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ARM based Telemetry Subsystems Qualification for Micro-Satellite

Haitham Akah , Dalia Elfiky

Abstract*: Developing spacecraft telemetry subsystem utilizing commercial of the shelf (COTs) components to meet the technical design requirements with low-cost is big challenge for designers, due to the considerations of harmed ionizing space radiation effect, specially the total ionizing dose effect (TID). This effect induces performance degradation and failure in satellite electronic components (ECs). Because of the complexity of microcontrollers and their various integrated functionality, they present a hardness assurance encounter. A careful technique was followed in analyzing the space radiation effects. Then rigorous tests should be conducted to test the performance of the candidate microcontrollers under these effects. This paper presents the predicted dose depth curve and the total ionizing does test results for a commercial ARM microcontroller for Low Earth Orbit (LEO) satellites. Such test results help estimate the effect of space environment on the microcontroller and decide if such microcontroller is an accepted candidate for LEO missions or not.

***Keywords* : Microcontroller, COTS, TID, satellite, ARM.**

I. INTRODUCTION

The space radiation environment is inhomogeneous and dynamic environment. Which consists of high-energy ionizing particles (protons, heavy ions and electrons) induces many observable effects on electronics subsystems on-board satellite These effects range from performance degradation that can affect any system operations to total loss of electronic components and as consequence satellite failure. [1]. Total ionizing dose (TID) effect is one of the most important cumulative long-term ionizing damage induced by protons and electrons. The total accumulated dose depends on orbit altitude, orientation, and time. The devices expose to those particles can suffer threshold shifts, increased device leakage (& power consumption), timing changes, and decreased functionality [1]. Another harmed effect to electronics components is single event effect (SEE) which is resulted from spontaneous effect of high energetic protons or heavy ions. The effect of SEE in LEO is relatively high.[1]

Utilizing Commercial Off the Shelf (COTs) components in low risk satellites is a trend for engineers to reduce the cost and acquire advanced technology. But, the radiation tolerant of COTs is the main challenge for this approach.

Satellites and spacecraft are exposed to TID between 10 and 100 Krad (Si) [1]. Usually, COTs components can withstand doses in range of ~3-30 Krad(Si), higher accumulative dose may lead to mission failure. Accordingly, candidate parts need to be tested and qualified against the requirements of a spacecraft mission to prevent such failure.

Monitoring spacecraft telemetry data is one of the most important tasks to maintain the spacecraft performance and predict malfunctions beforehand. Telemetry subsystem collects spacecraft sensors readings and keep a record of its operation environment, operability status and health information. The satellite health data includes temperature reading, digital and analog measurements of different parts and subsystems of the satellite. The collected data are record into telemetry storage unit then send to the Ground Control Station (GCS) during communication sessions [2].

Within the framework of developing a telemetry module for NexSat2 LEO satellite (second Egyptian micro satellite mission) as shown in Fig **1**.

Fig 1 NexSat-2 proposed platform.

Selecting a suitable and reliable microcontroller was one of the key challenges in the project. This paper presents the process of picking a microcontroller that fulfill the mission requirements. By listing the candidate micro controllers for the telemetry subsystem, and prioritize them according to the technical specifications including their radiation tolerance. The TID test results of the selected ARM-microcontroller is reported. The workflow of this paper is as follows: the related work is in section II. Mission requirements, the telemetry subsystem and its requirements are presented in section III. Section IV demonstrates the experimental method. Section V discuses and analyze the results. Finally, the conclusion will be in section VI.

II. RELATED WORK

A survey for previous radiation tested COTS microcontrollers that can be used for the telemetry subsystem is demonstrated in this section.

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***** Correspondence Author
Haitham Akah, Space Science, National Authority of remote sensing and space science, Cairo, Egypt, Email: haitham_akah@narss.sci.eg
Dalia Elfiky*, Space Science, National Authority of remote sensing and space science, Cairo, Egypt, Email: delfiky@narss.sci.eg

Quinn et al. [3] select different Microprocessors (MSP430, Hercules, Stellaris, Tiva and Zynq) to use them instead of space hardened microprocessors, due to its lower cost and power, but they were not tested for radiation sensitivity. The tested microprocessors went through SEL, SEU, and SET tests.

The results of these tests showed that most of the components are sensitive to SEUs, fewer are sensitive to SETs, while the flash based MSP430 and feRAM based MSP430 were sensitive to high current and SEL[3].

Tairbank et al. [4] tested two microcontrollers LPC2148 produced by NXP Semiconductors and STM32F417IGH6 manufactured by STMicro. The TID test results showed that the flash of the LPC2148 can no longer be written to after 20-25 Krad (Si), most parts are non-functional above 55 krads (Si), some latchup or high current events in neutron, and destructive latch in Xenon Linear Energy Transfer (LET) =58.78 Mev-cm2/mg. While, STM32F417IGH6 showed two SEUs events in neutron irradiation. The test done on evaluation board where SEUs observed in proton and non-destructive latch-ups observed with all ions> LET=2.19 Mev-cm2/mg [4].

Hirofuni [5] used COTS components for development of cubesatellites. He presents that the main problem of using COTS in space are the heavy energetic particles in the Low Earth Orbit (LEO) which cause SEU and SEL[5].

Kingsbury et. al.[6] test the effect of TID on COTS components which commonly used on CubeSats. They test different types from electronic components such as PIC microcontrollers, SD memory and crystal oscillator, where the PIC24 microcontroller fails after 24 Krad.

III. Mission Requirements

AS mentioned before, the modified telemetry subsystem is planned to be used on NExSat-2 mission. Table I shows the orbital parameters of this mission which is scheduled to be launched in 2021. This section define the space radiation environment and its effects on NexSat-2 mission, and Telemetry subsystem technical requirements specifications is determining.

A. Define Radiation Environment and its Effects

In accordance with ECSS-Q-ST-60-15C, radiation hardness assurance of COTS starts with define the external radiation environment the device must be survive in, then calculate the effect of this radiation on internal satellite electronic components [7]. Table I shows NexSat-2 mission orbital parameters used to determine the space radiation effects on satellite. SPENVIS software package was used to predict the space radiation hazards and its effects on satellite subsystems. It is an online service provided by ESA that includes different modules for all space radiation effects in an easy-to-use interface [8].

The TID will be calculated theoretically using SHIELDDOSE2 model in SPENVIS package (with shield 1 mm)[4]. The resulted dose depth curve defines the mission top-level dose requirement. Fig **2** shows the contribution of the different space environment sources (trapped electrons and protons and solar protons) to the total dose. The TID at 1 mm aluminum thickness is also calculated for one year, three years and five years to be 1.72 kad, 4.5 krad and 6.73 krad respectively.

Table I NexSat-2 Mission Orbital Parameters

Parameters	Value
Orbit Type	Circular
Semi-major Axis	7039.00 km
Apogee	668 km
Perigee	668 km
Eccentricity	0.001 deg
Inclination	97 deg
True Anomaly	0
Argument of Perigee	0
Orbit period	1.63 hrs
Launch window	2021
Lifetime	1 year

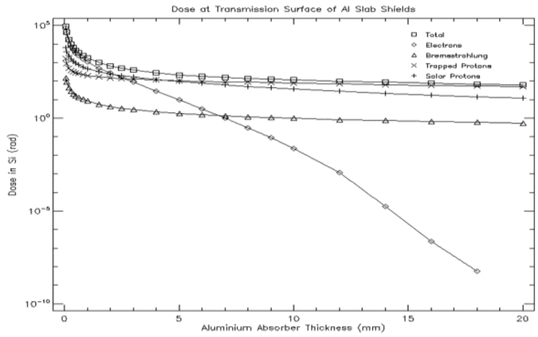

Fig 2 Dose Depth Curve for 1-year mission.

B. The Telemetry subsystem technical requirements specifications.

The developed Telemetry module is divided into two units: data-acquisition unit and processing unit. The data acquisition unit includes Temperature Sensors Commutator (TSC), Digital Sensors Commutator (DSC) and Analog Sensors Commutator (ASC) as shown in Fig **3**. On the technical side, the telemetry module should include certain peripherals to meet the system requirements and required functions while maintaining a certain performance level. The subsystem will contain a master board and slave boards. The master is responsible for many functions; it has to control and monitor the slaves, ensures the synchronization of the whole Telemetry system and collects the desired Telemetry measurements from the slaves. Finally, the master processes the collected telemetry data and sends them to the On-Board Computer (OBC) upon request. The specifications of the master microcontroller board are listed below:

- Memory interface
- A high processing power not less than 40 MIPS
- Two Serial Peripheral Interface (SPI).
- Two UARTs

The next section shall present the space environment test results for many microcontrollers and its technical specifications. Then two microcontrollers shall be selected to meet both master and slave requirements.

IV. Components Selection

The success of a space mission depends on a number of factors including design (radiation

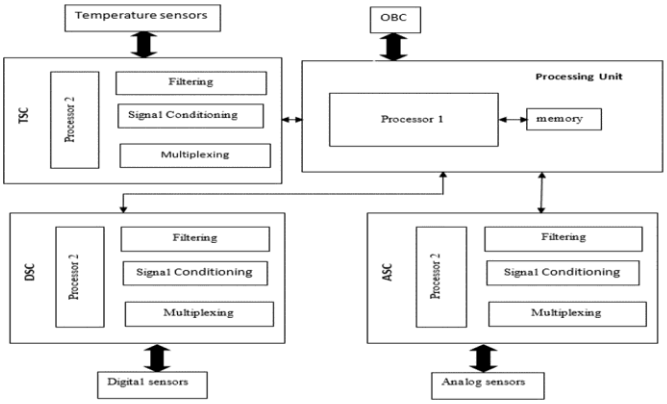

Fig 3 General block diagram of TLM module.

tolerant, de-rating, redundancy, etc.), part selection, degree of unit and system testing. ECSS-Q-ST-60 [9] is a ESA-ESTEC standard used for electronic component selection to meet space mission requirements.

After applying the standard methods to select appropriate microcontroller for telemetry subsystem, five microcontrollers are the best candidates could be fulfilling the technical requirements, as listed in

Table **II**

The selection of master microcontroller was a difficult job, due to the lack of radiation qualification tests information for such powerful microcontrollers. Also, the mission heritage plays an important role in assuring the initial acceptance of such controllers in space.

The simplest prioritization scheme used for the five microcontrollers candidates is established according to predefined weight points of the following parameters:

- The weight of microcontrollers technical specifications is **35 points**.
- The weight of single event latch-up (SEL) tolerant reported from radiation qualification tests results was done in other laboratories is **25 points**.
- The weight of TID tolerant reported from radiation qualification tests results was done in other laboratories is **20 points**.
- The weight of microcontroller heritage in previous space mission is **20 points**.

As shown in

Table II the LPC2378 and TM4c123G6pm Tiva didn't have space heritage, however the LPC2378 was tested for TID and passed the required level by the mission. In case of STM32F1, AT91M40800 and AT91SAM9G20 all of them had mission heritage, while both STM32F1 and AT91SAM9G20 SEL test results is accepted for NexSat-2 mission requirements. AT91M40800 pass the TID test and no SEL test information for it.

According to this prioritization scheme the highest points achieved is for STM32F1. TID testing is a mandatory requirement before use it, to assure the TID tolerant.

In case the STM32F1 failed we will test the next candidate in the list and so on.

V. TID Test for STM32F1

A. Test Conditions

The test was done at the Military Technical College Laboratory facilities at Cairo, Egypt. Low dose rate of gamma ray was conducted at the ^{60}Co facility. As shown in Fig **4**. it has a concentric cylindrical container with 172 mm in diameter and 205 mm in height with a maximum irradiated volume capacity of 5000 cc. This cell was designed according to 6-N 433.1. The test was executed inside the radiation cell in the presence of air with dose rate 2.08 kGy/h at the room temperature. The test method for TID was done according to MIL-STD- 883G, method 1019.7 [9].

Fig 4 ^{60}Co facility at the Military Technical College Laboratory, Cairo, Egypt.

B. Test Setup

The schematic diagram for test board used in monitoring the test is shown in Fig 5.

The DUT exposed to pre-calculated doses equivalent to TID of one year, three years and five years to be respectively, 1.72 Kad, 4.5 Krad and 6.73 Krad as mention in section III. Dose rates at each step were measured with the Radcal ionization gauge. The STM32F1 was irradiated while biased for functional tests operating at 3.3 V, repeating the process for each dose stepThe internal clock generation program was continuously running. Device were removed from the cell for functional testing and returned to the test chamber within one hour if they were still functional. The testing program used the internal clock to generate external clock, this clock is then measured before the sample return back to the chamber. This process continued till the program is no longer respond.

VI. Results and Discussion

As shown in Fig **6** The STM32F1 microcontroller is respond till 113 Krad. This means that microcontroller can withstand in

.

Table II Technical Specs, SEU,TID and Heritage of Candidate Microcontrollers.

Peripherals / Part Number	Technical specifications									SEL	TID	heritage	Priority point
	Freq.	**ADC**	**DAC**	**UART**	**SPI**	**I2C**	**CAN**	**RAM**	**External memory interface**				
STM32f1	72 MHz	3	2	5	3	2	1		√	Non-destructive latch-up at 2.18 Mev-cm2/gm at 14 Mev Neutrons [12]	N/A	FoxSat TubSat [12]	
Weight Points	**30**									**20**	**0**	**20**	**70**
AT91SAM9G20	400 MHz	1	X	4	2	X	X		√	NO SEL OBSEVED TILL LET=85 Mev-cm2/gm [13]	N/A	SOMP Cube-Sat [11], Aalto-1Com pass	
Weight Points	**30**									**25**	**0**	**20**	**65**
AT91M40800	40 MHz	X	X	2	2	X	X	X	√	N/A	at 10 krad no degradation	DTU Sat-1[10]	
Weight Points	**30**									**0**	**15**	**20**	**65**
LPC2378	72 MHz	1	1	4	1	3	2		X	N/A	at 20 krad(Si) start degradation [4]	No heritage	
Weight Points	**15**									**0**	**20**	**0**	**35**
TM4c123G6pm Tiva	80 MHz	2x 12-bit	X	8R	4	6	2	32 K	X	N/A	N/A	No heritage	
Weight Points	**25**									**0**	**0**	**0**	**25**

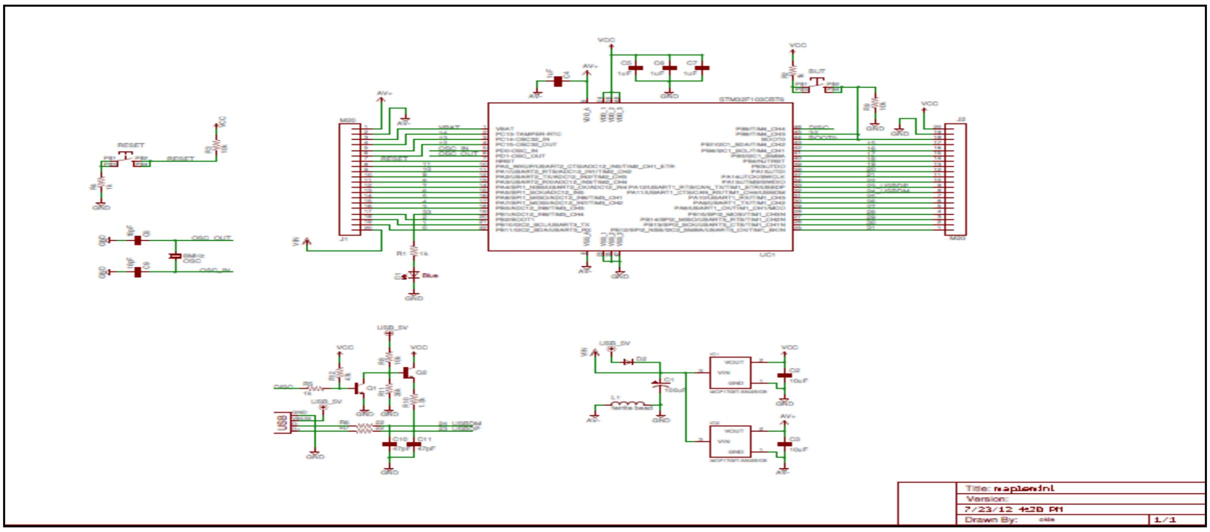

Fig 5 Schematic diagram of test board.

radiation environment for more than 5 years at the selected orbit. The clock degradation is mostly credited to the microcontroller oscillator. At low gamma doses the clock frequency of microcontroller varies significantly even more than in higher gamma doses. Frequency change at doses higher than 1 Krad can be explained by inducing the impurities-defect. Radiation can lead to a varies in the location of weakly bound compensators which changes the quartz elastic constants and thus may cause a change in frequency. The movement of ions often results in a reduction in the Q of the crystal, i.e., an increase in the equivalent resistance of the series of crystals, particularly when subjected to a pulse of ionizing radiation [14]. The microcontroller stopped at high doses 113 Krad due to photocurrents induced in the transiant termination in the crystal and transistors of its oscillator [14]. Testing for STM32F1 prove it is TID hardened for the NexSat-2 mission.

As seen from Fig **6** the actual operating frequency for this microcontroller in space is approximately 85% from its configured frequency. Such degradation should be included during evaluating the processing capability and requirements when selecting the components. Subsystem design should compensate such clock frequency shift (degradation).

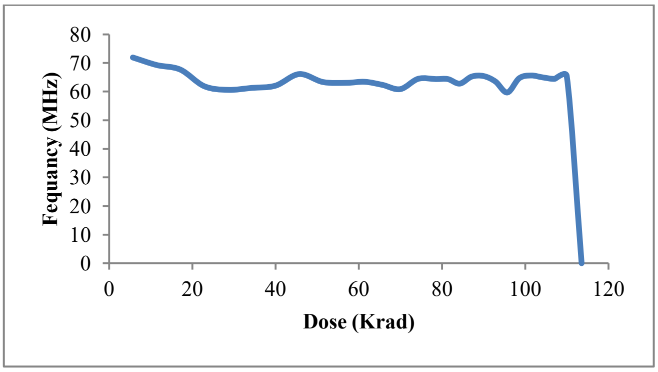

Fig 6 STM32F1 TID test result as a function of clock frequency operating at 3.3V.

VII. CONCLUSION

External radiation environment for NexSat-2 mission was predicted based on mission orbital parameters. Accordingly, the TID at 1 mm aluminum thickness is calculated for one year, three years and five years to be 1.72 kad, 4.5 krad and 6.73 krad respectively. Prioritization scheme was proposed to select the most suitable microcontroller for telemetry subsystem. STM32F1 shows the highest priority points, but TID test was mandatory. After expose STM32F1 doses of ^{60}Co equivalent to TID exposed in space, STM32F1 was found to be TID hardened. The failure dose was determined to be 113 Krad. The actual operating frequency for this microcontroller in space is approximately 85% from its configured frequency. STM32F1 is the most suitable microcontroller for the required Telemetry module, since it has all the required technical specifications and radiation hardened.

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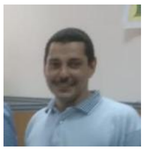
AUTHORS PROFILE



Haitham Akah is the head of the communication department, NARSS for more than17 years. He is communication group leader in Egyptian Space Agency (EgSA). He received his PhD from Ain Shams University, Cairo, Egypt in 2010. His research interest includes communication subsystem in different satellite category, Embedded system.

Dalia Elfiky is the head of structural, thermal control and space environment Department at NARSS. Space Environment group leader in Egyptian Space Agency (EgSA). She has been a NARSS member since 2001. She completed her Ph.D. at Faculty of science Ain Shams University. She was a PhD research student at Toyota technological Institute, Nagoya, Japan from 2009–2011. Her research interests lie in the area of space radiation effects on satellite components ranging from simulation model to experimental testing.