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Compendium of Radiation Effects Test Results from NASA Goddard Space Flight Center

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Abstract: Total ionizing dose, displacement damage dose, and single event effects testing were performed to characterize and determine the suitability of candidate electronics for NASA space utilization. Devices tested include optoelectronics, digital, analog, and bipolar devices.

Introduction

NASA spacecraft are subjected to a harsh space environment that includes exposure to various types of radiation. The performance of electronic devices in a space radiation environment is often limited by its susceptibility to single event effects (SEE), total ionizing dose (TID), and displacement damage dose (DDD). Ground-based testing is used to evaluate candidate spacecraft electronics to determine risk to spaceflight applications. Interpreting the results of radiation testing of complex devices is quite difficult. Given the rapidly changing nature of technology, radiation test data are most often application-specific and adequate understanding of the test conditions is critical [1].

These test results show sensitivities of candidate spacecraft and electronic devices to SEE including single-event upset (SEU), single-event functional interrupt (SEFI), single-event latchup (SEL), single-event burnout (SEB), single-event gate rupture (SEGR), single-event transient (SET), TID, and DDD effects. All tests were performed between March 2020 and February 2021.

Test Techniques and Setup

A. Test Method

TID testing was performed using MIL-STD-883, Test Method 1019.9 [2] unless otherwise noted as research. All tests were performed at room temperature and with nominal power supply voltages, unless otherwise noted. Based on the application, samples would be tested in a biased and/or unbiased configuration. Functionality and parametric changes were measured after step irradiations (for example: every 10 krad(Si)).

Unless otherwise noted, SEE testing was performed in accordance with JESD57A test procedures [3]. Depending on the DUT and the test objectives, one or two SEE test methods were typically used:

Dynamic – The DUT was exercised and monitored continuously while being irradiated. The type of input stimulus and output data capture methods are highly device- and application-dependent. In all cases the power supply levels were actively monitored during irradiation. These results are highly application-dependent and may only represent the specific operational mode tested.

Static/Biased – The DUT was provided basic power and configuration information (where applicable), but not actively operated during irradiation. The device output may or may not have been actively monitored during irradiation, while the power supply current was actively monitored for changes.

In SEE experiments, DUTs were monitored for soft errors, such as SEUs, and for hard errors, such as SEGR. Detailed descriptions of the types of errors observed are noted in the individual test reports.

SET testing was performed using high-speed oscilloscopes controlled via NI LabVIEW® [4]. Individual criteria for SETs are specific to the device and application being tested. Please see the individual test reports for details.

Heavy ion SEE sensitivity experiments include measurement of the linear energy transfer threshold (LET_{th}) and cross section at the maximum measured LET. The LET_{th} is defined as the maximum LET value at which no effect was observed at an effective fluence of $1×10^7$ particles/cm^2. In the case where events are observed at the smallest LET tested, LET_{th} will either be reported as less than the lowest measured LET or determined approximately as the LET_{th} parameter from a Weibull fit.

B. Test Facilities - TID

TID testing was performed using a gamma source. Dose rates used for testing were between 10 mrad(Si)/s and 2.6 krad(Si)/s.

C. Test Facilities - DDD

Neutron DDD tests were performed at the University of Massachusetts Lowell's (UML) Fast Neutron Irradiation Facility (FNI) [5].

D. Test Facilities – Laser

Laser SEE tests were performed at the pulsed laser facility at the Naval Research Laboratory (NRL) using single-photon absorption.

E. Test Facilities – SEE

Heavy ion experiments were conducted at the Texas A&M University Cyclotron (TAMU) [6] and Brookhaven National Laboratory's NASA Space Radiation Laboratory (NSRL). Energies and Linear Energy Transfers (LETs) available varied slightly from one test date to another.

Low-energy electron SEE testing was performed at Goddard Space Flight Center using the 2-MeV Van de Graaff. [7]

Principal Investigators, Abbreviations and Conventions

Abbreviations for principal investigators (PIs) are listed in Table I. Abbreviations and conventions are listed in Table II. Summary of TID, DDD, and SEE test results from February 2020 through February 2021 are listed in Table III. Please note that these test results can depend on operational conditions.

Table I: List of Principal Investigators

Abbreviation	Principal Investigator (PI)
MCC	Megan C. Casey
MJC	Michael J. Campola
TW	Edward (Ted) Wilcox

Table II: Abbreviations and Conventions

< = SEE observed at lowest tested LET
> = no SEE observed at highest tested LET
CMOS = Complementary Metal Oxide Semiconductor
DDD = Displacement Damage Dose
DUT = Device Under Test
FNI = Fast Neutron Irradiation Facility
GSFC = Goddard Space Flight Center
HDR = High Dose Rate
LDC = Lot Date Code
LDR = Low Dose Rate
LET = Linear Energy Transfer
NEPP = NASA Electronics Parts and Packaging

NSRL = NASA Space Radiation Laboratory
PI = Principal Investigator
REAG = Radiation Effects & Analysis Group
SEB = Single-Event Burnout
SEE = Single-Event Effect
SEFI = Single-Event Functional Interrupt
SEGR = Single-Event Gate Rupture
SEL = Single-Event Latchup
SET = Single-Event Transient
SEU = Single-Event Upset
SOI = Silicon-on-Insulator
SRAM = Static Random-Access Memory
TAMU = Texas A&M University
TID = Total Ionizing Dose
UML = University of Massachusetts Lowell
VDD = Positive Supply Voltage

Table III: Summary of Radiation Test Results

Part Number	Manuf.	LDC; (REAG ID#)	Device Function	Tech-nology	PI	Sample Size	Test Env.	Test Facility (Test Date)	Test Results (Effect, Dose Level/Energy, Results)
22FDX SRAM-based Line-Monitor Test Vehicle	Global Foundries	n/a; (18-007)	SRAM	SOI	MCC	2	Electron	GSFC (Oct 2020)	Measured SEUs due to direct ionization of low-energy electrons. Upsets were measured at all electron energies tested from 130 keV to 1.6 MeV. [8]
61055-305	Micropac	2018; (21-003)	Photo-transistor	Si	TW	12	Neutron	UML (Dec 2020)	Unbiased irradiation; No degradation noted to 4.55 x 10^{11} n/cm^2
62087-305	Micropac	2018; (21-004)	LED	GaAs	TW	12	Neutron	UML (Dec 2020)	Unbiased irradiation; No degradation noted to 4.55 x 10^{11} n/cm^2
80SCLQ060SCS	International Rectifier	1839; (20-007)	Schottky Diode	Si	TW	3	Heavy Ion	TAMU (Dec 2020)	SEB LET_{th} > 42.7 (Vr: 61.5 V, 25 MeV/amu Xe, normal incidence, range: 220 um, fluence: 1x10^7/cm^2) SEB LET_{th} > 60 (Vr: 65 V, 25 MeV/amu Xe, normal incidence with beam degraders, range: 88 µm, fluence: 1x10^6/cm^2). [9]
ACPL-785E	Avago	1649; (17-047)	Analog Isolation Amplifier	Bipolar	MJC	2	Heavy Ion	NSRL (Dec 2020)	No destructive SEEs or SETs observed. Largest observed transient was 5V, 40µs with a DC input. A varied response was seen using an input square wave including delays in one and/or both output channels. [10]
AD9814	Analog Devices	1531A; (19-051)	Processor	CMOS	MCC	8	Gamma	GSFC (Sep 2020)	TID LDR, All parameters tested remained within specification up to 16.3 krad(Si).
ADG201	Analog Devices	1635; (21-002)	Analog Switch	CMOS	TW	1	Heavy Ion	TAMU (Dec 2020)	SEL LET_{th} > 75 (VDD: 16.5 V, Temp: 90 °C, 25 MeV/amu Xe at 45 degrees, fluence: 1x10^7/cm^2). [11]
DS25BR100	Texas Instruments	n/a; (20-016)	LVDS Buffer	CMOS	TW	3	Heavy Ion	TAMU (Dec 2020)	SEL Observed: 20 < LET_{th} < 31 MeV-cm^2/mg. Parts failed catastrophically.
JANS2N2222	Semicoa	2013; (20-012)	NPN Transistor	Bipolar	TW	22	Gamma	GSFC (Jan 2021)	TID LDR, All parts within specification at 20 krad(Si) h_{FE3} below specification at 30 krad(Si) (minimum gain observed: 94)
		2006; (20-013)				22			TID LDR, All parts within specification at 20 krad(Si) h_{FE3} below specification at 30 krad(Si) (minimum gain observed: 96)
		2006A; (20-014)				22			TID LDR, All parts within specification at 20 krad(Si) h_{FE3} below specification at 30 krad(Si) (minimum gain observed: 91)
LP2951	Texas Instruments	1911A; (19-049)	Voltage Regulator	Bipolar	MCC	8	Gamma	GSFC (Aug 2020)	TID LDR, Tested to 16.3 krad(Si), Output voltage went out of spec between 2.5 and 5.9 krad(Si) when biased with 5 V and between 5.9 and 7.5 krad(Si) when biased with 3.3 V. The load regulation went out of spec between 12.4 and 14 krad(Si) (5 V and I_L = 100 mA) and 10.8 and 12.4 krad(Si) (3.3 V and I_L = 100 mA). The load regulation for the unbiased parts also went out of spec for 3.3 V and 75 mA between 14 and 16.3 krad(Si), but all of the other parts stayed in spec. Ground current went out of spec (5 V and I_L = 100 mA) between 8.5 and 12.4 krad(Si) and (3.3 V and I_L = 100 mA) between 8.5 and 10.8 krad(Si).
MAX4651EUE	Maxim	1831; (21-001)	Analog switch	CMOS	TW	12	Gamma	GSFC (Feb 2021)	TID HDR, All parameters tested remained within specification up to 50 krad(Si). [12]
QI-SWIR-VGA15XS	Semi Conductor Devices	n/a; (20-008)	Camera Electronics Module	InGaAs/ CMOS	MCC	1	Gamma	GSFC (Sep 2020)	TID HDR, All parameters tested remained within specification up to 17.7 krad(Si).

Test Results and Discussion

As in our past workshop compendia of GSFC test results, each device under test has a detailed test report available online at http://radhome.gsfc.nasa.gov [13] and at http://nepp.nasa.gov [14] describing in further detail the test method, conditions and monitored parameters, and test results. This section contains a summary of testing performed on a selection of featured parts.

DS25BR100, Texas Instruments, LVDS Buffer

This BiCMOS, COTS, LVDS buffer was tested at the Texas A&M Cyclotron with a 25 MeV/amu tune. The highest nominal LET was 25 MeV/amu Xe, at 42.7 MeVcm^2/mg. Worst case conditions for single-event latchup were tested with VDD = 3.6 V and case temperature greater than 85°C. Power supply current was monitored for high current states. For most testing, all three devices on the evaluation board were attached in series, with only a single buffer actively irradiated. Testing was also performed with individual devices isolated to ensure the effects observed were not influenced by the attached buffers. Fig. 1 is a photograph of the evaluation board.

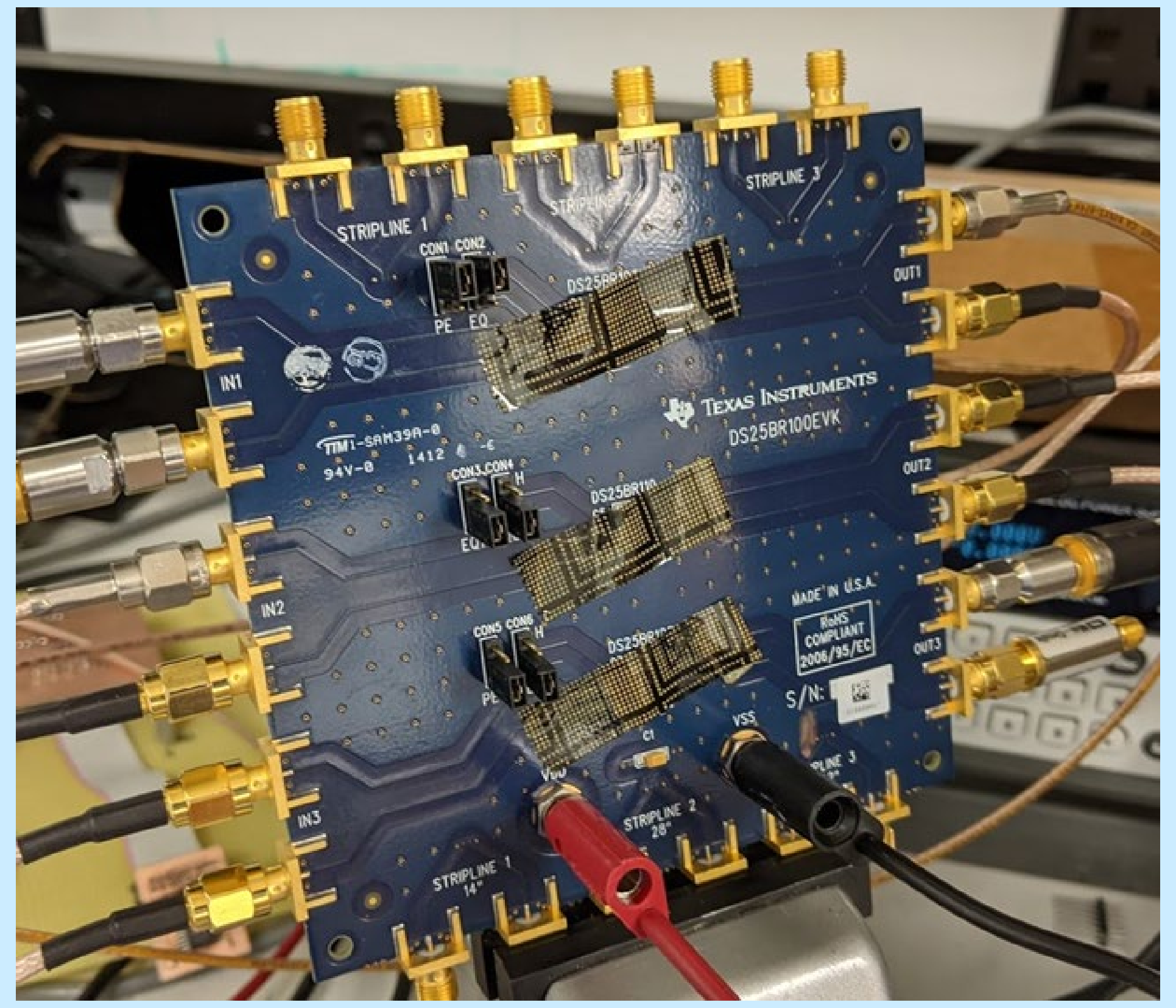

Fig. 1: COTS evaluation board for DS25BR100 buffer (top device)

The DS25BR100 was first irradiated with 42.7 MeVcm^2/mg Xe, with a range of 220 µm in silicon. At ambient temperature and nominal voltage (3.3 V), single-event latchup was observed. The power supply current jumped to the hardware limit of 500 mA (see Fig 2). This was repeated on several runs and several devices, and for the four runs on which fluence-to-failure was noted, the average cross-section was 2.18x10^{-6}cm^2. A sample was heated to 85°C and exposed to greater than 1x10^7/cm^2 at an effective LET of 60.4 MeVcm^2/mg by use of beam degraders to reduce energy. Single-event latchup was again observed, limited by the 500mA power supply compliance. No parts were catastrophically damaged during this phase of testing. At an LET of 30.8 MeVcm^2/mg and ambient temperature, SEL was observed. After one test to 2.3x10^6/cm^2, the device was catastrophically destroyed and could not be restored to functionality (current remained high). Finally, at an LET of 21.3 MeVcm^2/mg, three tests to a total of 5x10^6/cm^2 at ambient temperature did not result in any single-event latchup, but time did not allow for additional testing at elevated temperature.

Single-event upset data was a secondary objective of this test. Many runs were obscured by SEL that caused a near-infinite number of errors to be recorded. No clear cross-section vs LET curve is possible from the limited dataset, but it may be useful in understanding the relative magnitude of possible errors from this device (see test report).

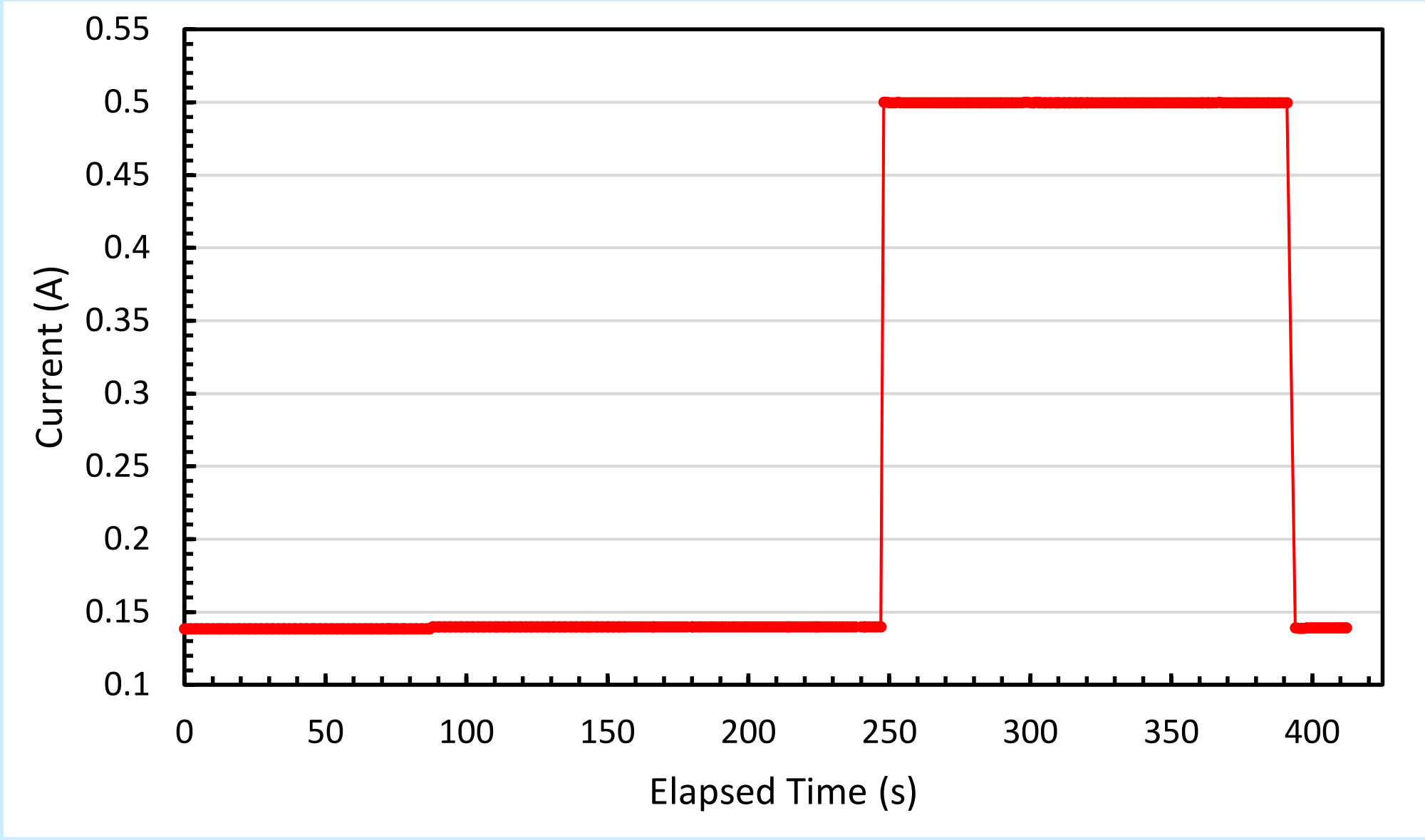

Fig 2: DS25BR100 SN2 power supply current spike.

LP2951, Texas Instruments, Voltage Regulator

Texas Instruments' LP2951 is an adjustable micropower voltage regulator. It can accommodate a wide input supply voltage range up to 30 V. This voltage regulator can output either a fixed or adjustable voltage. [15]

The LP2951 was TID tested at GSFC's gamma chamber with a low dose rate (LDR) up to 16.3 krad(Si). Eight parts were irradiated with two used as controls. Three DUTs were biased at 5 V, three were biased at 3.3 V, and the remaining two were unbiased during irradiation. Output voltage went below specification between 2.5 and 5.9 krad(Si) when biased with 5 V (see Fig. 3) and between 5.9 and 7.5 krad(Si) when biased with 3.3 V. The load regulation (with conditions 5 V and IL = 100 mA) went above specification between 12.4 and 14 krad(Si) and 10.8 and 12.4 krad(Si) with the conditions 3.3 V and IL = 100 mA. The load regulation for the unbiased parts also went above specification (for conditions 3.3 V and IL = 75 mA) between 14 and 16.3 krad(Si), but all of the other parts stayed in specification. Ground current (with conditions 5 V and IL = 100 mA) went above specification between 8.5 and 12.4 krad(Si) and (with conditions 3.3 V and IL = 100 mA) between 8.5 and 10.8 krad(Si). All remaining measured specifications stayed within specification up to 16.3 krad(Si).

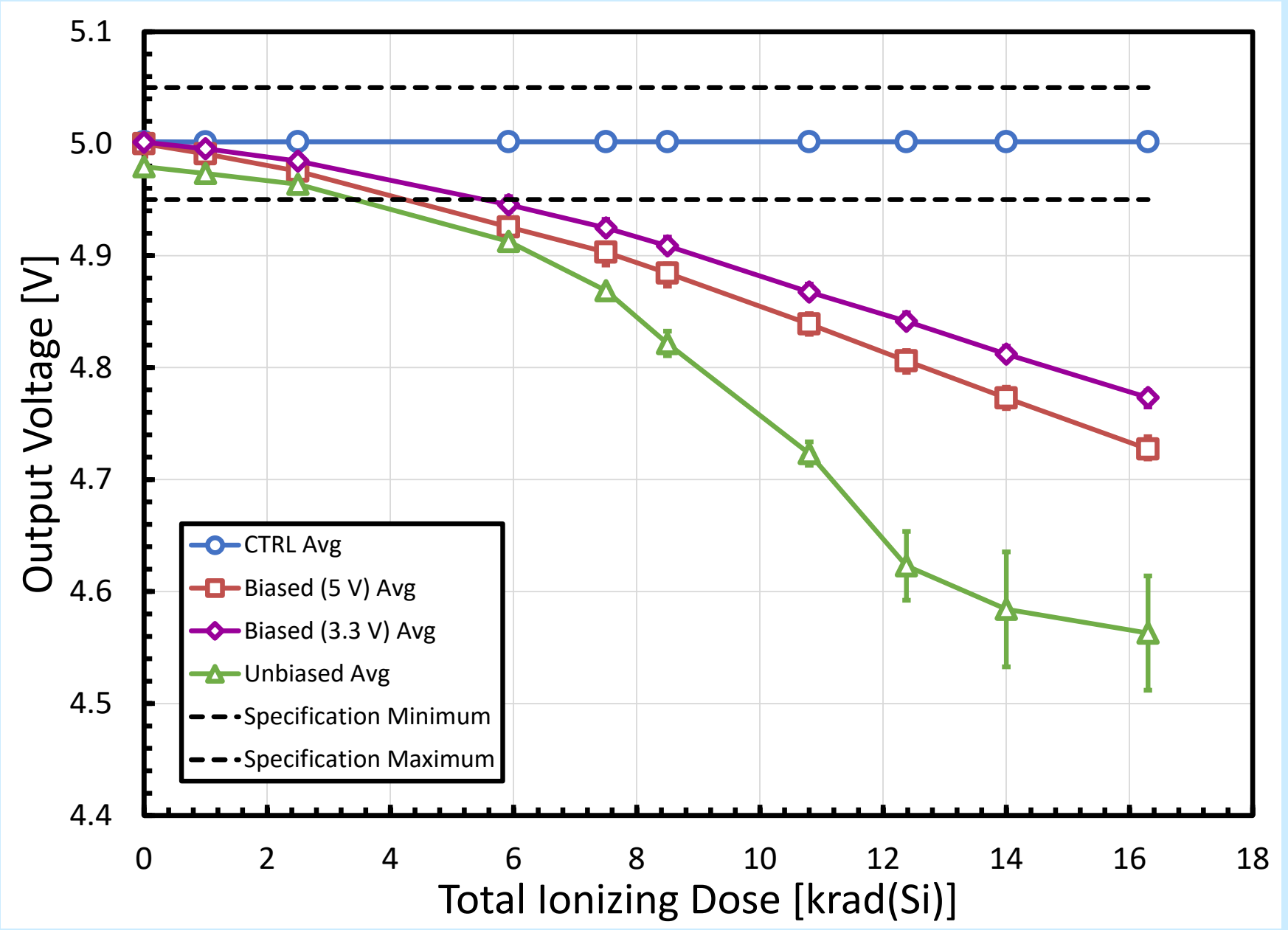

Fig. 3: LP2951 Output Voltage (V) vs. Total Ionizing Dose (krad(Si)).

Summary

We have presented data from recent TID, DDD, and SEE tests on a variety of devices. It is the authors' recommendation that this data be used with caution due to many application- or lot-specific test conditions. We also highly recommend that lot-specific testing be performed on any commercial devices, or any devices that are suspected to be sensitive. As in our past workshop compendia of GSFC test results, each DUT has a detailed test report available online describing in further detail, test method, test conditions/parameters, test results, and graphs of data.

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