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Low Rate TID Test of DS1820 class 1-wire temperature transducers

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1 INTRODUCTION

Scope of this document is to describe the activity of low dose rate irradiation testing, using a Cobalt 60 source, of two types of digital temperature transducers with possible future use for space applications.

Related documents

- Test procedure for ELDRS One-Wire temperature transducers

Test personnel

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Table 1 : Test personnel

2 SCOPE

A meaningful total dose test cycle was performed (at ESTEC, Noordwijk) to obtain information on the radiation hardness of the COTS Maxim-Dallas digital temperature transducers DS18B20 / DS18S20. The test initially planned was targeting a total dose of 25 Krad. The test was then extended until destruction of the transducers. The results of this test are the basis for further evaluation for the use of these transducers and of the One-Wire communication protocol inside spacecraft.
The devices under test were manufactured by Maxim-Dallas semiconductors. The sensors were designed for the demands of terrestrial use: temperature control in buildings, automotive industry etc.

2.1 Devices information

Component designation	Digital thermometers
Sample size	3.8 x 3.8 mm
Number of samples	16 (7 DS18S20, 9 DS18B20)
Project	Preliminary assessment of the suitability of One-Wire temperature transducers for space related use
Family	Digital transducers
Package	3-Pin TO-92 Packages (Plastic)
Manufacturer Name	Maxim-Dallas Semiconductors

Manufacturer Address	Maxim Integrated products, Inc. 120, San Gabriel Drive Sunnyvale, CA 94086 Tel : 408-737-7600 Fax: 408-737-7194
Test House Name	Radiation effects and component Analysis Techniques section
Test House Address	ESA/ESTEC Keplerlaan 1 2201 AZ Noordwijk The Netherlands
Originator Name	On- Board computer and data systems section, ESA/ESTEC, The Netherlands
Facility	ESTEC Co-60 ECF facility
Source	Co-60 Present activity (January 2004) : 1460 Ci
Irradiation	Simple
Dose Rate	2.5862 Rad/min
Irradiation conditions	• Biased and unbiased in-situ test • VDD : +5.3 V • Temperature : room temperature (except next to the hot devices where temp : 40 to 50 degrees Celsius)

Table 2 : Devices information

3 TEST CONFIGURATION

A schematic of the test configuration is shown below. It consists of the test board for the devices under test (9 DS18B20 transducers and 7 DS18S20 transducers), a power supply and the control computer, which are located outside of the irradiation chamber.
On the test board, the transducers as well as two resistors working as heaters are present to increase the temperature locally.
All cables which are connected to the test board are at least 4 m long. The supply voltages are:

- Supply voltage for the transducers : VDD = 5.4 V
- Current in the resistors (used as heaters) : IDR = 1.710 A

All currents of the above supply voltages were monitored.

During the whole Low Dose total ionizing irradiation test of the transducers, a custom test software was running on the control computer to monitor the temperature read by the transducers and the CRC errors occurring. All temperatures and CRC-errors were logged in specific files and stored on the hard disk of the computer.

The configuration of the test is detailed in figure 1.

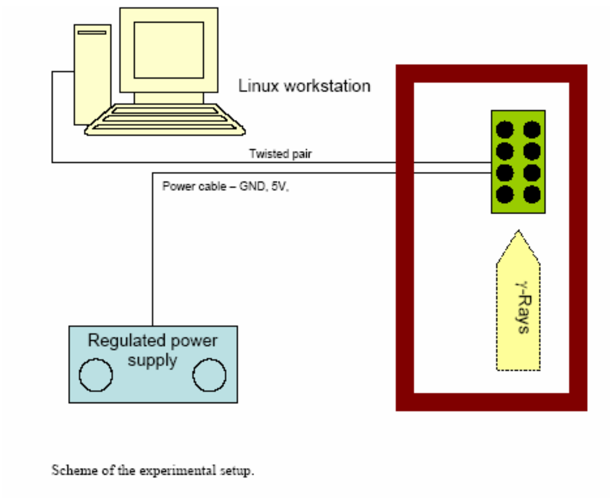

Figure 1 : test configuration

Position of the sensors on the test board is represented in figure 2:

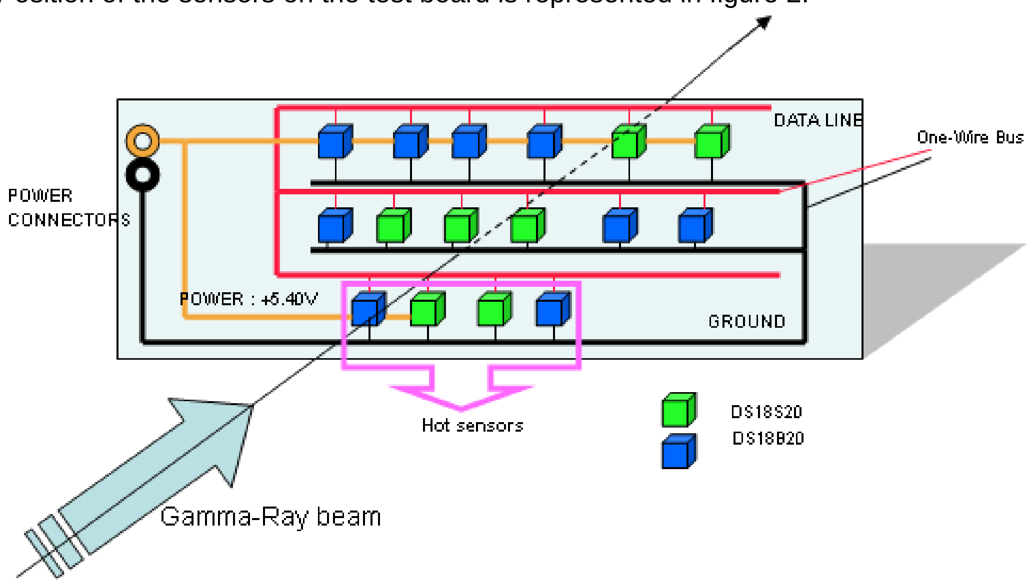

Figure 2 : detail of the test board

The sensors were tested under different conditions: some of them were biased, some unbiased, some were operating in the area where the temperature was increased (see Figure 2). The different test conditions for each sensor are detailed in the table 3:

transducer	type	Bias	resolution	Hot sensors
S0	S	Yes	9 bits	Ambient
S1	S	No	9 bits	Hot
S2	S	Yes	9 bits	Hot

S3	S	No	9 bits	Ambient
S4	S	No	9 bits	Ambient
S5	S	Yes	9 bits	Ambient
S6	S	No	9 bits	Ambient
S7	B	Yes	10 bits	Ambient
S8	B	Yes	10 bits	Ambient
S9	B	Yes	9 bits	Ambient
S10	B	No	12 bits	Ambient
S11	B	No	9 bits	Hot
S12	B	Yes	9 bits	Hot
S13	B	No	12 bits	Ambient
S14	B	No	10 bits	Ambient
S15	B	Yes	12 bits	Ambient

Table 3 : Test conditions for each sensor

The data presented in the results part of this note are only a part of all performed measurements, but the components behaved in a very similar way during irradiation.

Total duration of the test	456 hours
Total number of temperature readings	Around 26400 (1 read each 4 minutes for each sensor)

Table 4: data about the test

4 TEST RESULTS

4.1 Experimental results

Action performed	Irradiation of device until a total dose of 25Krad
Device name	DS18S20, DS18B20
Device condition	Biased and unbiased, ambient temperature
Parameters to be examined	***coherence of temperature read by the sensors operating at ambient temperature***
Radiation level	25 Krad
Dose rate	2.5862 Rad/min

The coherence between the temperature values read by the devices under test at ambient temperature has been monitored: in Figure 3, the evolution of the temperature read by the different DS18S20 and DS18B20 is shown to be similar; until 25 Krad, the sensors are reading coherent temperature which is a first proof of optimal behavior.

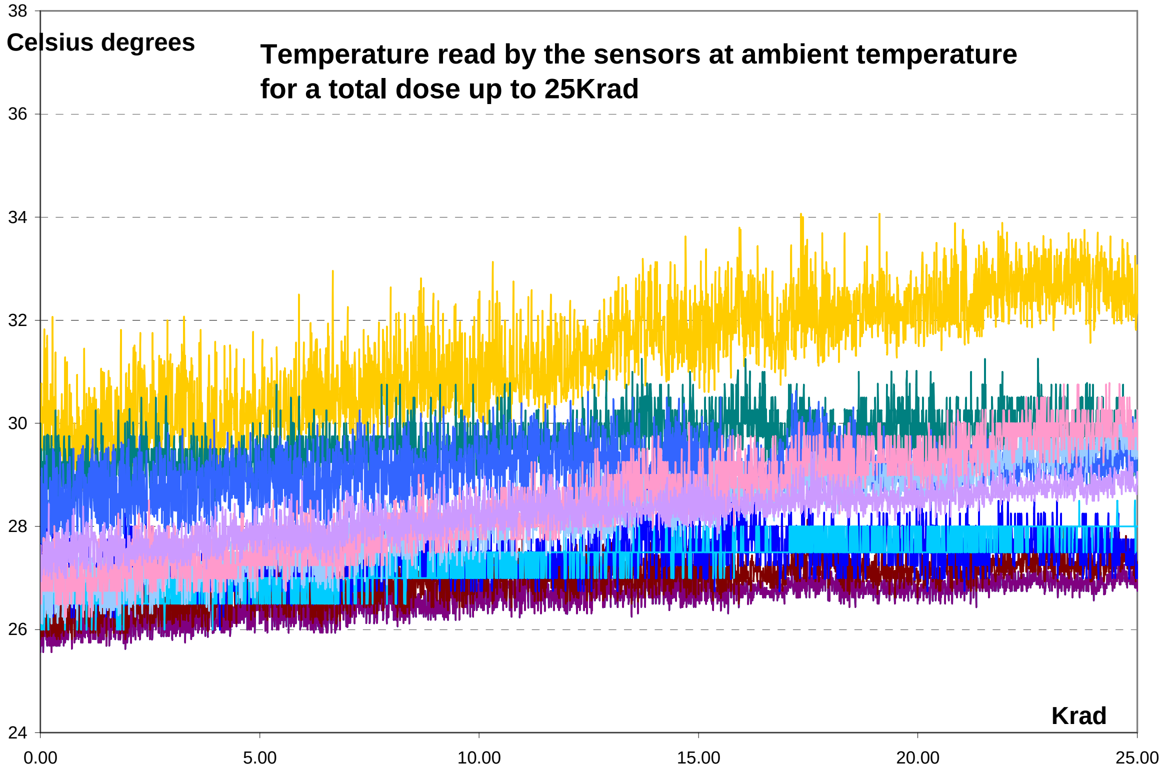

Figure 3 : temperature read by DS18S20 ambient T sensors during the first week of irradiation

Action performed	Irradiation of device until 25Krad level
Device name	DS18S20 and DS18B20
Device condition	Biased and unbiased hot devices
Parameters to be examined	***coherence of temperature values read among the hot sensors***
Radiation level	25 Krad
Dose rate	2.5862 Rad/min

The same measurements were performed for Hot Sensors only. In Figure 4 one can notice that the evolution of the temperature read by both hot DS18S20 is similar, and the temperatures read are coherent according to the voltage applied to the heaters. Until 25 Krad, even under hot temperature conditions (40 to 50 ° Celsius) sensors behave optimally.

In figure 4, the temperature read by the sensor number 12 (DS18B20) has shown a constant increase of its temperature during the testing campaign. Anyhow the temperature increase was partly due to ambient temperature increase (~ 2ºC) and partly due to loss of sensor calibration (~4º at 25 Krad). It has been the only sensor behaving this way.

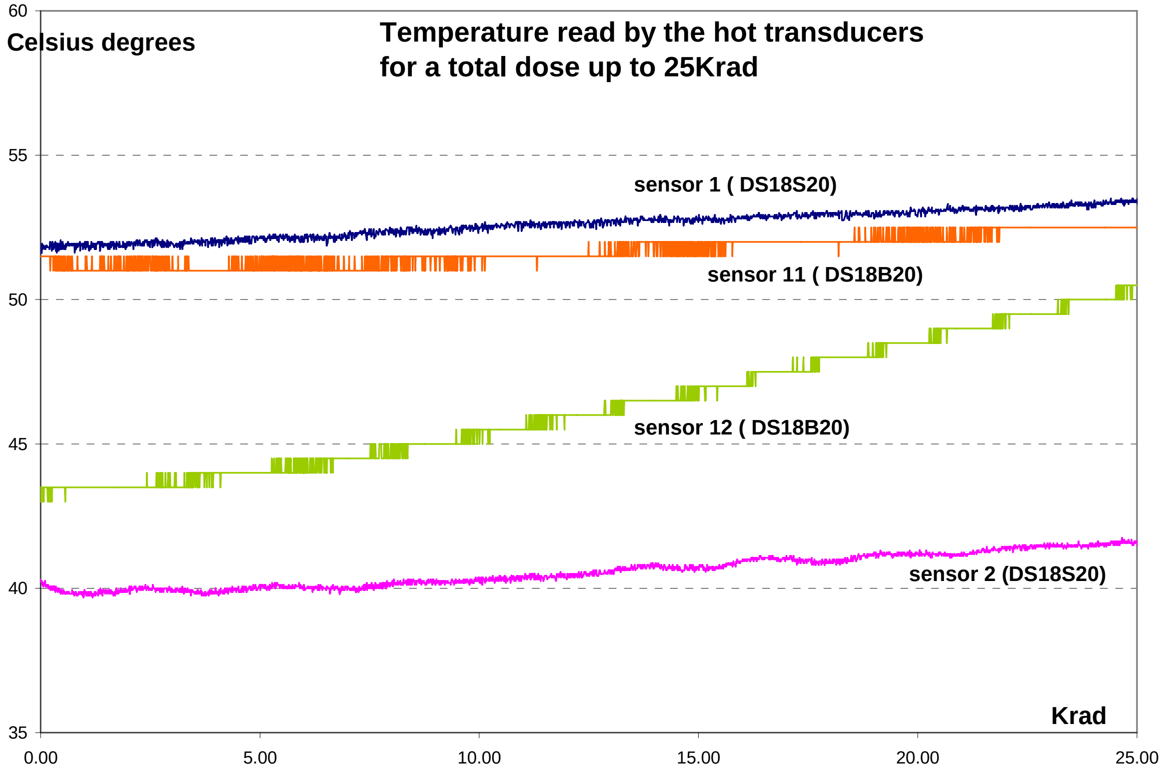

Figure 4 : temperature read by DS18S20 hot sensors during the first week of irradiation

Action performed	Irradiation of devices until a total dose of 25 Krad
Device name	DS18B20 and DS18S20
Device condition	Biased and unbiased (hot and ambient)
Parameters to be examined	***Number of CRC errors***
Dose rate	2.5862 Rad/min

Figure 5 shows the number of CRC errors in function of the total ionizing dose, for the sensors that have shown more than 2 CRC-errors during the test campaign. The maximum number of CRC-errors is 5, for sensor number 10 (DS18B20). The conclusion that can be drawn from figure 5 is that until 25 Krad, the transducers are not showing any high number of crc-errors that could indicate a communication malfunction due to radiation.

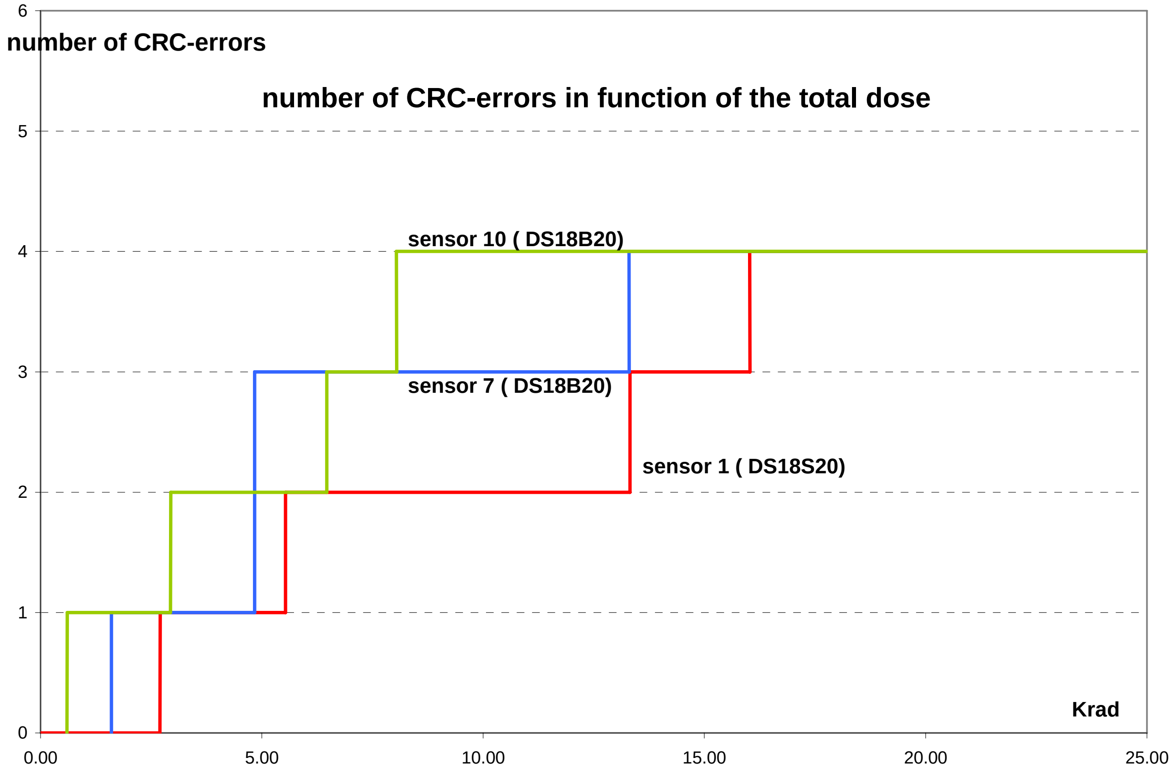

Figure 5 : amount of crc-errors in function of total ionizing dose

4.2 Conclusion

The conclusion that can be drawn from the above results is that the initially planned Low Dose TID test has been successful, for all transducers have shown an optimal behavior for a total dose up to 25Krad.

To complete the initially planned test, the irradiation of the transducers has been continued until the destruction of the devices. The results of this extension of the Low Dose TID test of the transducers are presented in the following part.

5 TEST EXTENSION RESULTS

5.1 Experimental results

Action performed	Irradiation of devices until destruction of the sensors
Device name	DS18B20 and DS18S20
Device condition	Biased and unbiased (hot and ambient)
Parameters to be examined	***Temperature decrease after shutting down the heaters, coherence of temperature read among the sensors.***
Dose rate	2.5862 Rad/min

After 16 days, the heaters were shut down, in particular to monitor their impact on the noise level in the data link. The temperature dropped quickly after the shut down, which shows that the transducers were able to detect the temperature change properly. Figure 6 shows the temperature read by all the sensors during the test extension and after the shut down of the heaters. During the test extension, and up to 34 Krad, the devices were reading temperature properly.

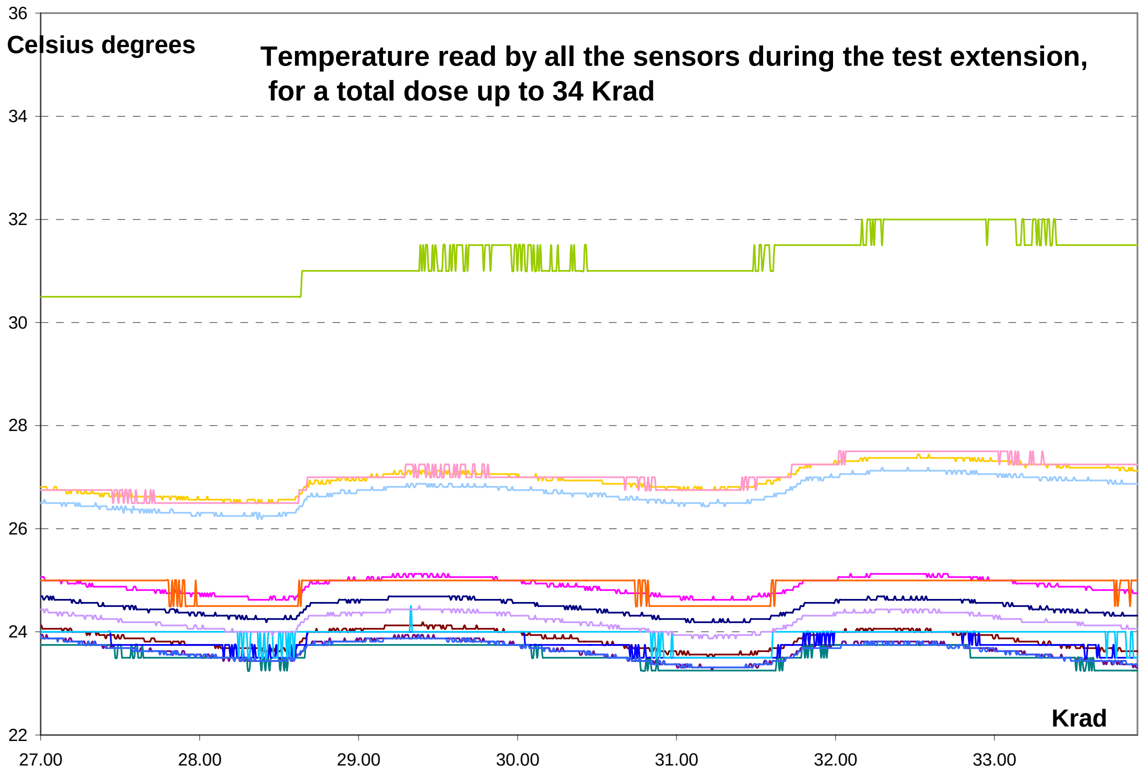

Figure 6 : temperature read during the test extension for a total dose up to 34 Krad

Action performed	Irradiation of devices until destruction of the sensors
Device name	DS18B20 and DS18S20
Device condition	Biased and unbiased (hot and ambient)
Parameters to be examined	***Temperature incoherencies***
Dose rate	2.5862 Rad/min

The graph in figure 7 shows the first observable signs of the non-optimal behavior of the sensors: sensor number 10 and sensor number 1 begin to read 85 ^{o}. The time when the 85 ^{o} was read coincides with the presence of CRC-errors detected and stored in the specific files. At some point, the sensor 1 has read values of temperature of more than 85 ^{o}, which shows a memory error (the maximum temperature that such sensors can read is 85 ^{o} Celsius).
But in order to detect the communication failures induced by the radiations, it is necessary to analyze the CRC-errors, as communication failures can appear without the temperature read being incoherent. This is the purpose of the next point.

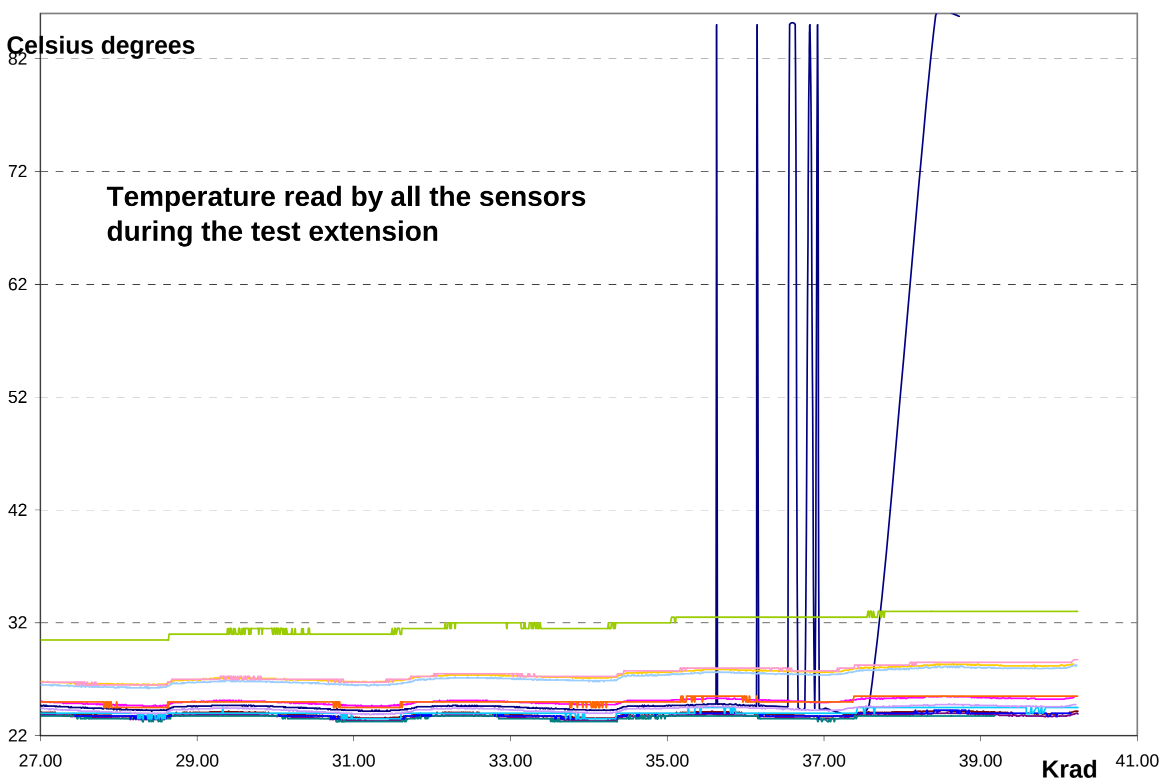

Figure 7 : temperature read during the whole test extension

Action performed	Irradiation of devices until destruction of the sensors
Devices names	DS18B20 and DS18S20
Devices conditions	Biased and unbiased (hot and ambient)
Parameters to be examined	***CRC errors***
Dose rate	2.5862 Rad/min

Figure 8 shows the number of CRC errors in function of the total ionizing dose, for the sensors which have shown the greatest total number of CRC-errors (more than 1000) during the extension of the test, which suggests they have been the most affected by the radiation.
What figure 9 is showing, is that the maximum total dose that the sensors can handle while behaving optimally is **29 Krad**.
This number is the most important result of the irradiation campaign.
The average dose leading to destruction of the sensors is for the DS18S20: **37.18 Krad**, and for the DS18B20: **37.00 Krad**.

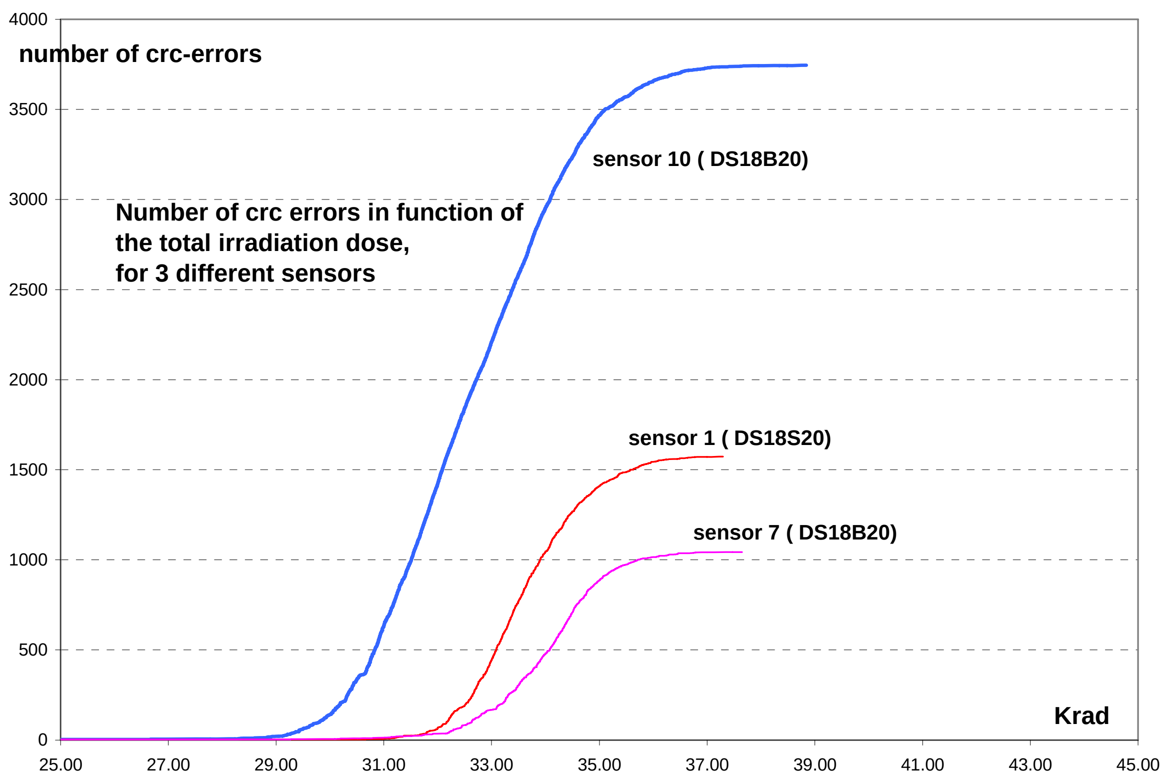

Figure 8 : number of crc-errors depending on the total irradiation dose

5.2 Conclusion

The conclusion that can be drawn from the extension of the Low Dose TID test is that the worst case total dose measured, for which the behaviour of the transducers is still optimal, is **29 Krad.**

6 CONCLUSION

One-Wire devices, DS18B20 and DS18S20, and then by extension the One-Wire bus protocol, are suitable for space missions whose radiation requirements are below 29 Krad (from a TID point of view).

This allows One-Wire devices to be used at least for LEO missions, which is a very encouraging result that will push forward to the use of transducers' networks in a large amount of space systems.

The result of this irradiation campaign gives a solid proof to those who needed one, that among other COTS components, transducers networks can be easy implemented using COTS components, and are reliable enough to be used for space purposes.

7 APPENDIX: FURTHER ANALYSIS OF THE BEHAVIOR OF THE TRANSDUCERS AND OF THE NETWORK PROTOCOL

Action performed	Irradiation of devices until destruction of the sensors
Devices names	DS18B20 and DS18S20
Devices conditions	Biased and unbiased (hot and ambient)
Parameters to be examined	***Changes in resolution of DS18B20***
Dose rate	2.5862 Rad/min

As it has been shown in the previous section, the radiation has generated CRC-errors; but radiation can affect the sensors by other means: by modifying the values stored in the inside memory of the sensors (EEPROM). To estimate the effect of radiation on memory, the test software has been very useful, as it was reading temperature and the values of the inside memory. That way a monitoring of the values of the memory has been possible, in particular of the resolution written in the DS18B20 Eeprom. The resolution of the DS18B20 had been written during the initialization procedure at the beginning of the test, and the EEPROM memory was not addressed during the test.
Here are the results of the monitoring of the resolution for different DS18B20:
Figure 9 concerns the resolution changes of sensor number 15.
Obviously the number of changes is small. The temperature measurements were not affected by these changes.

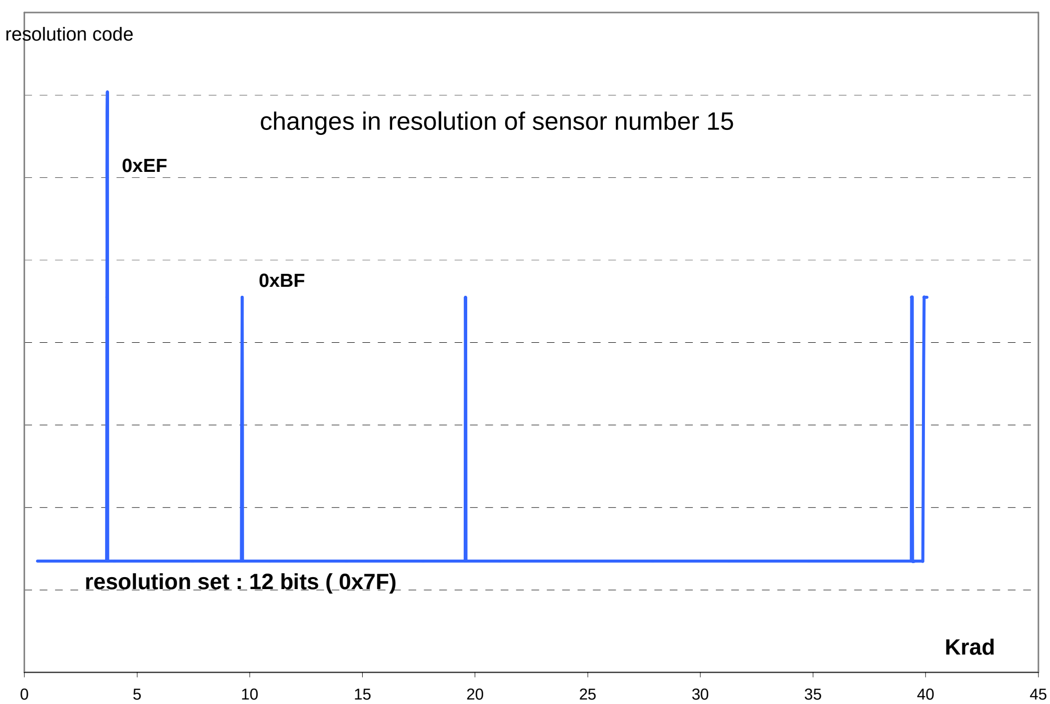

Figure 9 : changes in sensor 15 resolution

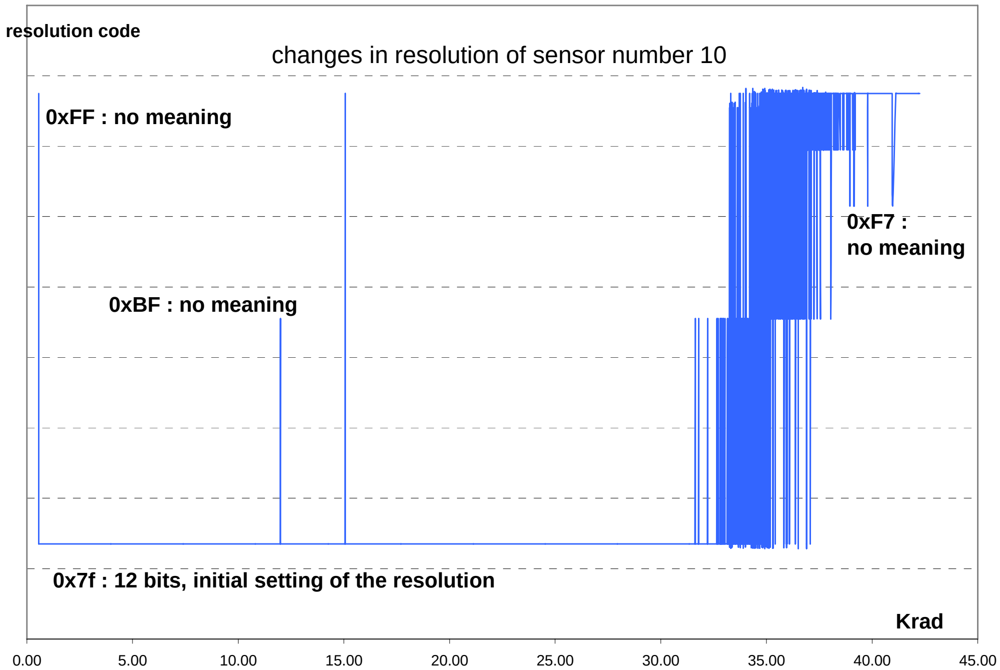

Figure 10 : changes in sensor 10 (ds18B20) resolution

Figure 10 represents the changes in the resolution of the sensor number 10:
Sensor 10 is the one whose resolution has experienced the biggest amount of changes during the irradiation campaign.
According to this graph, the resolution began to change significantly after the total irradiation dose had reached the value of 30 Krad. This confirms the value of **30 Krad as a maximal total dose for optimal behavior of the sensors.**
The others DS18B20 had shown no changes in their resolution during the irradiation campaign.

Action performed	Irradiation of devices until destruction of the sensors
Devices names	DS18B20 and DS18S20
Devices conditions	Biased and unbiased (hot and ambient)
Parameters to be examined	***Optimal behavior of the One-Wire bus protocol after 30 Krad***
Dose rate	2.5862 Rad/min

On the 26th of September, even after the moment the sensors could not read any correct temperature anymore, a complete discovery and walk of the One-Wire LAN was done, leading to the .digitemprc file (the configuration file), containing all the ROM addresses of all sensors, as well as all the paths for storing the logfiles.
A copy of the content of this file is shown below:

```
TTY /dev/ttyS0
LOG ./temperature.log
READ_TIME 1000
LOG_TYPE 1
LOG_ERROR_TYPE 1
LOG_FORMAT "%b   %d    %H:%M:%S   S-%s  sec:  %t    C:    %.2C  D:    %u
      count:     %c"
ERROR_FORMAT"%b  %d    %H:%M:%S   S-%s  sec:  %t    crc:  %m"
EXTEND_FORMAT"%b %d    %H:%M:%S   S-%s  scratchpad:     0x%A  0x%B  0x%C
      0x%D  0x%E  0x%F  0x%G  0x%I  0x%J  0x%K  count:     %c"
ERROR_FILE ./error.log
EXTEND_FILE ./extend.log
SENSORS 16
ROM 0 0x10 0x08 0xA1 0xB7 0x00 0x08 0x00 0xC5
ROM 1 0x10 0xCC 0x9D 0xB7 0x00 0x08 0x00 0x23
ROM 2 0x10 0x42 0x57 0xB7 0x00 0x08 0x00 0x45
ROM 3 0x10 0x32 0x78 0xC6 0x00 0x08 0x00 0x6D
ROM 4 0x10 0x11 0x87 0xB7 0x00 0x08 0x00 0x6C
ROM 5 0x10 0x4D 0x5A 0xB7 0x00 0x08 0x00 0x8D
ROM 6 0x10 0xCF 0x22 0xC6 0x00 0x08 0x00 0x7D
ROM 7 0x28 0x88 0x24 0xA2 0x00 0x00 0x00 0x1C
ROM 8 0x28 0x02 0xEA 0xA1 0x00 0x00 0x00 0x31
ROM 9 0x28 0x92 0x0D 0xA2 0x00 0x00 0x00 0x83
ROM 10 0x28 0x5A 0xFB 0xA1 0x00 0x00 0x00 0x0F
ROM 11 0x28 0x21 0x11 0xA2 0x00 0x00 0x00 0x80
ROM 12 0x28 0xF5 0xBF 0xA1 0x00 0x00 0x00 0x81
ROM 13 0x28 0xAB 0xDE 0xA1 0x00 0x00 0x00 0x60
ROM 14 0x28 0x2F 0xDE 0xA1 0x00 0x00 0x00 0x56
ROM 15 0x28 0xFF 0xE6 0xA1 0x00 0x00 0x00 0x28
```

All the ROM numbers beginning with 0x10 are representing DS18S20 sensors, whereas all ROM numbers beginning with 0x28 are DS18B20 sensors.
This file shows that even for a total dose of 30 Krad, the detection of all sensors on the bus is possible. The discovery of the One-Wire network occurs even with failure devices present on the bus.

Action performed	Irradiation of devices until destruction of the sensors
Devices names	DS18B20 and DS18S20
Devices conditions	Biased and unbiased (hot and ambient)
Parameters to be examined	***Comparison of the performance of DS18B20 and DS18S20***
Dose rate	2.5862 Rad/min

First of all, it is important to examine if the 2 types of sensors have similar resistance to radiations or not.
In the previous part, the average dose leading to the destruction of each type of sensor was calculated:
For the DS18B20 it is 37.00 Krad
For the DS18S20 it is 37.18 Krad.
But the median value is more representative in that case, because the influence of a single value very different from the others stays limited; the median values for each type of sensors are:
For the DS18B20: ***37.83 Krad***
For the DS18S20: ***37.52 Krad***
These values are similar. They lead to the conclusion that the 2 types of sensors are showing similar resistance to ionizing radiations, as expected because the CMOS technology is the same. This result can be used to expect similar performances from other One-Wire devices from the same manufacturers.