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Co-60 TOTAL IONISING DOSE TEST REPORT OF 20-BIT CS 5508 ADC

for

RPC MAG / ROSETTA
ESA PROJECT

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1 Abstract

This report presents the results of a number of Co-60 radiation tests carried out on CS 5508, a 20-bit A/D Converter from Crystal Semiconductor Corp. The main purpose of these tests was to establish the amount of gamma radiation the CS 5508 could withstand and still remain within data specifications. Electrical parameters monitored during the tests were; Supply Currents, Standard Deviation and Signal to Noise and Distortion ratio.

2 Introduction

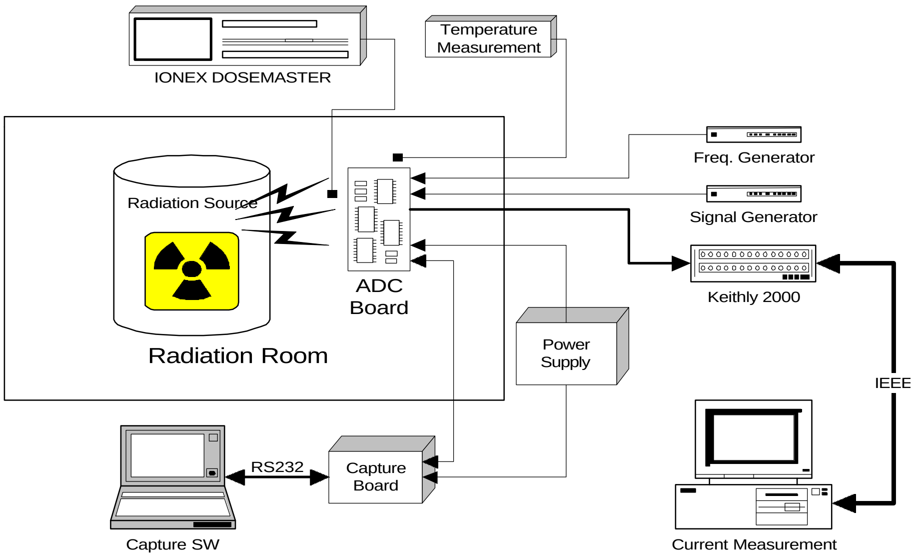
The CO^{60} facility at ESTEC, Noordwijk was used as the gamma ray source during a series of CS 5508 ADC total dose tests carried out in support of the ROSETTA project in January 1999. The 20-Bit CS 5508 is required for the Plasma Consortium Magnetometer (RPC – MAG) but have unknown radiation behaviour. The ADC was chosen because of its good performances: 20 Bit, very low power 3.72 mW dual supply operation, on-chip self calibration and extended temperature range. During the test the CS 5508 was biased. The first set of CS 5508 radiation data, based on Supply Current, Standard Deviation and Signal to Noise and Distortion ratio will be presented here.

Device	Dose rate (rad(Si)/min)	Start (Date / Time)	End (Date / Time)
# 1	75.98 rad(Si)/min	12/01/99 at 9: 45	12/01/98 at 15:00
# 4	20.43 rad(Si)/min	12/01/99 at 15:35	13/01/99 at 10:30
	43.68 rad(Si)/min	13/01/99 at 11:00	13/01/99 at 12:55
# 5	43.68 rad(Si)/min	13/01/99 at 11:00	13/01/99 at 17:45
# 6	12.74 rad(Si)/min	13/01/99 at 19:35	14/01/99 at 14:40
# 7	12.74 rad(Si)/min	13/01/99 at 19:35	15/01/99 at 14:50
#8	12.74 rad(Si)/min	13/01/99 at 19:35	15/01/99 at 14:00
After annealing , device #6 (20 hours at 100° C without bias) and device #5 (31 hours at room temperature + 20 hours at 100° C without bias) were tested again.			
# 5	68.12 rad(Si)/min	15/01/99 at 14:30	15/01/99 at 17:08
# 6	68.12 rad(Si)/min	15/01/99 at 14:30	15/01/99 at 17:08
In addition, the devices #5, #7and #8 were irradiated unbiased with a dose rate of 12.14 rad(Si)/min			
# 5,7,8	12.14 rad(Si)/min	15/01/99 at 17:48	18/01/99 at 13:00

Table 1: Co-60 radiation test schedule

To characterise the behaviour of the device and to set up a test schedule for further tests the first ADC was tested at a higher dose rate. The total dose of 20 kRad was reached in about five hours when the device stopped to function. Further tests were performed at slower dose rates, resulting in longer device functionality. In total five devices were tested and one was used as the control device. After each radiation exposure and annealing treatment, the devices were electrically tested and the data compared with the Crystal's data specification.

3 Test Configuration and Equipment



The ADC Board is designed to provide a means of testing up to three CS 5508 A/D converters. It is configured for operation from ±5V Dual Supply Voltage, with ADCs operated by 32.768 kHz crystal in a bipolar mode, as well as for external clock with frequencies from 30 kHz to 163 kHz, with an off-chip precision reference of 2.5 V.

Figure 1: Test set-up equipment

The Capture Interface Board is a development tool, which interfaces an ADC board to a PC. When operating digital data is collected from the ADC, and then transferred to
the PC over a serial port. Once in the PC, evaluation software analyses the data and displays the ADCs' performances. This software permits analysis in time domain, frequency domain and noise histogram analysis. The supply currents were monitored with another PC controlled via IEEE Bus, using test sequences programmed under "Test Point".
Test results are displayed on the screen and saved in a file for further evaluation and analysis.
Overall, 6 devices were Co^{60} tested during this evaluation. The measurements were carried out by using different dose rates and starting-stopping times as given in *Table 1*. Placing the devices at different distance form the Co-60 sources varied the dose rate. The doses were monitored by an Ionex Dosimeter equipped with an ion probe placed alongside the components to be irradiated. The measurements were performed under the room temperature (approximately 19.2°C).

3.1 ADC Board for Evaluation of CS 5508 ADC

The ADC board provides the mean of testing up to three CS 5508 analogue-to-digital converters. The CS 5508 requires a minimal amount of external circuitry. The board is configured for operation from ±5 Volt supply (V_A+ & V_A-), but can operate from a single supply if the V_A- is connected to the ground.
The schematic in *Appendix 1* presents the connections of the ADC and its circuitry as well as the list of parts used for the board. Each ADC is configured to operate from the on board 32.768 kHz crystal or from the external clock (30 kHz to 163 kHz). The board is designed for an operation with external and internal voltage reference. The ADC can convert the bipolar as well as unipolar input signal. The control pins of the CS 5508 (CS\, SCLK, SDATA and

DRDY\) are available on the JP8 header connector. Prior the powering up the board, the calibration process is required. Then the measurements can be taken.
On the board, the ADC operates in Synchronous Self Clocking mode (SSC). In the SSC mode, ADC provides both the serial output (SDATA) and the serial clock (SCLK). After the serial port is updated, the 20-Bit digital data will appear. Subsequently the SCLK will fall. The SCLK and SDATA will return to the high impedance state.

3.2 The Capture Interface Board and Evaluation Software

The capture interface board used in this research is manufactured by the Crystal. It is used to capture the data from an analogue-to-digital converter on the ADC board. The data can be transferred to the personal computer (PC) for the further analysis.
CDB Capture board collects the data form an ADC. When the data sample has been collected and stored in the serial on-board FIFO, the µC reads the data from FIFO and then transfers it to the PC over the serial cable RS-232. Figure 2 is the functional block diagram, illustrating the data flow, from the ADC to the board.

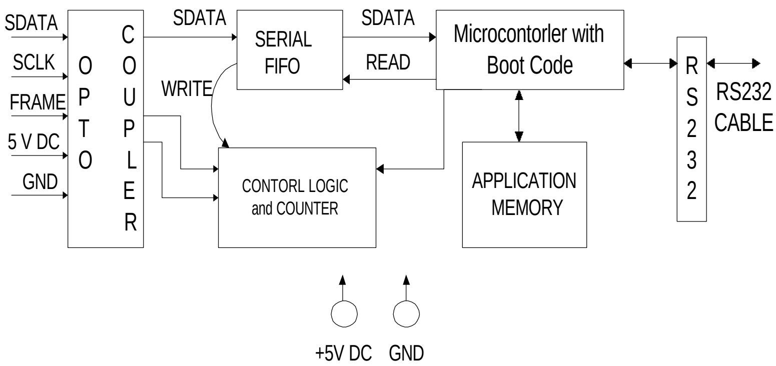


Figure 2: Functional Block Diagram

The evaluation of the performance of the ADC was made by the evaluation software developed using "LabWindows" software package. Time plots, FFT and histogram analysis are included. The software allows a maximum of 8192 of samples to operate with and it is user selectable.

3.3 Current Measurements

During the irradiation of the ADCs, the supply currents were monitored. For the purpose a high precision Keithly 2000 Multimeter (6 decimal digits) programmable device was used. A coax cable is connected between the ADC supply cable and Keithly 2000. An IEEE bus is connected between Keithly 2000 and the PC. The frequency of the measurements was user selectable. The currents from each of the three on-board ADCs were measured every 10 seconds and its values were saved in the user selectable file for later analysis.
For the purpose the software package "Test Point" was used.

4 Test Method

In the present test set-up, two basic tests are used to measure and quantify the performance of analogue-to-digital converters. The histogram analysis is used to measure the DC accuracy or static performance of ADCs, such as offset. FFTs are used to measure dynamic performance characteristic such as linearity.
For the Differential Nonlinearity (DNL) and Histogram analysis, the A/D Converter is used to operate in the bipolar mode. A DC input signal of 1.24 V (battery source) was used while 1024 samples were collected from ADC. The Standard Deviation was calculated.
The significant increase of the standard deviation indicates noise on the signal source or voltage reference to the ADC. At the end of the test, DNL is plotted. This helps to visualise the linear characteristic of an A/D converter. The more positive/negative DNL values are, the less linear the part becomes.
The FFT input signal was 1Hz, $1V_{pp}$ sinus signal. Windowing was used to reduce the spectral leakage of the input signal. 1024 samples of the signal were used.
Unfortunately, due to the quality of the used sinus generator as well as the connections used between equipment (i.e. long cables etc.), some additional deviations are noticed.

5 Results

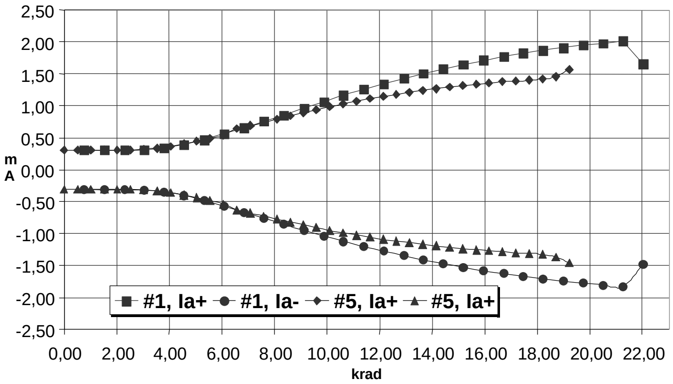
These Crystal CS 5508 devices were proved to be very difficult to analyse because of their erratic behaviour and very unexpected results. All three parameters monitored were affected during radiation, but sometimes only slightly and within specification.
Six parts were tested, all of them biased when being irradiated. Devices #1 and #5 were tested under high-dose, rapid testing regime, #1 at 75.98 rad(Si)/min and #5 at 43.68 rad(Si)/min.
These two devices showed good performances to approximately 20 krad(Si), but their power consumption become progressively high, as the dose level increased. No measurements could be taken after a total dose of 20 krad(Si). After annealing, 31 hours at room temperature + 20 hours at 100° C without bias, the device #5 was tested again. The return of functionality along with the decrease of power consumption indicated that the device had completely recovered.
Devices #4, #7 and #8 were tested at much lower dose rates, device #4 at 20.43 rad (Si)/min and devices #7 and #8 at 12.74 rad (Si)/min. Device #8 was clocked with an external clock rate of 100 kHz and device #7 with internal crystal oscillator, with a clock rate of 32.768 kHz. Both devices showed similar performance during irradiation. After approximately 3 krad(Si) the supply currents started to increase**,** but remained reasonably stable, changing slowly up to approximately 27 krad(Si). After 27 krad(Si) they rapidly decreased, and remained stable for approximately 2 krad(Si). After 29 krad(Si), until approximately 30, krad(Si) strong fluctuations in power consumption was noticed. After approximately 30 krad(Si) devices were malfunctioning and further measurements were not possible.
Device #6 was used as a control device. It was irradiated with a slow dose rate, 12.74 rad(Si)/min up to approximately 15 krad(Si). After annealing, 20 hours at 100° C without bias, the device was tested again and showed reduction in power consumption, as well as improvement in functionality
Following biased irradiation, devices # 5, # 7 and # 8 were further irradiated unbiased at a dose rate of 12.14 rad(Si)/min. The supply currents of those devices were decreased and their functionality was improved.

5.1 Biased Testing

5.1.1 Supply Currents

Devices # 1 and # 5

Devices # 1 and # 5 were irradiated during operating conditions with dose rates of 75.98 rad(Si)/min and 43.68 rad(Si)/min respectively.



Although the currents were increased by 0.09 mA/krad(Si) for # 1 and 0.07 mA/krad for # 5 no degradation in functionality was observed. Standard Deviation as well as Signal to Noise and Distortion ratio remained constant during irradiation. Measurements were not possible for device # 1 above the 22 krad(Si), and for device # 5 above 19.21 krad(Si).

Figure 3: Icc versus total dose, dose rates: 75.98 rad(Si)/min (# 1) and 43.68rad(Si)/min (# 5)

Device # 4

Device # 4 was irradiated at a lower dose rate; 20.43 rad(Si)/min. Both statically and dynamically biased samples performed satisfactory up to total dose, changing slightly prior to failure. Starting with approximately 22 krad(Si), the device was irradiated with dose rate of 43.68 rad(Si)/min. The current consumption increased approximately 0.026 mA/krad(Si), starting from 3 krad(Si). Prior to failure max analogue supply currents were 0.94 mA and –0.92 mA.

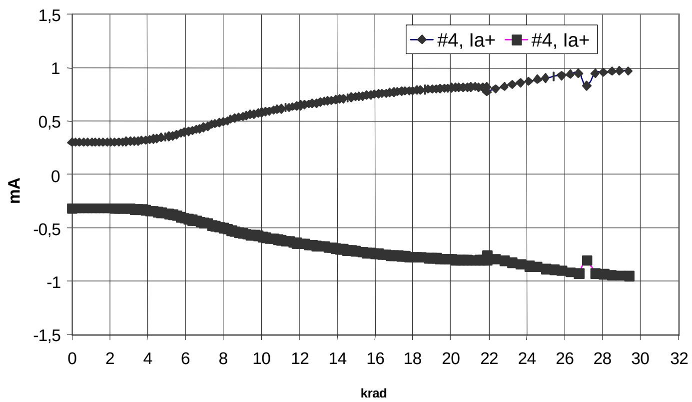
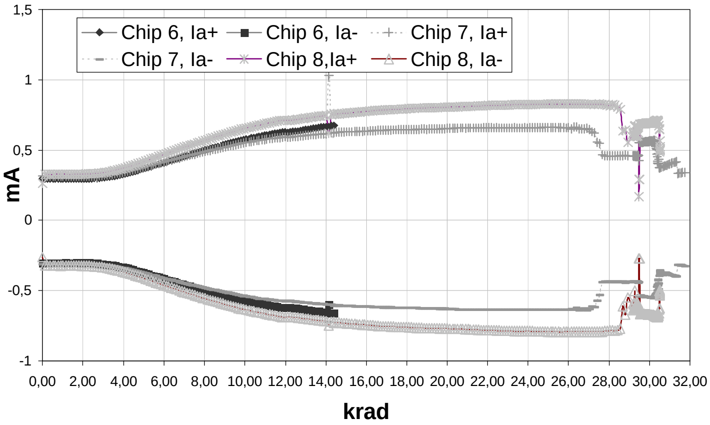


Figure 4: Icc versus total dose, dose rate 20.43 rad(Si)/min (# 4)

The device was not functioning above 27 krad(Si). The test set-up was restarted (power up/reset and calibration process were performed) at 27.17 krad(Si) but the device functionality was not regained. It was left under bias in the radiation chamber for additional hours. Periodically, the measurements were repeated but without success. The device was not functioning. Only the consumption of analogue supply currents continued to increase.
The device was taken out at a total dose of 29.9 krad(Si).

Devices # 6, # 7 and # 8



Low dose rate testing of devices # 6, # 7 and # 8 at 12.74 rad(Si)/min caused lower supply currents increase as shown in the Figure 5. From about 3 krad(Si) to 22 krad(Si), the currents increased with approximately 0.023 mA /krad(Si). Starting with 22 krad(Si) the currents were changing with only 0.01 mA/krad(Si). The performance of the two devices was similar.

Figure 5: Icc versus total dose, dose rate 12.74 rad(Si)/min # 6, # 7 and # 8

Device # 6 was tested only to total dose of 15 krad(Si), performing as same as the other two devices. Devices # 7 and # 8 were tested to total dose 30 krad(Si).
After approximately 27 krad(Si) for # 7 and 29 krad(Si) for # 8, supply currents had decreased in value to about 0.46 mA and 0.60mA respectively. The currents continued to decrease, as the accumulated dose rate increased. The consequence was a strong degradation in functionality that could be observed in the Standard Deviation value as well as in Signal to Noise and Distortion ratio, which will be examined in the following chapters.

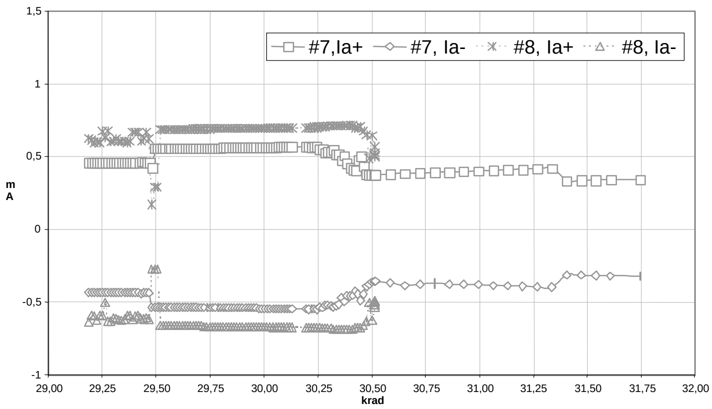


Figure 6: Device # 7 and # 8, zoom from 29 to 31 krad (Si)

5.1.2 Standard Deviation

<u>Device # 1, # 4, # 5</u>

Devices # 1 and # 5 showed no irregularity in Standard Deviation performances during the irradiation process up to 20 krad(Si). The starting values of the Standard Deviation of devices were rather high, around 13 dB and remained high during the whole irradiation, probably because of the equipment's cabling, which caused additional noise in the converted signal.
Pre-irradiation tests as well as post irradiation tests, made in the laboratory in Graz, showed the Standard Deviation to be approximately 3 dB for both devices. When device # 5 received a 12 krad(Si) of total dose the of Standard Deviation was surprisingly decreased to 4 dB, and remained to be 4 dB until device failure. The reason for such behaviour was probably the Crystal Oscillator that was not shielded during the irradiation of this device. After 22 krad(Si) for # 1 and 20 krad(Si) for # 5 of total dose no measurements could be taken.

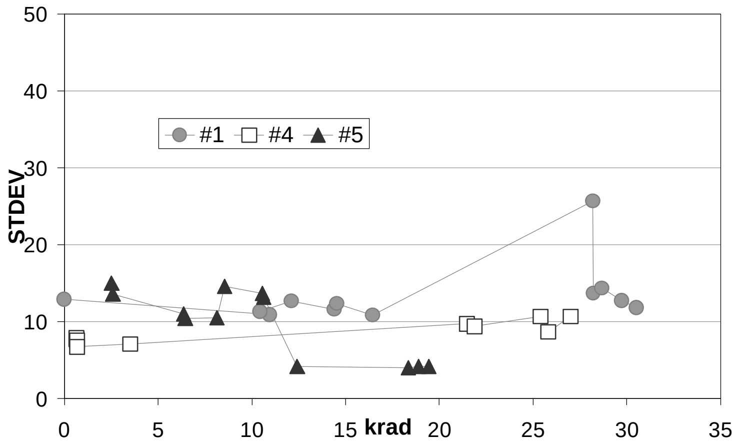
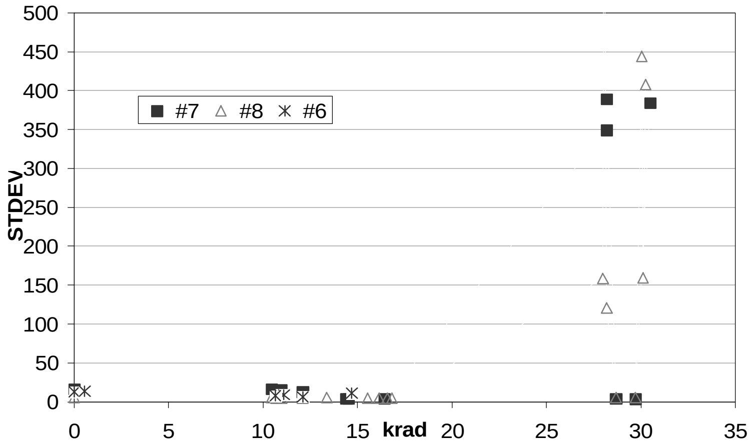


Figure 7: STDEV measurements for devices # 1, # 4 and # 5

Device # 4 was first irradiated with a dose rate of 20.43 rad(Si)/min over night to 21.89 krad(Si) and then with the dose rate of 43.68 rad(Si)/min. The Standard Deviation measurements showed a slight trend to increase. Device # 4 got a total dose of 27.13 krad(Si) before function failure.

<u>Devices # 6, # 7, # 8</u>



Devices # 7 and # 8 were tested continuously over two nights and two days, as the devices were irradiated with a lower dose rate of 12.74 rad(Si)/min. As our test set up was not automated, it was not possible to take the output value of the ADC for the night (see Figure 8).

Figure 8: STDEV measurements for devices # 6, # 7 and # 8

The initial value of the devices remained stable to probably 27 krad(Si) and then become very high. After the power up/reset and calibration process was performed (test set up system restarted) at approximately 28.81 krad(Si) and 29.4 krad(Si) the functionality of these devices improved although not for long time. Device # 7 stopped to converting at total dose of 30 krad(Si), and so did device # 8 at 31 krad.
Device # 6 was irradiated to the total dose of 15 krad(Si). After annealing, for 20 hours at the 100°C, device # 6 was irradiated again to the total dose of 15 krad(Si) (see Table 1).The current consumption decreased and reached normal value (0.3 mA). Standard Deviation has shown no major changes up to 15 krad(Si), oscillating between 4 and 5 dB.

5.1.3 Signal to Noise and Distortion Ratio

<u>Device # 1, # 4, # 5</u>

Almost no irradiation degradation in the Signal to Noise and Distortion ratio in the devices # 1 and # 5 could be observed. As previously mentioned, only an increase in the supply currents was observed. Prior to failure, device # 1 had a S/N+D value of 79 dB and device # 5 of 84 dB. The deviations of device # 5 below 10 krad(Si) are caused by the crystal oscillator which was not shielded for this part during the irradiation. Device # 5 stabilised his S/N+D ratio after 10 krad. Low dose rate testing of the device # 4 caused a slow increase in current consumption, but no major changes in ADC characteristics. It operated up to 27 krad(Si).
However, a small degradation in S/N+D ratio above approximately 25 krad(Si) can be observed (see Figure 9).

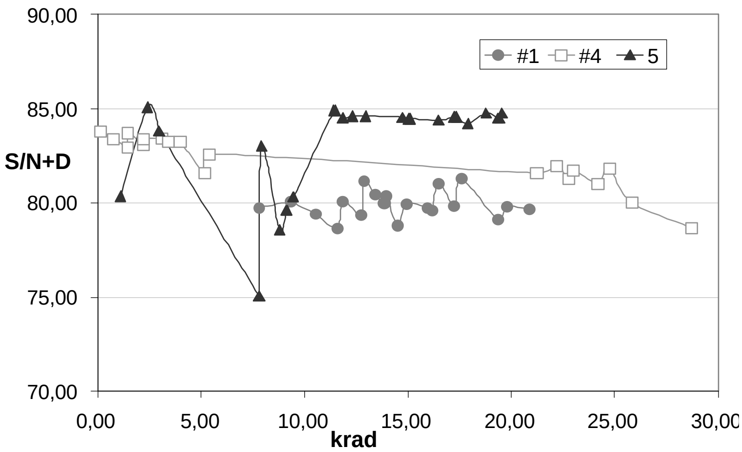


Figure 9: S/N+D measurements versus total dose, devices #1, #4 and #5

<u>Devices # 6, # 7 and # 8</u>

Irradiation of devices # 7 and # 8 was performed over night and therefore measurements were taken at the beginning of irradiation, between 9 and 17 krad(Si) and between 27 and 31 krad(Si). Prior to failure, the tested devices had an S/N+D value around 80 dB and 84 dB, respectively. Degradation in S/N+D was observed after approximately 27 krad(Si) for both devices, and its value decreased to 66 dB for device # 7 and to 30 dB for device # 8. After power up reset and a calibration process were carried out at total dose of approximately 28 krad(Si) and 29 krad(Si), the S/N+D value was improved, but decreased again as the accumulated dose increased.
Device # 6 was irradiated up to 15 krad(Si) of total dose. It showed similar performance as devices # 7 and # 8.

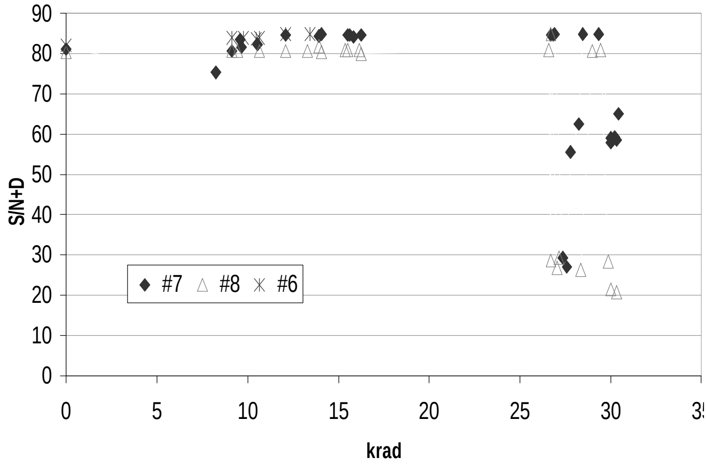
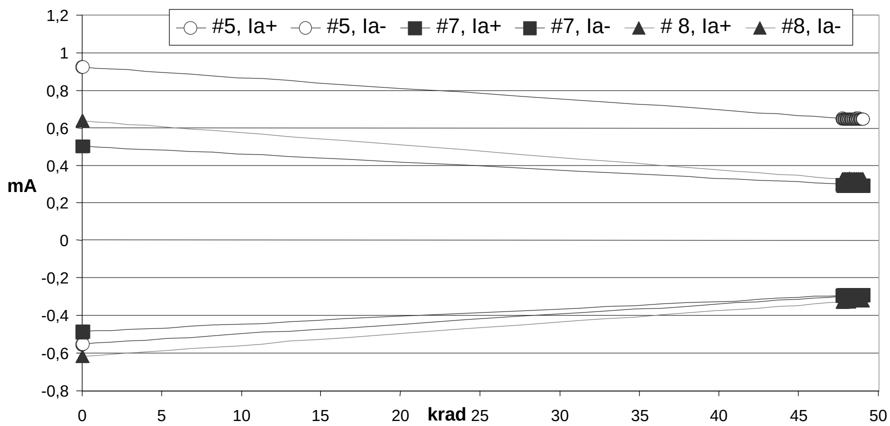


Figure 10: S/N+D measurements versus to total dose, devices # 6, # 7 and # 8

5.2 Unbiased Testing

After being irradiated under bias, devices # 5, # 7 and # 8 were irradiated unbiased with a dose rate of 12.14 rad(Si)/min to a total dose of 47 krad(Si). Before and after unbiased irradiation the ADCs were tested to Standard Deviation and Signal to Noise and Distortion ratio.



After the total dose of 47 krad(Si) a power up reset and calibration process was performed. Electrical measurements were taken from 47 to 49 krad(Si). The supply currents were also measured.

Figure 11: Icc before and after unbiased radiation, devices # 5, # 7 and # 8

Due to the fact that the irradiation was made over a weekend and therefore limiting access to the testing facility, no intermediate measurements were possible.
All devices under test decreased their power consumption during irradiation. There were small increases in Standard Deviation, but no changes in the S/N+D ratio. This means that the

linearity of the devices was slightly affected during unbiased testing, but no increase in the ratio of the input signal to the sum of the individual noise was noticed.

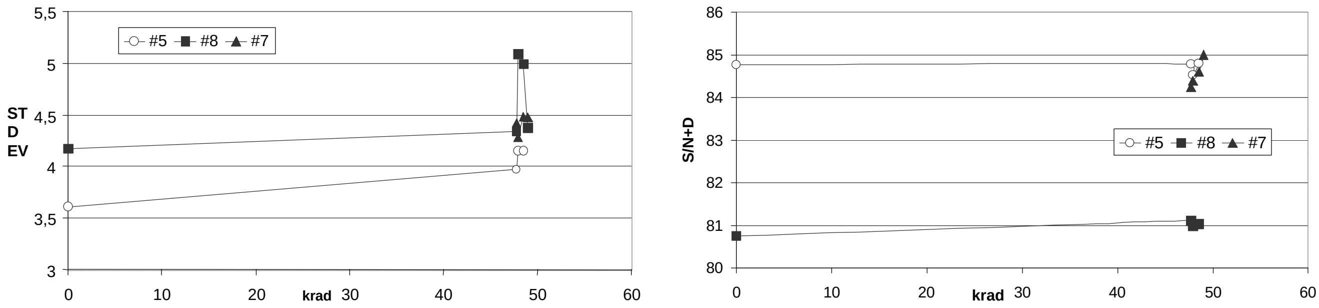


Figure 12: Standard deviation and Signal to Noise and Distortion ratio

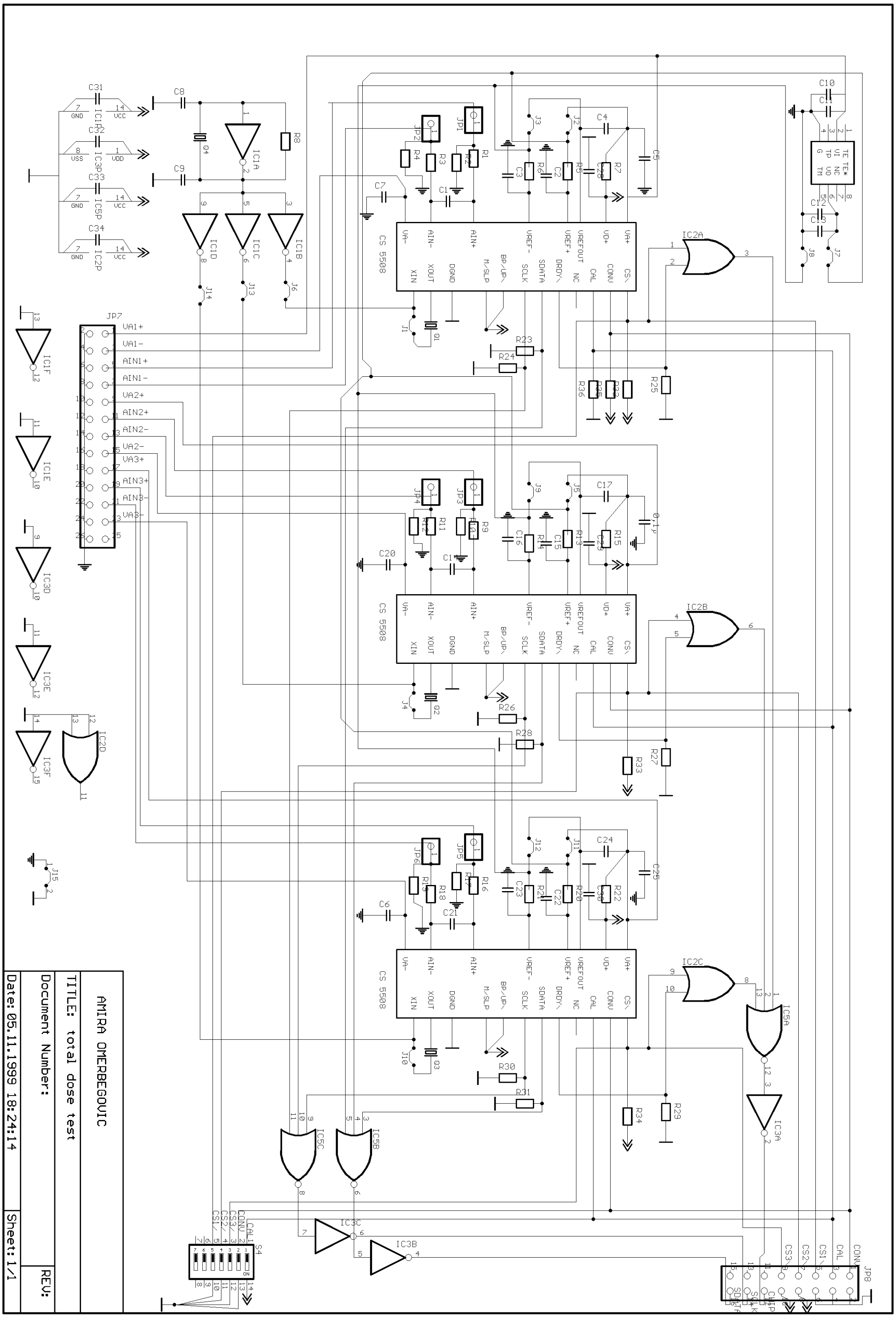
before and after unbiased irradiation of 47 krad(Si), devices # 5, # 7 and # 8

6 Conclusion

Six Crystal CS 5508 analogue-to-digital Converter devices, all from the same lot, were total dose tested using Co-60 facilities at ESTEC, Noordwijk. Devices were irradiated at different dose rates and their performances compared.
To evaluate dynamically and statically parameters of the ADCs, Standard Deviation and Signal to Noise and Distortion ratios were monitored. The power consumption was measured as well. It was found that power consumption of the devices increased faster when the ADCs were irradiated at higher dose rate than when they were irradiated at low dose rates.
Biased and irradiated with higher dose rate ADCs, CS 5508 withstand approximately 20 krad(Si) of total dose. However, a large increase in current consumption was measured, almost 0,09 mA/krad(Si) of the initial value. But devices showed no degradation in their performances and surprisingly just stopped to operate after approximately 20 krad(Si).
Biased and irradiated with lower dose rate, CS 5508 withstand approximately 30 krad(Si) of total dose. Current consumption increased for about 0.02 mA every krad(Si), up to 22 krad(Si) and then remained rather stable.
Both statically and dynamically biased devices performed satisfactory up to 27 krad(Si). After 27 krad(Si) the degradation in ADCs characteristics was observed. After approximately 30 krad(Si) CS 5508 stopped operating.
Unbiased testing performed to 47 krad(Si) revealed decreasing power consumption with no other changes in ADCs performances.
Devices showed a good tendency to recover. Already after 31 hours at room temperature and 20 hours at 100°C the power consumption decreased and functionality of the devices regained. Two weeks later, additional measurements showed fully recovered devices.

Appendix 1

Printed Circuit Board for the TID Test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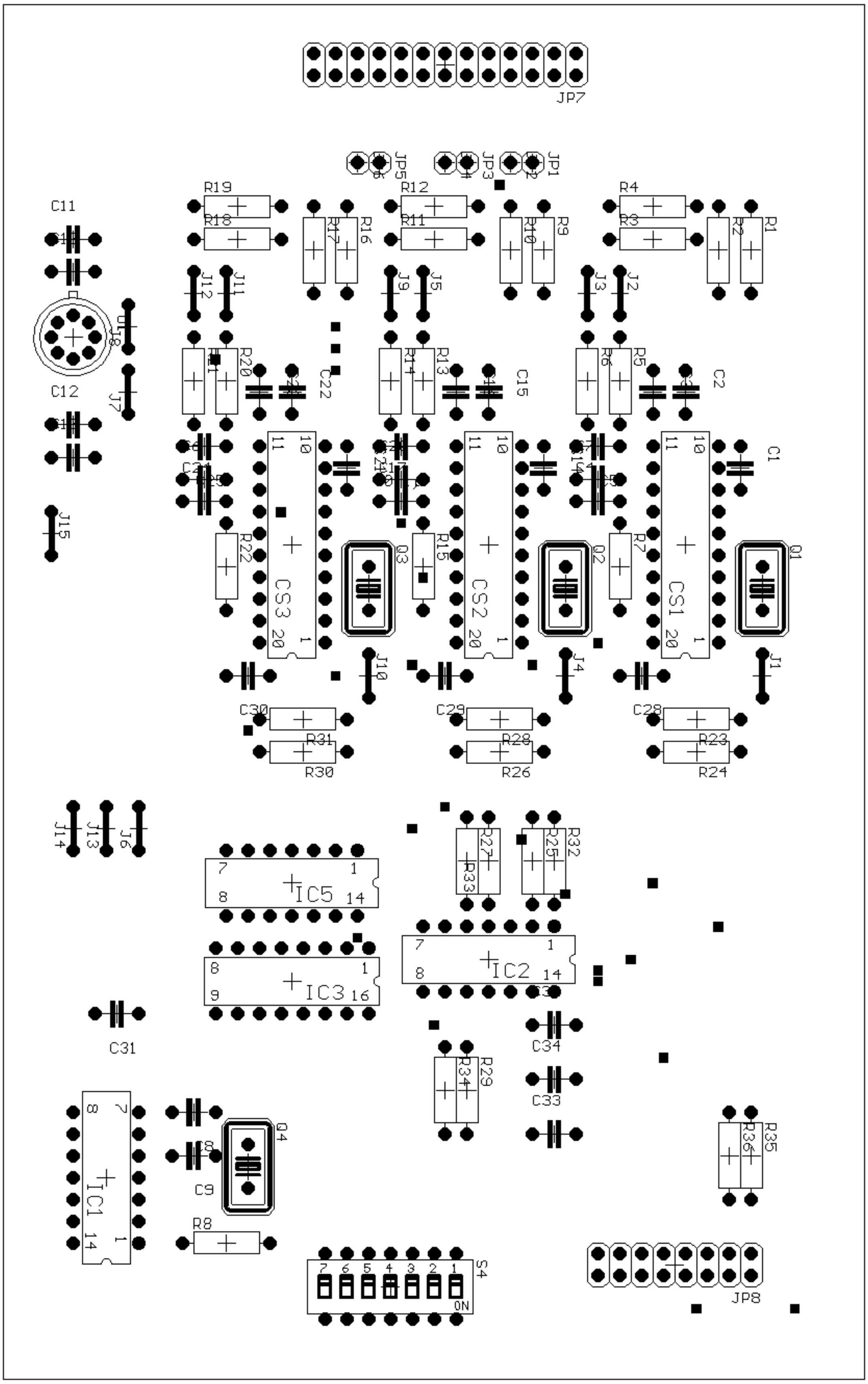
Schematic



Component Placements

Appendix 2

Standard Deviation Figures

Dose krad (Si)	1.43	3.85	3.94	5.60	6.59	6.92	7.14	8.68	11.21	13.08	14.17	16.37	18.35	19.01	19.23
StDev	12.93	10.90	11.30	12.71	11.59	12.36	10.87	13.68	14.35	11.08	12.53	12.78	10.05	12.69	13.59

Table 2: StDev Device # 1

Dose krad (Si)	0.63	0.64	0.66	3.49	21.48	21.89	25.38	25.81	27.00
StDev	7.74	7.9	7.55	7.1	9.76	9.42	10.68	8.68	10.68

Table 3: StDev Device # 4

Dose krad (Si)	2.53	2.59	6.37	6.45	8.13	8.55	10.55	10.64	12.42	18.35	18.90	19.44
StDev	14.97	13.63	10.97	10.45	10.5	14.6	13.66	13.15	4.17	4.02	4.13	4.15

Table 4: StDev Device # 5

Dose krad (Si)	0.00	10.96	10.45	12.10	14.40	14.53	16.44	28.18	28.20	28.68	29.72	30.05
StDev	16.23	15.37	16.16	12.47	4.09	4.10	4.10	349.4	389	4.04	4.00	384

Table 5: StDev Device # 7

Dose Krad (Si)	0.00	10.96	10.45	10.71	12.10	13.38	15.53	16.14	16.57	16.82	28.00	28.05	28.20	28.68	29.72
StDev dB	5.24	4.79	5.73	4.80	4.80	4.93	4.71	4.69	4.49	4.71	158.8	771.5	120.2	4.95	5.11
Dose Krad (Si)	30.06	30.12	30.26												
StDev	444.7	159.1	408.1												

Table 6: StDev Device # 8

Appendix 3
Signal to Noise and Distortion Value Figures

Dose krad (Si)	7.8	9.34	10.55	11.56	12.75	13.41	14.50	15.93	16.15	16.48	17.25	17.58	19.34	19.78	20.88
S/N+D (dB)	79.75	80.09	79.40	78.63	79.36	80.45	78.81	76.76	79.63	81.04	79.85	81.28	79.14	79.79	79.66

Table 7: S/N+D Device # 1

Dose krad (Si)	0.11	0.77	1.43	2.20	3.41	3.96	5.16	21.21	22.20	22.75	22.96	24.17	24.72	25.82	28.68
S/N+D (dB)	83.82	83.40	83.72	83.39	83.27	83.26	81.59	81.58	81.96	81.30	81.75	81.04	81.84	80.02	70.70

Table 8: S/N+D Device # 4

Dose krad (Si)	1.10	2.97	7.82	8.79	9.14	9.47	11.48	12.97	14.72	15.05	16.48	17.36	19.34	19.43	19.56
S/N+D (dB)	80.35	83.83	75.07	78.56	79.61	80.32	84.90	84.61	84.55	84.48	84.39	84.57	84.49	84.49	84.78

Table 9: S/N+D Device # 5

Dose krad (Si)	0.00	8.24	9.56	10.55	13.95	15.49	16.26	26.70	26.92	27.36	27.58	27.80	28.24	28.46	29.34
S/N+D (dB)	81.08	75.43	83.45	82.36	84.46	84.54	84.72	84.66	84.94	29.37	26.88	55.67	62.62	84.85	84.79
Dose krad (Si)	30.00	30.05	30.11	30.22	30.33	30.43									
S/N+D (dB)	57.92	59.17	28.52	59.31	58.52	65.03									

Table 10: S/N+D Device # 7

Dose Krad (Si)	0.00	9.12	9.45	10.66	12.09	13.95	15.49	16.26	26.59	26.70	26.70	27.03	27.14	28.35	28.99
S/N+D (dB)	80.43	80.78	80.71	80.70	80.59	81.87	81.03	80.02	80.90	28.68	84.85	26.81	29.27	26.17	80.76
Dose Krad (Si)	29.43	29.89	30.00	30.33											
S/N+D (dB)	80.82	28.45	21.29	20.63											

Table 11: S/N+D Device # 8

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