Compendium of Single Event Effects (SEE) Test Results for COTS and Standard Electronics for Low Earth Orbit and Deep Space Applications

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Abstract— We present the results of SEE testing with high energy protons and with low and high energy heavy ions. This paper summarizes test results for components considered for Low Earth Orbit and Deep Space applications.

I. Introduction

As NASA continues to operate the International Space Station (ISS) in Low Earth Orbit (LEO), it is facilitating the commercialization of LEO by working with companies through Commercial Crew Program. Relevant to the design and operation of hardware in this environment, there is a need to select electronic components that are known to function for various mission durations. The environments here are relatively benign with occasional passes through the South Atlantic Anomaly region of the trapped proton Van Allen belt. Certification has primarily been carried out through high energy proton testing, which has been successfully used to test for Single Event Effects (SEE) in LEO for over two decades in the Space Shuttle and ISS programs (references 1 and 2) It is anticipated that high energy protons will continue to be used by companies intending to fly short duration programs in LEO.

The new focus of the human space exploration program at NASA is focused on destinations at cis-lunar space and eventually to Mars with the Orion Crew Module being developed by the Lockheed Martin Corporation. For these missions, the hardware is exposed to Solar Particle Events (SPE) and Galactic Cosmic Radiation (GCR). SPEs are primarily proton events, but contain concentrations of heavy ions, whereas GCR are heavy ions ranging from hydrogen through iron spanning many orders of magnitude in energy. For these missions, program performance and reliability requirements necessitate the need for heavy ion certification. To date, this has been carried out by traditional (low energy) heavy ion testing as well as using the Variable Depth Bragg Peak method for part characterization and for destructive screening.

NASA has primarily conducted proton testing at the Indiana Cyclotron Facility until closure in December 2014, and afterwards, at the Francis Burr Proton Facility (FBPTC) in Boston, Ma. For heavy ions, NASA continues to use Lawrence Berkeley National Laboratory (LBNL) and the Texas A&M Cyclotron Facility (TAMU) for low energy testing. For high energy testing, NASA has been using the techniques developed by the NASA Johnson Space Center to use the high energy beams at Brookhaven National Laboratory at the NASA Space Radiation Laboratory.

This paper summarizes the test results through the year 2016 on the above mentioned program and provides generic information to allow the user to evaluate radiation performance for various radiation environments.

II. Test Protocol

A. Proton Testing

NASA uses 200 MeV protons to test for destructive and nondestructive errors for hardware intended for LEO, i.e. for ISS. (references 3 and 4). This test exposes all known failure modes that have a Mean Time Before Failure (MTBF) <= 10 years in the LEO environment. Proton testing replicates approximately 6-10 years of the heavy ion linear energy transfer (LET) environment up to an LET of approximately 10-14 MeV-cm^2/mg in silicon. The proton beam typically loses less than 10% of its energy while passing through the electronic parts. Secondary recoils are typically produced though the inelastic collisions of individual protons with the nuclei in the device, which is primarily silicon, but may contain higher charge elements such as tungsten.

The typical test exposes the device under test to a fluence of ≥ 1E+10 protons/cm2 which accomplishes two goals. The first is to look for single event effects caused by heavy ions up to LET of ~10 MeV-cm^2/mg. Secondly, the test produces a total ionizing dose (TID) of at least 600 rads (Si), which corresponds to about 10 years of dose exposure in LEO.

This NASA method does not fully characterize the part, but it intends to screen for hard failures and provides very conservative estimates up to a 10 year MTBF in LEO (refs. 3, 4). This test can be performed at the board or box level which provides a means to reduce the cost of testing, especially with modern Commercial Off-The-Shelf (COTS) units. The test can be used for down-selection for both LEO and Deep Space application as well as provide conservative SEE and TID results.

B. Traditional Heavy Ion Testing

NASA uses traditional methods to perform heavy ion testing and requires each part be characterized to high LET (depending on mission) or failure (references 5 and 6). Traditional methods require delidding of the parts for single piece part testing, and characterization of the part. Often times, components with specific application voltages representative of flight like conditions are tested to understand transient radiation induced responses to these devices or test for the effectiveness of mitigation strategies. Analyses of the SEE signatures at the system level are required to determine the system effects and what mitigations are necessary. Testing complex parts and applying those results to complex systems is a difficult task. The analysis typically involves circuit analysis to evaluate the system level effects while cataloging the effects of each part in the system.

C. High Energy Heavy Ion Testing

Increasingly, the human rated missions are incorporating complex parts that are too difficult (or costly) to delid or have sensitive volume depths unreachable by low energy heavy ion beams. Additionally, designs include more Commercial Off-The-Shelf (COTS) units to support crew activities for which there are no rad-hard versions available. In these cases, the traditional test facilities at TAMU and LBNL cannot provide beams with enough energy to penetrate these devices. NASA JSC has been using the Variable Depth Bragg Peak (VDBP) method for single part characterization and board level screening using the high energy (~several hundred MeV/n) beams at the NSRL (references 7-10).

III. Test Results Overview

Table 1 is an excerpt from the testing results table that includes over 100 parts. For each part, the table gives the report number, the part number, the Lot Date Code (LDC), part type, manufacturer, where it was tested and to what LET and characterization data when determined, i.e. a set of Weibull parameters for heavy ion data and Bendel parameter for proton test data, along with important notes. The LDC's are provided for the tested parts because part manufacturing variations are known to affect radiation susceptibility and this information is useful when assessing current parts against previously tested parts.

Table 1 Excerpt from Testing Results Table

Ref #	Part #	LDC	Part type	Manu-facturer	Facility	*Max LET	**Weibull Parameters	Notes
2011-013	OLF300	0504	Opto	Iso Link	TAMU	80.2	σ=1.4E-4	Max SET=450mV
2011-015	RH1499	1002A	Quad opamp	AD	TAMU	80.2	Lo=15, σ_0=8.5E-3, W=19, S=1.4	SET pos=2us, ,2V, SET neg = 0
2011-017	REF05A	0640A	Volt Reg	AD	TAMU	85.4	σ =4E-7, no SET at LET=63	Max SET=5.56V (5V output)
2015-073	NSW-12GT-1	N/A	12 bit Ethernet Switch	TTC	FBPTC		SEFI requiring power cycle: Bendel A=13.07 DSEE: Bendel A=18.03	200MeV protons, 1E10+
2012-007	REF02	1025A	Volt Reg	AD	LBNL	75.7		No SET above 6V, Vsup=15, Vout=5V
2012-013	RH1016MW	1011A	High Speed Comp	LT	LBNL	75.7	Lo=12.5, σ_0=6E-5, W=50, S=2.5	SET= +/- 0.5V
2012-015	SNV54AHC244W	0726A	Octal buffer	TI	LBNL	75.7		No SET between 1.3V and 0.8V. Operating at 3.3V
2012-017	HYSE-117RH-Q	Proto – same as flight	Adj Pos volt reg	Intersil	LBNL	75.7	Lo=7, σ_0 =1.2E-4, W=40, S=3	15V in, 5V out. SET is 6V. Max SET=6.88V/ 50us @58.5 LET
2012-019	OLI249	114814	Opto	Isolink	LBNL	75.7	Lo=25, σ_0 =6.0E-3, W=50, S=4	SET>= 2.2V,Vsup and Vout=3.3V, 60us duration maximum

* LET Units (MeV/mg/cm^2)

** Weibull Parameters: Lo=LET Threshold, so=saturation cross section (cm^2), W=width parameter, S=shape parameter

IV. Test Results and Discussion

In this section, additional details for individual tests are discussed to provide more information as required. Additionally, test results analysis is discussed. The usage of the 1 parameter Bendel curve is discussed along with the development of the Weibull parameters from the high energy heavy ion test.

V. Conclusions

We have presented proton test data and/or heavy ion test data results for a variety of piece parts and/or COTS units being considered for applications in a LEO or Deep Space radiation environment. Additionally, new test data from high energy heavy ion testing (VDBP) has been discussed and presented. As NASA continues to develop plans for deep space missions, new radiation-related challenges will exist with the increasing use of COTS parts and hardware. With limited budgets, designers are increasingly looking to published data in compendiums such as this to help make decisions on parts.

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