	0.000026	520	23.4E-3	12.5E-6	-0.000189	-769	99	0.000293	-0.004939	0.005231	4670	-4731	9401
C6025-001r	0.3000	0.003900	0.000026				0.003100	-344407	56617						
C6025-001a	0.3000	0.004141	0.000027		11.4E-3	12.8E-6	0.002320	-994	99	0.002920	-0.001907	0.004827	4326	-4179	8505
C6025-008	0.3087	0.004204	0.000028	596	13.7E-3	10.1E-6	0.008345	694	506	0.019404	-0.007833	0.027237	2386	-5528	7914
C6025-008r	7.0000	2.280000					-1.820000	947958							
C6025-008a	4.0000	0.002181	0.000005		2.2E-3	3.1E-6	-0.011776	901816		-0.010513	-0.012493	0.001980			
C6025-058	0.2984	0.004693	0.000025	798	11.9E-3	10.3E-6	-0.002228	2	532	-0.002228	-0.004284	0.002056	3017	-5684	8701
C6025-058r	0.3000	0.004400	0.000024				-2.170000	998735							
C6025-058a	0.3000	0.004731	0.000026		11.3E-3	15.6E-6	-0.000615	-100	534	-0.000236	-0.002125	0.001889	2603	-5316	7919
C6025-089	0.3024	0.003816	0.000027	511	12.4E-3	13.1E-6	-0.001409	-1239	99	-0.001060	-0.003418	0.002359	5165	-4406	9571
C6025-089r	6.0000	0.000607	0.000080				-0.182000	912376					-901413	-902425	
C6025-089a	3.5000	0.001689	0.000005		5.9E-3	1.9E-6	0.044550	903414		0.046222	0.045483	0.000739	-902887	-903948	

Conclusion:

- the supply current increases rapidly above 5 kRad
- after annealing (T=100℃, t=168h) the supply current is halved
- sensors with 10kRad and more show no/very low sensitivity
- both sensors (001 and 058) with 5kRad show no significant change after radiation
- no bias during radiation: low current change, but no/low sensitivity
- all temperature sensors seem to work after radiation