Compendium of Current Heavy Ion Single-Event Effects Test Results for Candidate Electronics for NASA Johnson Space Center

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***Abstract*—We present radiation effects test results and analysis produced by NASA JSC in 2021 for candidate electronic components and devices. Devices tested include integrated circuits, MOSFETs, DC-DC converters, and various commercial solutions.**

I. Introduction

The need to choose electronics for a variety of missions, environments, applications, and durations continues at NASA Johnson Space Center (JSC) in support of hardware development for human spaceflight missions, including—International Space Station (ISS), Gateway to be launched into cislunar near-rectilinear halo orbit, exploration of Lunar surface, and eventually onto Mars.

ISS operates in a relatively benign space radiation environment in Low-Earth Orbit (LEO). There is a region, known as the South Atlantic Anomaly, where the orbit crosses trapped protons from the innermost Van Allen belt. Due to the unique ISS radiation environment, non-critical electronics have been successfully certified for flight with low-fluence 200 MeV proton tests for nearly three decades [1,2].

In recent years, the focus is shifting to harsher space radiation environments. In near-future missions, avionics supporting human spaceflight missions will be exposed to Galactic Cosmic Radiation (GCR) and potentially Solar Particle Events (SPE). GCR consist of protons and heavy ions ranging from helium to iron that span many orders of magnitude in energy. SPEs are primarily composed of protons, although can include heavy ions as well. Particle energy is higher for GCR than for SPE [3].

Thereby, program requirements for availability and survivability necessitate heavy ion Single-Event Effects (SEE) testing. Largely dependent upon our ability to remove device or hybrid packaging and samples being provided as piece-parts or circuit boards, traditional characterization testing is accomplished with low-energy ion beams or destructive screening tests leverage high-energy ion beams.

This paper summarizes 2021 heavy ion test results and analysis and provides generic information to the reader to assess radiation performance in various radiation environments. Tests utilized low-energy ion beams at Texas A&M University (TAMU) in College Station, TX and leveraged special techniques [3] with the high-energy ion beams at the NASA Space Radiation Laboratory (NSRL) located within the Department of Energy's Brookhaven National Laboratory in Upton, NY.

II. Test Protocol

A. Low-Energy Heavy Ion Testing

Low-energy heavy ion beams were used to characterize parts at specific high Linear Energy Transfer (LET) depending on mission and/or risk avoidance criteria. It is well understood that this requires delidding, or removal of packaging materials. Table I lists information on the low-energy ion beam. An aluminum degrader adjusted the surface LET on each part.

Table I: Energy, LET, and range in silicon for low-energy heavy ion beams used at TAMU

Ion	Energy (MeV)	Surface LET (MeV-cm^2/mg)	Peak LET (MeV-cm^2/mg)	Range (µm)
Kr^{84}	1259	25.4	41.0	131

B. High Energy-Heavy Ion Testing

High-energy heavy ion beams were used to characterize parts at specific low LET and for destructive screening scans above a certain LET threshold--typically 37 MeV-cm^2/mg. Complex parts packaging is often too difficult or expensive to remove making high-energy heavy ion beams the only suitable test method; the Orion Multipurpose Crewed Vehicle program encountered this problem [4]. For more information on the capabilities of the staff and facility, see the NSRL user guide [5]. Table II lists information on the high-energy ion beams selected for testing. High-Density Polyethylene (HDPE) degraders were placed in the beam to scan the Bragg Peak through each part in a similar manner as described in [3].

Table II: Energy, LET, and range in silicon for high-energy ion beams used at NSRL

Ion	Energy (MeV/n)	Surface LET (MeV-cm^2/mg)	Peak LET (MeV-cm^2/mg)	Range (mm)
Kr^{84}	383	3.26	41.0	26.9
Ag^{107}	475	5.02	59.4	28.4
Tb^{159}	446	9.32	78.2	21.4
Bi^{209}	359	17.6	100.0	12.2

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III. Test results overview

Table III is a summary of the test results. For each sample, part number, manufacturer, Lot Date Code (LDC) information where available, device function, technology / process, sample size, test facility (including test date), and test results (including configuration, effects, Weibull parameters, and remarks as necessary/available). Single-Event Latchup (SEL), Single-Event Burnout (SEB) and Single-Event Gate Rupture (SEGR) are categorized as Destructive SEE (DSEE). Single-Event Functional Interrupt (SEFI) and Single-Event Transient (SET) are categorized as Non-Destructive SEE (NDSEE). Where listed, units for LET are MeV-cm^2/mg and for cross sections are cm^2 or cm^2/device as applicable.

IV. Test Results and Discussion

In this section of the full paper, more detail for individual test results may be discussed with figures and tables to provide more information as required.

V. Conclusions

This paper presented summarized test data results for a variety of parts. As previously mentioned, more detail will be presented in the full data workshop paper.

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Table III: Summary of heavy ion test results produced at NASA JSC in 2021

Part Number	Manufacturer	LDC	Device Function	Technology / Process	Sample Size	Test Facility (Test Date)	Test Results (Configuration, Effects, Weibull Parameters, Remarks)
Analog / Linear / Mixed Signal							
TAS2505	Texas Instruments	-	speaker amplifier & audio processor	Bi(?)CMOS	1	TAMU (Oct. 2021)	No DSEE observed at LET=37 to 3.0E7 ions/cm^2
Digital / Logic							
ATMEGA128	Atmel	1838	microcontroller	CMOS	3	TAMU (Oct. 2021)	Biased and unbiased corruption of on-chip EEPROM and Flash memories. Results/discussion available in full paper.
Field-Effect Transistors (FETs)							
BSS806NE	infineon	-	150 V_{DS} n-channel	MOS	4	TAMU (Oct. 2021)	V_{DS}=5, 10, 15, & 20V, V_{GS}=0V, normal incidence, Kr^{84} range (Si)=61.4µm: No DSEE observed w/ 1 sample to 1.0E6 ions/cm^2 @ LET_{PASS}=28.6 No DSEE observed w/ 4 samples to 1.0E6 ions/cm^2 @ LET_{PASS}=37.0
NVBLS4D0N15MC	onsemi	-	150 V_{DS} n-channel	MOS	5	NSRL (Nov. 2021)	V_{DS}=120V, V_{GS}=0V, normal incidence: No DSEE observed* to 5.0E5 ions/cm^2 @ LET_{PASS}=9.3, 10.4, & 12.0 SEB and SEGR w/ >=2.8E5 ions/cm^2 @ LET_{FAIL}=17.0 *SEGR w/ 1 over-tested sample to 5.0E6 ions/cm^2 @ $LET_{OVERTEST}$=9.3 V_{DS}=150V, V_{GS}=0V, normal incidence: SEB observed @ LET_{FAIL}= 12 to 8.9E4 ions/cm^2
SFC85N9051	Solid State Devices Incorporated	-	900 V_{DS} n-channel	SiC	3	TAMU (Oct. 2021)	V_{DS}=45, V_{GS}=0V, normal incidence, Kr^{84} range (Si)=61.4µm: No DSEE observed w/ 3 samples to 5.0E5 ions/cm^2 @ LET_{PASS}=37.0 V_{DS}=90, V_{GS}=0V, normal incidence, Kr^{84} range (Si)=61.4µm: µSEGRs before full SEGR w/ 1 sample to 5.0E5 ions/cm^2 @ LET_{FAIL}=28.6 µSEGRs before full SEGR w/ 1 sample to 5.0E5 ions/cm^2 @ LET_{FAIL}=37.0 V_{DS}=12, V_{GS}=0V, normal incidence, Kr^{84} range (Si)=61.4µm: SEGR w/ 1 sample @ LET_{FAIL}=37.0 to 5.0E5 ions/cm^2
SFF80N20S1	Solid State Devices Incorporated	-	200 V_{DS} n-channel	SiC	3	TAMU (Oct. 2021)	V_{DS}=45, 75, 100, 110, & 115V, V_{GS}=0V, norm. inc., Kr^{84} range (Si)=61.4µm: No DSEE observed w/ 3 samples after 5.0E5 ions/cm^2 @ LET_{PASS}=37.0 V_{DS}=120, 125, & 450, V_{GS}=0V, norm. inc., Kr^{84} range (Si)=61.4µm: SEB and SEGR w/ 3 samples >=3.0E4 ions/cm^2 @ LET_{FAIL}=37.0
SFF120N10S1	Solid State Devices Incorporated	-	100 V_{DS} n-channel	SiC	3	TAMU (Oct. 2021)	V_{DS}=45, 75, & 80V, V_{GS}=0V, norm. inc., Kr^{84} range (Si)=61.4µm: No DSEE observed w/ 3 samples after 5.0E5 ions/cm^2 @ LET_{PASS}=37.0 V_{DS}=85 & 100, V_{GS}=0V, norm. inc., Kr^{84} range (Si)=61.4µm: SEB and SEGR w/ 3 samples >=1.7E4 ions/cm^2 @ LET_{FAIL}=37.0
SQP120N06-06	Vishay	-	60 V_{DS} n-channel	MOS	7	NSRL (Nov. 2021)	V_{DS}=28V, V_{GS}=0V, normal incidence: No DSEE observed w/ 2 samples after 5.0E5 ions/cm^2 @ LET_{PASS}=17.0 SEGR discovered in 1 of 2 samples after 5.0E5 ions/cm^2 @ LET_{FAIL}=27.6 No DSEE observed w/ 2 samples after 5.0E5 ions/cm^2 @ LET_{PASS}=34.9 V_{DS}=35V, V_{GS}=0V, normal incidence: No DSEE observed w/ 1 sample after 5.0E5 ions/cm^2 @ LET_{PASS}=34.9 V_{DS}=40V, V_{GS}=0V, normal incidence: No DSEE observed w/ 2 samples after 5.0E5 ions/cm^2 @ LET_{PASS}=17.0 SEB and SEGR w/ 3 samples >=1.8E5 ions/cm^2 @ LET_{FAIL}=34.9 V_{DS}=45V, V_{GS}=0V, normal incidence: SEB w/ 2 samples >=3.9E5 ions/cm^2 @ LET_{FAIL}=17.0
Power							
DCM2322	Vicor	-	DC-DC converter	hybrid	5	NSRL (Nov. 2021)	DSEE 95%CI upper limit, V_{IN}=120V: L_{th}=3.0, σ_{sat}=3.9E-4, W=20, S=1.08. Observed DSEE failures at LET=3.3, 5.0, 9.3, 17.0. Failed open or undulating output voltage. No NDSEE data collected.
DCM3623	Vicor	-	DC-DC converter	hybrid	5	NSRL (Nov. 2021)	DSEE 95%CI upper limit, V_{IN}=120V: L_{th}=3.0, σ_{sat}=1.1E-4, W=7.0, S=1.25. Observed DSEE failures at LET=3.3, 5.0, 9.3, 17.0. Failed open or undulating output voltage. No NDSEE data collected.

Part Number	Manufacturer	LDC	Device Function	Technology / Process	Sample Size	Test Facility (Test Date)	Test Results (Configuration, Effects, Weibull Parameters, Remarks)
Power (continued)							
RS12-2412SZ	RECOM	-	DC-DC converter	hybrid	10	NSRL (Nov. 2021)	DSEE for V_{IN}=36V: L_{ent}=19.1, σ=8.5E-6 & L_{ent} =21.9, σ=1.0E-5. Not observed at L_{ENT}=17.0,17.6,18.3, σ_{null}<=1.0E-6 for each DSEE for V_{IN}=28V: L_{ent} =20.3, σ=2.3E-6 & L_{ent} =21.9, σ=1.0E-5. Not observed at L_{ent} =17.0,17.6,18.3,19.1, σ_{null}<=1.0E-6 for each SET 95%CI upper limit, V_{IN}=36&28V: L_{th}=3.0, σ_{sat}=2.4E-4, W=9.8, S=3.00. $\Delta t_{self-recovery}$ = 20-25 milliseconds, -ΔV_{out} = 1.2-2.7 volts SEFI 95%CI upper limit, V_{IN}=36&28V: L_{th}=7.1, σ_{sat}=2.6E-5, W=8.0, S=2.30 $\Delta t_{self-recovery}$ unknown but >100 milliseconds, -ΔV_{out} = 7-11 volts
Miscellaneous							
A660	Aitech	-	Network Switch	COTS	1	NSRL (Nov. 2021)	DSEE @ LET=9.3
ACM-DB-3M	Doodle Labs	-	Wi-Fi Radio	COTS	2	NSRL (Nov. 2021)	No DSEE observed w/ 1 sample after 1.0E7 ions/cm^2 @ LET=17.6 No DSEE observed w/ 2 samples after 10 steps of 1.0E6 ions/cm^2, LET>=37 SEFI 95%CI upper limit: L_{th}=1.0, σ_{sat}=1.0E-2, W=15.0, S=3.0
AP650X	Aerohive	-	Wireless Access Point	COTS	1	NSRL (Nov. 2021)	DSEE: Failed at LET = 17.6+, highest survival LET= 9.3+ Recoverable SEFIs: σ=2.85E-4 @ L=3.3, σ=1.34E-4@ L=5.0, σ=6.85E-5 @ L=9.3
AWK-4131	MOXA	-	Wireless Access Point	COTS	1	NSRL (Nov. 2021)	DSEE @ LET=9.3
MC031CG-SY-FV	Ximea	-	4K HD camera	COTS	2	NSRL (Nov. 2021)	No DSEE observed w/ 1 sample after 6.0E6 ions/cm^2 @ LET=9.3 Nonrecoverable NDSEE observed after >1.0E6 ions/cm^2 @ LET=17.6+ SEFI 95%CI upper limit: L_{th}=1.0, σ_{sat}=8.0E-3, W=6.0, S=3.0