# CO-60 Total Dose Test of 14- and 16-Bit ADCs

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## Abstract

Irradiation tests using Co-60 to a total dose of 50krad(Si) on unbiased and biased 14- and 16-Bit ADCs have been carried out. Power consumption, Reference Voltage stability, Temperature, Signal-to-Noise-and-Distortion ratio (SINAD) and the Standard Deviation of a sampled DC were monitored. The devices evaluated were the ADS-937, AD9243 and LTC1419.

## 1 Introduction

A number of total dose tests were carried out in support of the ROSETTA project. For the CCD camera OSIRIS (Optical, Spectroscopic and Infrared Imaging System) high speed 14- or 16-bit analog-to-digital converters will be used. There are three ADCs that could fulfill the OSIRIS requirements concerning accuracy and sample rate, the ADS-937 from DATEL, the AD9243 from Analog Devices and the LTC1419 from Linear Technology, see Table 1. Unfortunately no or only marginal information on these converter's behavior in a radiation environment are available. So as a first step these ADC types were total dose tested using the Co-60 source at ESTEC, Noordwijk.

## 2 Test Configuration

To get a complete overview of possible changes due to irradiation the measurements comprised static and dynamic parameters. The devices under test were separated into two groups and irradiated unbiased as well as biased. To be sure to avoid irradiating the glue logic around the ADC special test boards with ADC extenders have been developed.

Monitored static parameters were the supply currents and the reference voltage and in addition to that the ambient temperature.

To get fast reliable results of ADC accuracy and parameter deviations the following measurements have been accomplished:

a) Sampling a constant DC voltage with the OSIRIS sample rate (about 1.6$\mu$s) for 1,000,000 and 32768 times. Calculating the normal deviation of the sampled data shows changes of the device's noise and could help to discover linearity degradation.
b) Sampling a pure sine wave over the (almost) full input voltage range gives data on linearity - using the Fourier transformed data - and input range

In order to get results accurate enough to be able to evaluate the ADC data a spectral pure sine wave with additional filtering had to be used. A number of 32768 (2^15) sampling points has been selected to get the results fast enough. We used the sampled data to calculate the signal to noise and distortion value (SINAD) and consequently the effective number of bits (ENOB) for a sine wave as input signal.

| Type<br>Manufacturer | Technology | Performance/<br>Operation |
|---|---|---|
| ADS-937MM<br>DATEL Inc. | Hybrid | 16 Bits<br>1 Msamples/s<br>1.25 W power<br>Two pass ADC |
| AD9243AS<br>Analog Devices Inc. | CMOS, monolith | 14 Bits<br>3 Msamples/s<br>145 mW power<br>4-stage pipeline,<br>4 flash ADCs, 3 switched capacitor DACs |
| LTC1419AISW<br>Linear Technology Corporation | CMOS, monolith | 14 Bits<br>800 ksamples/s<br>150 mW power<br>successive approximation converter |

**Table 1** Types of analog-to-digital converters (ADCs) that have been tested

The test setup as shown in Figure 1 is based on IEEE controlled equipment. A PC runs the test sequences programmed under LabView and controls the voltage sources as well as the measurement devices. The monitored test results are displayed on the screen, saved in a log file and can be printed out on a PC printer via LAN.

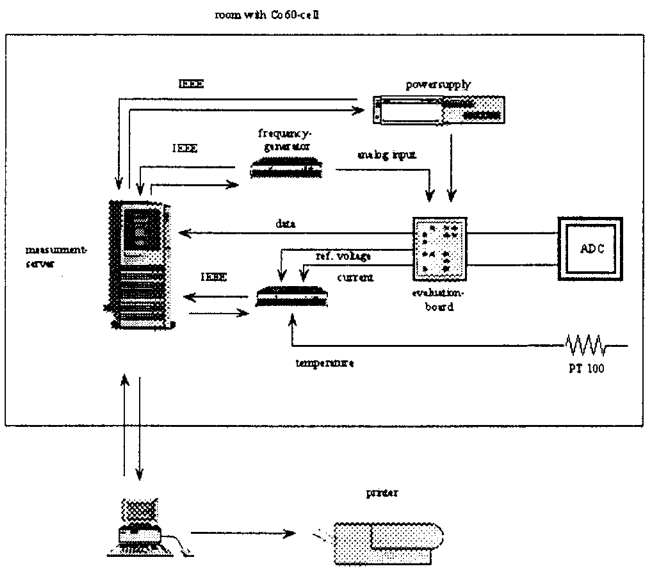


**Figure 1 Test Equipment - PC Controlled via IEEE Bus**

# 3 Results

## 3.1 *ADS-937MM DATEL*

### 3.1.1 unbiased testing - 3 parts (# _1, _2, _3)

Unbiased Co-60 testing of 3 parts was carried out at a dose rate of 12 krad(Si)/h with electrical measurements taken at 0, 5, 10, 15, 20 and 30 krad(Si). The ADS-937 has 4 supply voltages: +5V, -5V, +15V and -15V. While the ±15V currents remain constant the +5V current decreases for about 1% and the -5V for about 3%, see Figure 2.

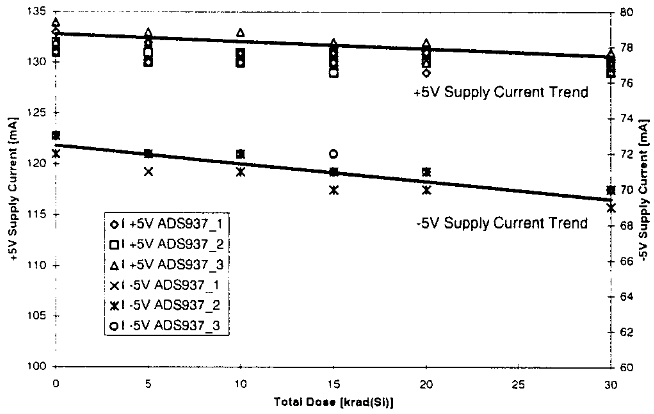


**Figure 2 ADS-937 unbiased - Power Supply Currents**

Part 2 had a strong drop in the SINAD value at 15krad(Si). The reason for this behavior was found in bit flips of bit 2^7. At 30krad(Si) all devices showed this error at different bit values, see Figure 3.

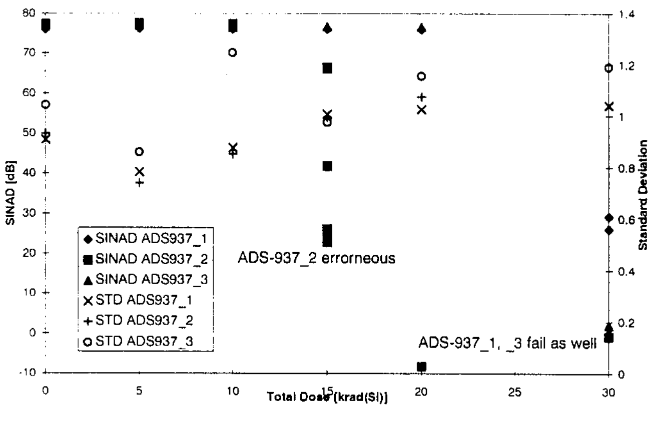


**Figure 3 ADS-937 unbiased - SINAD and Standard Deviation**

The degradation in functionality couldn't be observed in the Standard Deviation value because the error depends on the converted analog signal. There was also no influence in power consumption. After 2 days annealing at room temperature the bit flip errors disappeared.

The reference voltages (Figure 4) of the three devices tested didn't change within the measurement accuracy of 1 mV and showed no changes when the parts became defective.

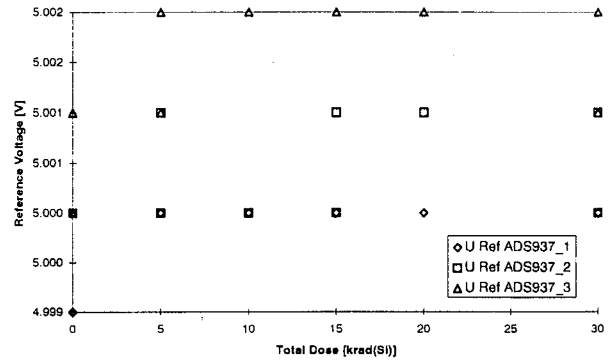


**Figure 4 ADS-937 unbiased - Reference Voltage**

### 3.1.2 biased testing - 1 part (# _5)

Due to time constraints only one sample of ADS-937MM has been irradiated during operation conditions and using a dose rate of 10 krad(Si)/h. Concerning the power consumption we got a reduction as we had observed during the unbiased test (Figure 5).

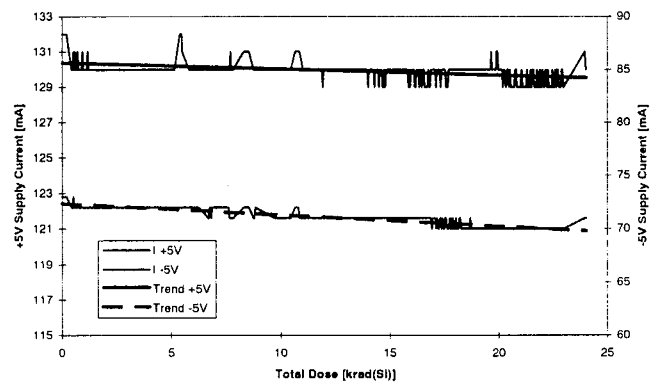


**Figure 5 ADS-937 biased - Power Supply Currents**

Surprisingly during Standard Deviation measurement at a total dose of 20.7 krad(Si) the device didn't change the output value any more and the Standard Deviation (Figure 6) therefor was zero.

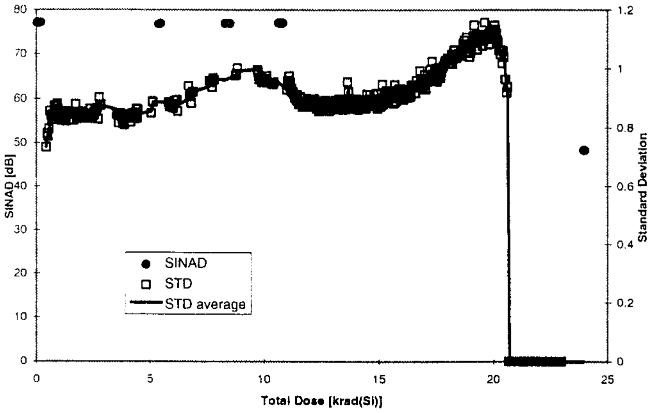


**Figure 6 ADS-937 biased - SINAD and Standard Deviation**

Measurements using the sinus signal showed several drop-outs over the analog input range. This malfunction remained irreversible also after two weeks of annealing under room temperature. Prior to the failure the tested part had a constant SINAD value of about 77dB after that it fell to values below of 50dB. The irradiation was finished at a total dose of 24krad(Si).

The Reference Voltage (Figure 7) increased about 1mV during the irradiation but didn't depend on or cause the observed error.

The ADS-937 has a power consumption of about 1.1W therefor the package temperature has also been plotted.

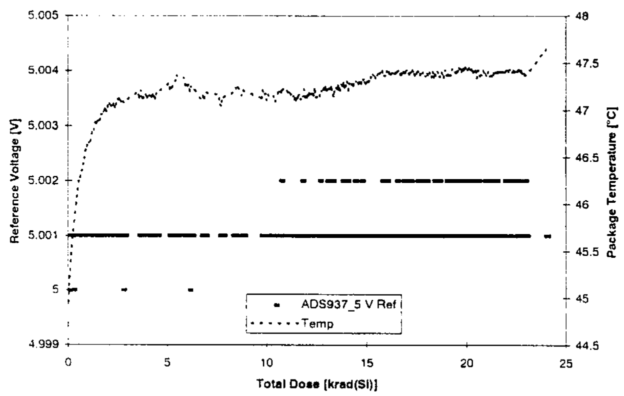


**Figure 7 ADS-937 biased - Reference Voltage and Temperature**

## 3.2 AD9243AS Analog Devices

### 3.2.1 unbiased testing - 3 parts (# _1, _2, _3)

Unbiased Co-60 testing of 3 parts was carried out at a dose rate of 12 krad(Si)/h with electrical measurements taken at 0, 5, 10, 15, 20, 30, 40 and 50 krad(Si). The AD9243 has only +5V supply voltages. In contrast to the hybrid ADC where the irradiation at 25 respectively at 30 krad(Si) could be finished the unbiased monolithic AD9243AS showed almost no radiation degrading up to 50 krad(Si). The supply currents (Figure 8) remained invariable as well as the SINAD value and the Standard Deviation (Figure 9).

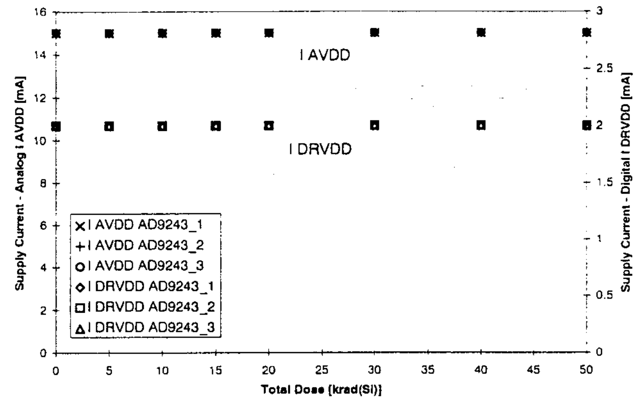


**Figure 8 AD9243 unbiased - Power Supply Currents**

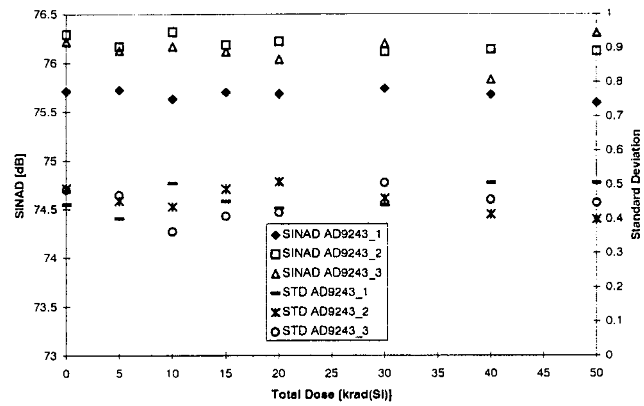


**Figure 9 AD9243 unbiased - SINAD and Standard Deviation**

A very small decrease of less than 1mV has been measured at the Reference Voltage output (Figure 10).

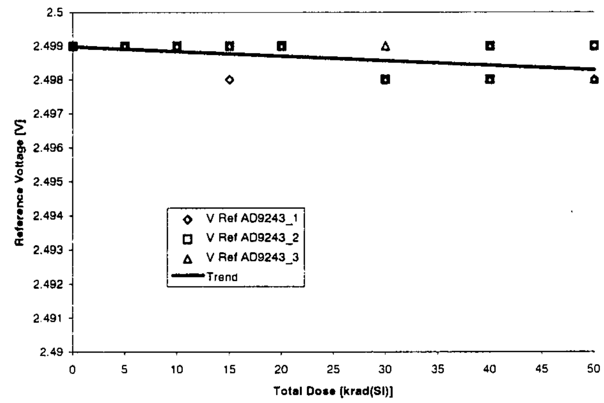


**Figure 10 AD9243 unbiased - Reference Voltage**

### 3.2.2 biased testing - 2 parts (# _0,_4)

Part # _0 was tested at a dose rate of 1.48 krad(Si)/h to a total dose of 21 krad(Si). Part # _4 was irradiated with a dose rate of 1.87 krad(Si)/h to a total dose of 29 krad(Si) and then with

10.3 krad(Si)/h to a total dose of 52.3 krad(Si). Compared to the unbiased irradiated AD9243 the two biased parts showed a different behavior starting at about 16krad(Si). First the digital and later also the analog supply current began to rise (Figure 11).

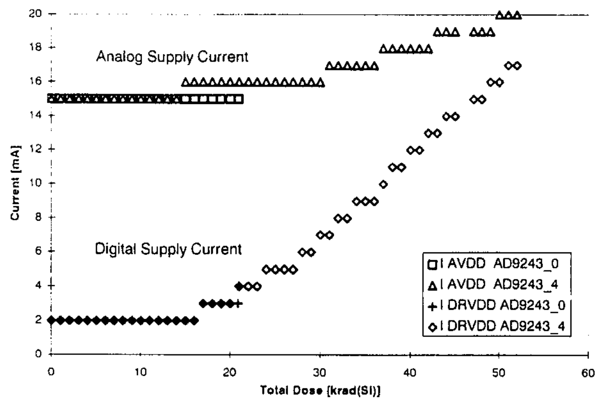


**Figure 11 AD9243 biased - Power Supply Currents**

The digital supply current having an initial value of 2mA increased from about 16krad(Si) with 2mA every 5 krad(Si). Part AD9243_0 was irradiated to 21 krad(Si) without performance degradation. Part AD9243_4 irradiation was performed during night to a total dose of about 29krad(Si). The small SINAD reduction was caused by the frequency drift of the sinus generator and had been corrected at 29krad(Si) (

**Figure 12**).

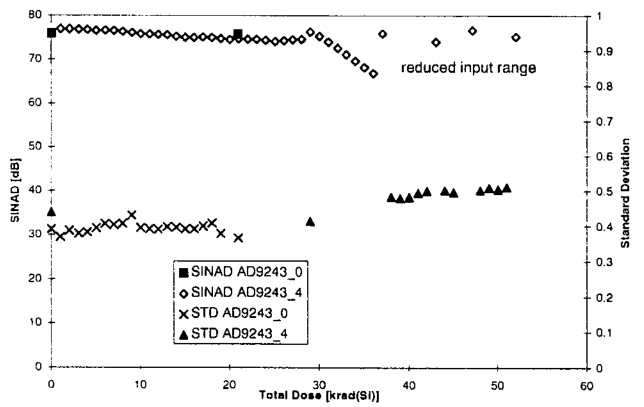


**Figure 12 AD9243 biased - SINAD and Standard Deviation**

Then the irradiation was continued and the SINAD value began to fall rapidly. Investigating this problem a strong non-linearity at the lower end of the input range was discovered. From the full range 0 to 16383 only the upper part starting at about 1970 remained usable and there an almost original SINAD value could be obtained. This behavior remained unchanged until the end of irradiation at 52.3krad(Si).
The reference voltage showed only a very low drift of less than 1mV over the full irradiation period (Figure 13).

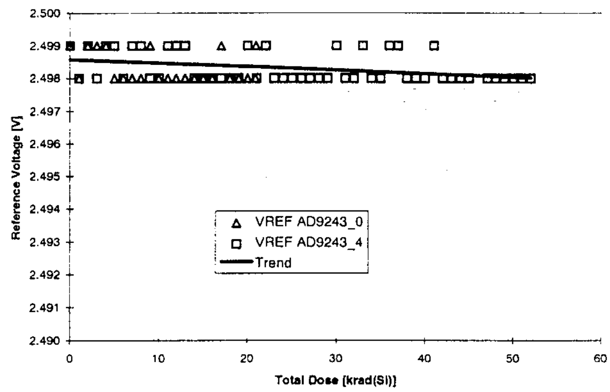


**Figure 13 AD9243 biased - Reference Voltage**

## *3.3 LTC1419AISW Linear Technology*

### 3.3.1 unbiased testing - 3 parts (# _1,_2,_3)

Unbiased Co-60 testing of 3 parts was carried out at a dose rate of 12 krad(Si)/h with electrical measurements taken at 0, 5, 10, 15, 20, 30, 40 and 50 krad(Si). The LTC1419 needs +5V and -5V as supply voltages. Analog and digital supply on the test board are connected. All devices under test decreased their power consumption during irradiation. The current IDD (+5V) was reduced by 0.3%/krad(Si) while ISS dropped 0.4%/krad(Si) (Figure 14).

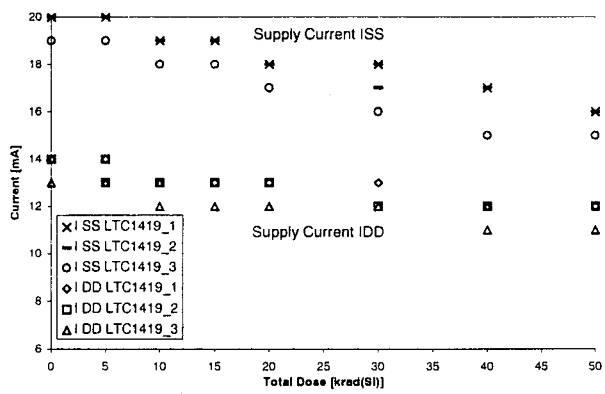


**Figure 14 LTC1419 unbiased - Power Supply Current**

Figure 15 shows only minor changes in the SINAD value below a total dose of 40krad(Si). This means that linearity as well as the input range keep almost their original values. Only sample 3 had a small SINAD reduction above 40krad(Si).

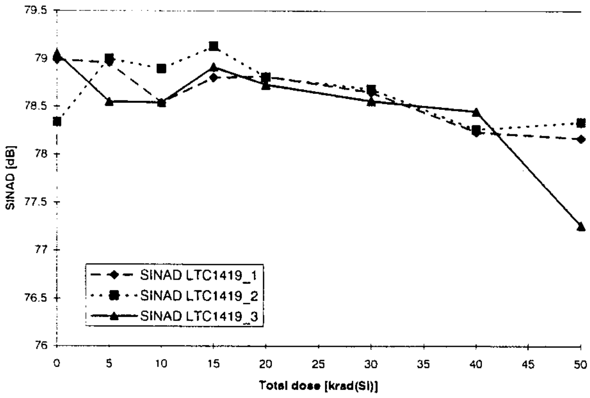


**Figure 15 LTC1419 unbiased - SINAD**

The LTC1419 has the lowest Standard Deviation of the three types. At this small deviation below of 0.5 the mean value of the Gaussian Distribution becomes important. If this is an integer number the deviation will have a minimum. A small drift makes the deviation worse and a mean value of 0.5 digits next to an integer gives a Standard Deviation that is greater than 0.5. Unfortunately due to time constraints we could not center the mean value. Therefore only Standard Deviations above of 0.5 should be considered. All samples show a rising Standard Deviation (Figure 16) but the measured values are well below one.

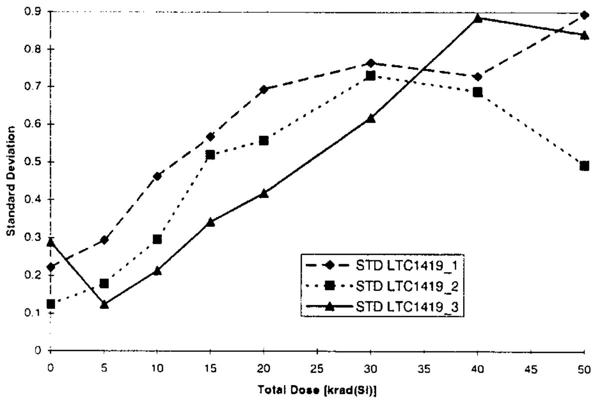


**Figure 16 LTC1419 unbiased - Standard Deviation**

During Standard Deviation measurement the histogram of the sampled data was also displayed. Prior to irradiating histograms like Figure 17 could be observed.

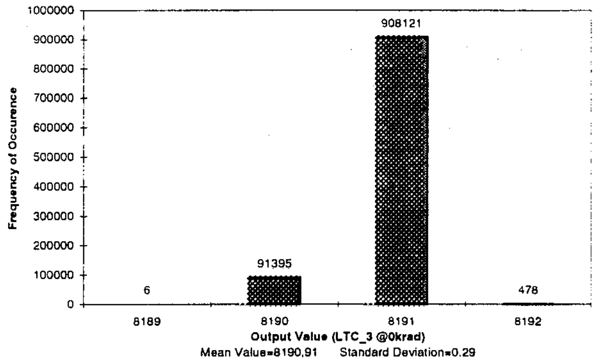


**Figure 17 LTC1419_3 Histogram prior to irradiation**

After irradiation sometimes the histogram showed double peaks (Figure 18) instead of a normal Gaussian distribution.

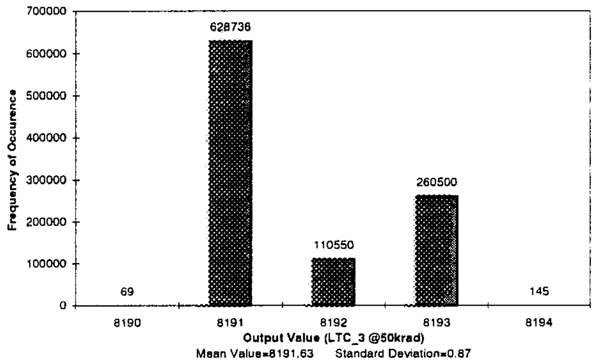


**Figure 18 LTC1419_3 after irradiating to 50krad(Si)**

This is caused by a deterioration of the integral linearity at some transitions to the next bit scale. The deviation is still under investigation. Until now we couldn't find Standard Deviations greater than 0.9 digits. It seems that the linearity after irradiating to 50krad(Si) is still within the data sheet limits.

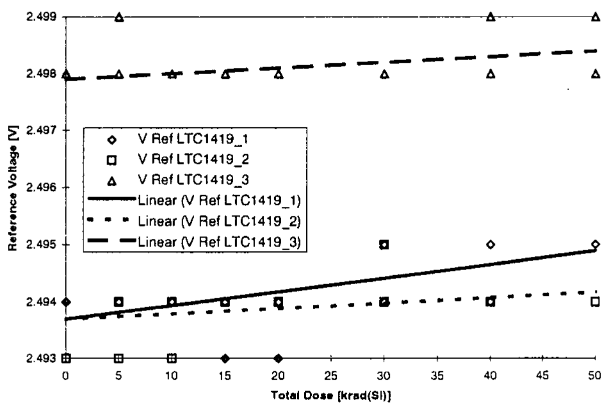


**Figure 19 LTC1419 unbiased - Reference Voltage**

As it could be expected from the excellent and constant SINAD value the reference voltage (Figure 19) remained almost unchanged and showed only a small increase of less than 1mV.

## 3.3.2 biased testing - 3 parts (# _4,_5,_6)

Part _4 has been irradiated with a dose rate of 10.8krad(Si)/h to a total dose of 60krad(Si). Part _5 got a total dose of 51.2krad(Si) at a dose rate of 16.4krad(Si)/h. Part _6 was irradiated during night with a dose rate of 3.8krad(Si)/h monitoring the power, the Reference Voltage and SINAD to a total dose of 56.7krad(Si).
The decrease of the power consumption perceived during the unbiased tests could also be seen in the biased tests.
IDD was reduced by 0.3%/krad(Si) and ISS by 0.4%/krad(Si) (Figure 20).

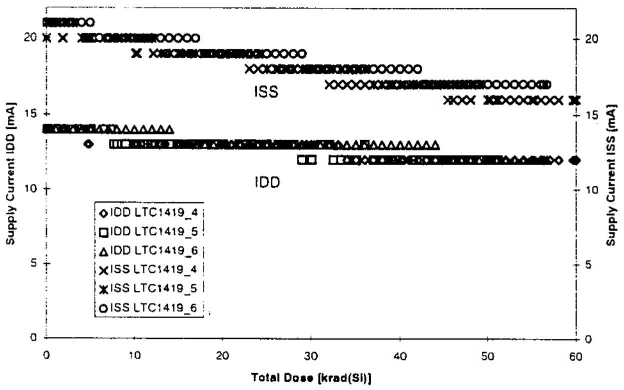


**Figure 20 LTC1419 biased - Power Supply Current**

The SINAD values (Figure 21) showed no major changes up to 30krad(Si). From 30 to 55-60krad(Si) a small decrease of 0.5dB can be stated.

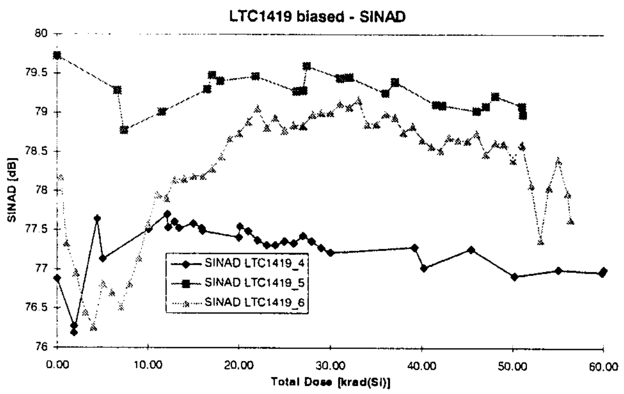


**Figure 21 LTC1419 biased - SINAD**

The deviations of sample _6 below of 20krad(Si) are caused by the drift of the sinus generator during the overnight measurement.
During the Standard Deviation measurements the very low original values did show only a little trend to increase (Figure 22). Apart from this the post irradiation tests showed the same results as for the unbiased samples. Another investigations will be proceeded.

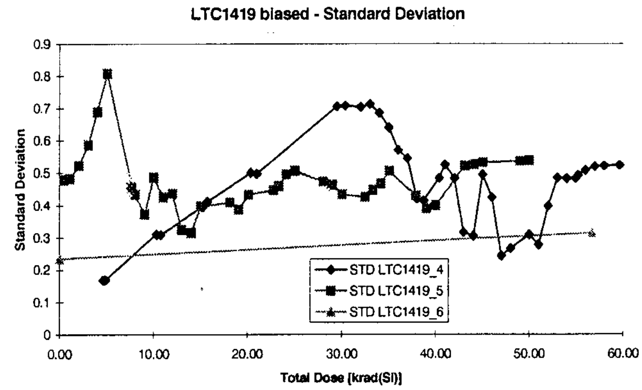


**Figure 22 LTC1419 biased - Standard Deviation**

The Reference Voltage (Figure 23) of part _5 and _6 has no or only minor changes while part _4 shows an increase of 2 to 3mV. This part had also the lowest SINAD value of all measured LTC1419 parts.

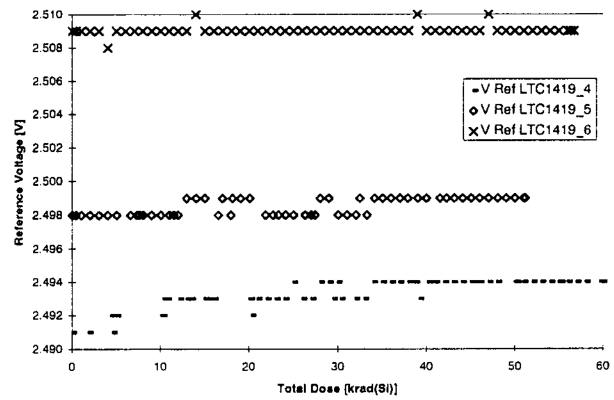


**Figure 23 LTC1419 biased - Reference Voltage**

# 4 Conclusion

Three types of ADCs have been irradiated, first unbiased then biased with Co-60. The measured parameters were:

- Supply currents
- Reference Voltage
- Temperature
- SINAD (signal-to-noise-and-distortion ratio) at full range, 32768 samples of a 10kHz sinus signal, FFT
- Standard Deviation: 32768 samples of a constant input signal

The unbiased DATEL hybrid ADS-937 showed bit errors that became visible between 15 and 30krad(Si) but disappeared

after 2 days of annealing. Biased irradiating produced a permanent error at about 20krad.
Analog Devices AD9243 withstand unbiased 50krad(Si) with no changes. If biased a strong power increase started at about 16krad and an 12% input range shrinking at the lower end at about 30krad(Si) has been observed.
The monolithic successive approximation converters LTC1419 survived unbiased 50krad(Si) with no remarkable changes in the signal-to-noise-and-distortion ratio (SINAD). The biased irradiated devices showed from 30 to 50krad(Si) a very small SINAD loss. Independent of biasing the original excellent low Standard Deviation became larger during irradiation but remained below of 1. The reason for this is still under investigation, but we assume a slight degradation of the linearity at the transitions between the bit ranges (from $2^{n} - 1$ to $2^{n}$).

# 5 Acknowledgments

The authors thank Mr. Andreas Fischer (MPAe), who assembled the test control setup and made the LabView programming as well as Mr. Helmut Schüddekopf (MPAe) for his hardware contributions and the test preparations.