CubeSat Star Tracker - Radiation

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Introduction

- CubeSats have been used by many organization such as military, commercial industries and research universities to accomplish their space mission in an economical way.

- One of the concern for CubeSat missions is precision determination of attitude and control. In original CubeSats, absolute attitude sensors are used for determination of attitude and control.

- Star tracker is an optical device that determines the satellite’s attitude by measuring the position of stars using photocells or a cameras. Star trackers are capable of having 2 orders of magnitude better accuracy in determination of attitude compared to the absolute attitude sensors.

Introduction

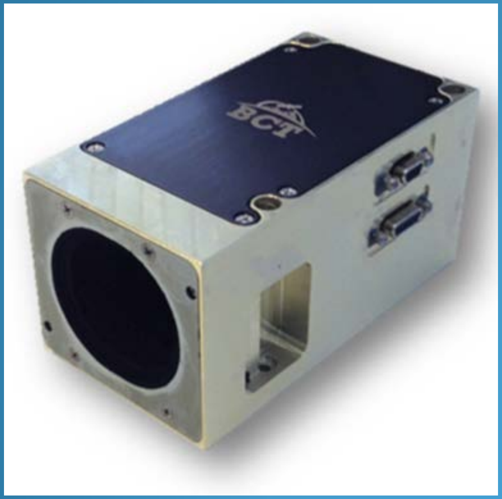
- The original star trackers were too large in size, power consuming and expensive to be utilized in CubeSats. Because of technology improvement, at present there are star trackers available to meet CubeSat specification that are being included in proposed CubeSat missions.
- CubeSat missions are characterized by use of commercial off-the-shelf (COTS) parts with little radiation effects concern. To use star tracker in CubeSat missions, there is need for at least a minimal radiation effect assurance.

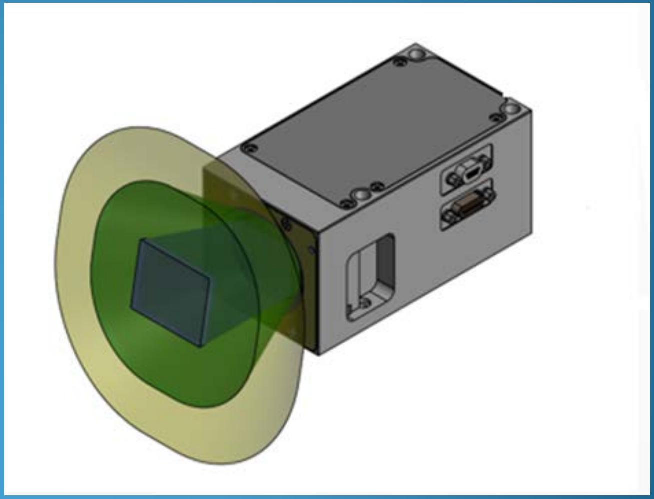
PART UNDER STUDY

- This work was focused on radiation testing of the Blue Canyon Technologies (BCT) Nano Star Tracker (NST) assembly and subassemblies.
- The BCT NST is a reliable, high performance star tracker, compatible with a variety of spacecraft configurations and missions. The tracker detects stars down to a 7.0 magnitude.
- The on-board star catalog contains greater than 23,000 stars, and includes a lost-in-space star identification algorithm.
- The tracker is contained within an extremely compact package (0.25 U) and weights about 500 gram.

Part under study

- The electronics board within the NST communicates with the detector on the lens flex to convert images used to generate an attitude on orbit. The lens flex board contains a CMOS detector.
- The BCT NST is flying in the NASA MinXSS CubeSat, which studies soft x-rays from the sun from an ISS orbit.





Experimental Procedure

- Proton and heavy ion radiation measurements were performed to characterize the unit's tolerance to radiation effects.
  - The single event latchup (SEL) response of the microelectronic components were tested with proton and heavy ion irradiation.
  - The proton data were also used to evaluate total ionizing dose (TID) on the microelectronics and optical components on the units.

TEST FACILITIES

- TRIUMF for proton irradiation
- TAMU for Heavy ion Irradiation

Experimental Procedure

For proton irradiation measurements the NST unit consisted of a main electronic board and lens flex board. The NST main board was divided in 12 zones. Each zone includes one active microelectronic component. Tables below display the list of microelectronics components associated with each zone in main board and lens flex board.

List of the BCT NST Board Active Components

Zone #	Description
1	FPGA XILINX
2	Digital Logic, Dual Schmitt Trigger Buffer
3	Analog to Digital Converter IC
4	RELAY OPTOMOS
5	IC OPAMP GP
6	SDRAM, 512M-Bit
7	RS485 I/F IC
8	NOR FLASH 256MBIT
9	Oscillators
10	Buck Converter
11	Regulator LDO 2.8V 0.3A
12	Voltage Regulator

List of the BCT NST Lens Flex Board Active Components

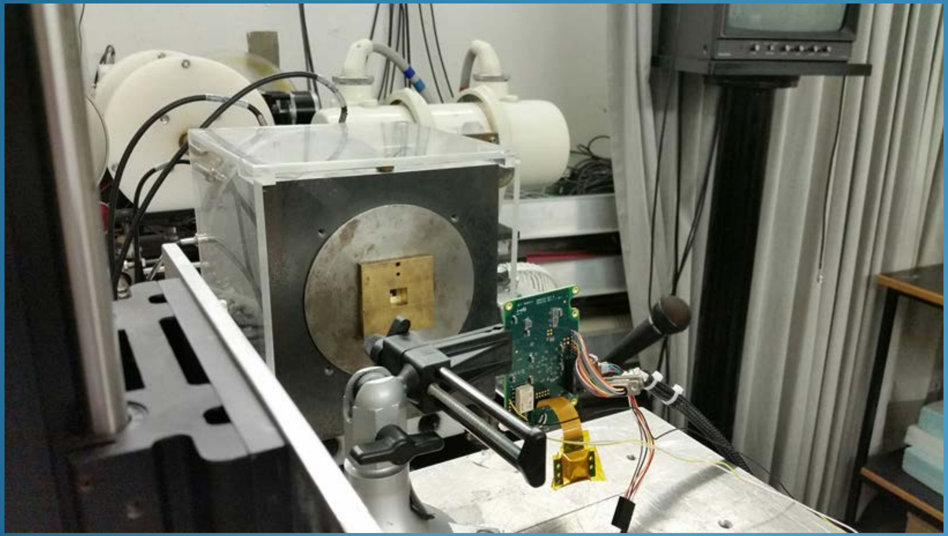
Description
High output Full-Duplex Rs-485 Driver and Receiver
Regulator LDO 1.8V 0.3A
Regulator LDO 3.3V 0.3A
CMOS Detector

Experimental Procedure

- The SEL test setup consisted of a computer, power supplies, and NST board to be tested.
- A computer-controlled Agilent N6700B power supply provides precision voltage control, current monitoring and latchup protection.
- SEL were detected via the test system software. The software controls the power supply voltage, and monitors the supply current.
- Separate computer was used to monitor the functionality of the NST device which was operated by BCT personnel.

Experimental Procedure

- SEL proton measurements were done at TRIUMF. The NST board was powered at 5 V during irradiation.
- The NST board current was about 280 mA. During proton irradiation the current instantaneously increased to around 300 mA. The current threshold for SEL detection was set to 600 mA.



Test setup at TRIUMF

Proton SEL Test Results

- The NST board was tested only at room temperature. Beam current during SEL measurements was set to 1 nA.
- During proton SEL measurements each zone was irradiated to a fluence of 1E10 per cm^2. Also, at the end the detector itself was also irradiated to a fluence of 1E10 per cm^2.
- For each run the dose accumulated on each component was recorded. Dose related to fluence of 1E10 of 105 MeV protons per cm^2 is about 0.91 Krad(Si).
- No SEL events were observed in any defined zones after irradiating each zone with 1E10 protons per cm^2.

Proton TID Test Results

- At the end of SEL measurements the total accumulated dose on the board was about 11.8 Krad(Si) (0.906 Krad(Si) on each zones and detector). Post-irradiation images indicated some degradation in detector performance.
- For TID measurements the beam current was increased to 5 nA. The NST board was divided into two segments, upper half and lower half.
- These two segments of the board were irradiated separately. The CMOS detector was also irradiated during the irradiation of the upper half of the NST board. The proton fluence in each irradiation was 5.25E10 per cm^2 which correspond to 5 Krad(Si).
- At the end of the 4^{th} proton irradiations, the BCT NST board accumulated 21 Krad(Si) and it was still functional, but the communication board died .
- The BCT Lens Flex board died between 11 to 16 Krad(Si).

Experimental Procedure

- The NST board provided to us by BCT for heavy ion testing included the following parts and had a minor differences with board that we used for proton testing:

Oscillators
OPAMP
ADC 8-Channel, 12-Bit
MULTIPLEXER
RELAY OPTOMOS
MOTOR DRIVER
VREF SHUNT PREC 3V
SDRAM, 512Mbit
FLASH 256MBIT
Schmitt Trigger Buffer
MOSFET P CH 30V
MOSFET N-Channel
REG BUCK SYNC 3.3V
Voltage Regulator
REG LDO 2.8V
RELAY TELECOM
FPGA
TRANS NPN 100V

Experimental Procedure

- SEL heavy ion measurements were done at TAMU. Parts were delided on the board. The NST board was powered at 5 V during irradiation.
- The NST board current was about 270 mA. During heavy ion irradiation the current increased to 400 mA. The current threshold for SEL detection was set to 500 mA.

Test setup at TAMU

Heavy Ion SEL Test Results

- With the possible exception of the flash memory, no SEL events or other destructive SEE were observed to the highest LET $\leq$ 42 MeV·cm^2/mg, at room temperature and nominal 5V input voltage. The flash had a read failure at LET of 10.5 MeV-cm^2/mg. We didn’t try to erase and reprogram the flash. We recommend further testing to determine if the flash can be reprogrammed or if the failure was permanent.

Heavy Ion SEL Test Results

- The single 3.3V buck regulator passed the heavy ion SEL test with a nominal 5V input voltage. At 16V and at the lowest LET of 10.5 MeV·cm^2/mg the regulator had an event that killed the 3.3V line.
- The triple buck regulator passed the heavy ion SEL test with a nominal 5V input voltage. At 10V and LET of 42 MeV·cm^2/mg the regulator destructively failed.
- MOSFET, oscillator, 3.0V voltage reference, SDRAM, and 2.8V voltage regulator were not delidded and thus were not tested.
- The 3.0V voltage reference and 2.8V voltage regulator are made with bipolar process and are immune to latchup.
- We are looking for SEL data for the SDRAM.

Conclusion

- BCT NST board is immune to proton SEL. The board still was functional after 21 Krad(Si) of proton irradiation.
- The BCT NST lens flex board died between 11 to 16 Krad(Si). The detector itself was still functional after 21 Krad(Si) of proton irradiation.
- With the possible exception of SDRAM and flash memory, no SEL events or other destructive SEE were observed to the highest LET ≤ 42 MeV·cm^2/mg, ambient temperature, nominal 5V input voltage.