

Compendium of Recent Total Ionizing Dose Test Results Conducted by the Jet Propulsion Laboratory from 2003 through 2009

Aaron J. Kenna, Bernard G. Rax, Dennis O. Thorbourn, Richard D. Harris, and Steven S. McClure

Abstract— Total Ionizing Dose (TID) and Enhanced Low Dose Rate Sensitivity (ELDRS) tests are being performed at the Jet Propulsion Laboratory on a continual basis to support various upcoming space missions and research and development projects. This compendium summarizes the results of the tests carried out over the last six years.

Index Terms— Co60, Enhanced Low Dose Rate Sensitivity (ELDRS), Microelectronics, Radiation Effects, Total Ionizing Dose (TID).

I. INTRODUCTION

TODAY's microelectronic devices are used in numerous military, commercial sector and space applications which all demand a high amount of reliability and functionality. This is especially true for spacecraft applications where device's electrical parametric degradation due to harsh space radiation can mean the difference between mission success and mission failure. To ensure both the reliability and functionality of these devices over the life of a mission, it is necessary for these devices to first undergo total ionizing dose (TID) effect testing. Data from this testing is then used to determine the radiation-hardness and functionality of the devices as well as to establish parameter sensitivity to radiation as a measure of reliability.

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The test results presented in this compendium will only cover recent total ionizing dose (TID) effect testing conducted at the Jet Propulsion Laboratory (JPL) from 2003 through 2009, and is an extension of the last compendium presented in this forum [1].

II. EXPERIMENTAL DETAIL

A. Total Ionizing Dose Radiation Facilities

JPL utilizes two Cobalt-60 sources in a quest to ascertain the radiation hardness, reliability and functionality of microelectronic devices used in spacecraft applications. These devices must be able to survive and operate in harsh space radiation environments in order for a successful mission.

JPL's radiation facilities consist of two separate, model 81-24, room irradiators manufactured by J.L. Sheppard and Associates [2] where the dose rate can be varied by increasing or decreasing the distance between the source and the device. One facility is called the high dose rate (HDR) facility where irradiation dose rates can be varied from 100 rad(Si)/s to 0.1 rad(Si)/s. The second facility is called the low dose rate (LDR) facility where irradiation dose rates can be varied from 1 rad(Si)/s to 0.001 rad(Si)/s. Irradiating at a LDR sometimes yields different effects from irradiating at a HDR on the same lot of devices. This effect is called Enhanced Low Dose Rate Sensitivity (ELDRS). Typically, HDR irradiations are carried out at 25 to 50 rad(Si)/s while LDR irradiations are carried out at 0.005 to 0.01 rad(Si)/s.

B. Test Methods

Applying a bias condition to the test method based upon the load of the electrical circuitry of the project application is critical during irradiation, and TID test results are directly affected as a result of bias conditions. Circuits that are highly sensitive to ELDRS are usually more affected when they are irradiated unbiased, but both unbiased and biased conditions must be considered per project application [3]. Bias conditions can consist of either static or dynamic bias based upon the device's individual application and the test method.

TID testing at JPL is generally conducted at ambient room temperature. Devices can be tested under specific temperatures in order to better simulate an environment per project application. Subjecting devices to high temperatures after

irradiation is an option for determining if a given dose effect can be annealed out.

In most cases, TID irradiations at JPL are conducted in stepped levels and are tested incrementally, while some devices can be remotely monitored and tested during irradiation.

A Pb/Al (Lead/Aluminum) shield is used as a JPL standard practice in accordance with MIL-STD-883, method 1019 “Ionizing Radiation (Total Dose) Test Procedure” [4]. The Pb shielding surrounding the devices during an irradiation reduces exposure from low energy gamma rays scattered in the room, and the Al creates an equilibrated environment. When a project application requires proton irradiation to produce the ionizing dose, these irradiations could be conducted at the University of California, Davis (UCD) Crocker Nuclear Laboratory (CNL) or the Indiana University Cyclotron Facility (IUCF).

C. Measurement Methods

The measurement methods used at JPL to extract data from microelectronic devices include two ATE (Automatic Test Equipment) systems: Eagle ETS-300 and an Analog Devices LTS-2020. Additional bench-top parametric measurements are made as required per project application. Parameters monitored are dictated by a combination of the manufacturer’s data specification sheet, Defense Supply Center of Columbus (DSCC) Standard Microcircuit Military Specification Drawing [5], and the project application.

III. TEST RESULTS & DISCUSSION

JPL’s TID test results have been compiled over the last six years and are listed in Table 1. Information within Table 1 identifies the Standardized Military Drawing (SMD) part number, generic part number, manufacturer, description, date code, process technology, test type, dose rate, dose rate level for first parametric failure, dose rate level for first functional failure, and provides a brief summary of results. General test results are provided in the following for a few selected devices while full details are available on JPL’s Radiation Database [6] where the final test reports and data can be reviewed.

A. LM113

The LM113 is a temperature compensated, low voltage reference diode packaged in a TO-46 can. This is a bipolar device from National Semiconductor. This test was conducted with a combination of flight lot devices with date code X8C0501A (5962-9684302VXA) which were tested at LDR (0.01 rad(Si)/s) only, and a set of commercial lot devices with date code 64AB (LM113H) that were tested at both LDR and HDR (25 rad(Si)/s).

In general, the devices that were unbiased during irradiation showed a considerable amount of degradation than those that were biased. There were no catastrophic failures observed. All parameters except forward voltage drop were observed to exceed the manufacturer’s specification limits during the test

for the unbiased condition at LDR for both the flight and the commercial lot devices. For the commercial devices which were irradiated at both HDR and LDR, the LDR degradation was considerably larger than that observed at HDR indicating a strong ELDRS effect. An example of this can be seen for the Dynamic Impedance parameter for commercial devices in Figure 1 below where the unbiased commercial devices at LDR first exceed the manufacturer’s upper specification limit of 1 ohm above the 55 krad level compared to all other commercial devices.

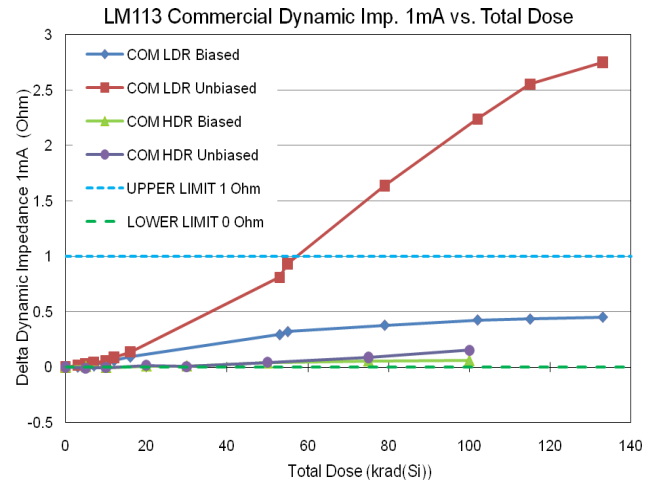


Figure 1 -LM113-Average values of 5 commercial devices for each bias condition at HDR and LDR for Dynamic Impedance vs. Total Dose. The manufacturer’s specification limit is 0 to 1 Ohm. LDR unbiased devices exceeded the manufacturer’s upper specification limit above the 55 krad level and exhibited significantly more degradation than biased devices at LDR and all other devices at HDR indicating an ELDRS effect where the unbiased condition is the worst case.

B. AD537

The AD537SH/883B is a bipolar, monolithic voltage-to-frequency converter manufactured by Analog Devices and packaged in a TO-100 can. These devices with date code 0719A and 0719B were tested at HDR (25 rad(Si)/s) and at LDR (0.01 rad(Si)/s). All devices irradiated at HDR first exceeded the manufacturer’s specification above the 30 krad level for the Input Bias Current parameter. Functional failures were observed for the Positive Linearity Error parameter above the 75 krad level when the unbiased devices exceeded manufacturer’s specification upper limit by a factor of 15. At LDR, unbiased devices exhibited early parametric degradation above the 5 krad level for the Absolute Temperature Reference parameter and the Input Bias Current parameter which exceeded the manufacturer’s upper specification limit of 100nA above the 10 krad level. An example of the Input Bias Current parameter at LDR can be seen in Figure 2 below demonstrating unbiased devices are the worst case when compared to biased devices which did not display as much considerable degradation as a function of dose.

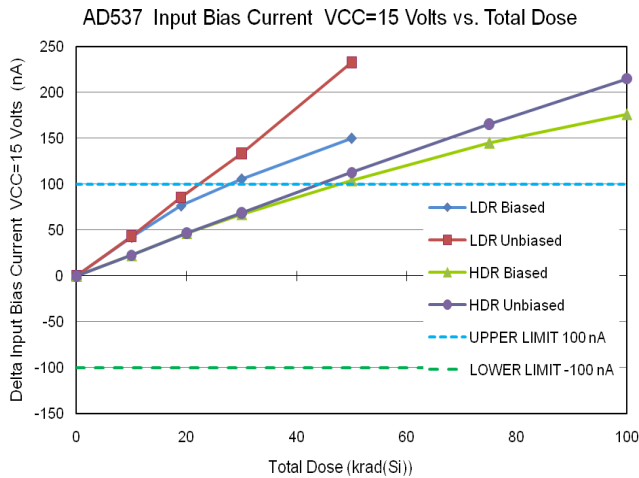


Figure 2 -AD537-Average values of 5 devices for each bias condition at HDR and LDR for Input Bias Current vs. Total Dose. LDR unbiased devices exceeded the manufacturer's upper specification limit of 100 nA above the 10 krad level and by the 50 krad level devices had exceeded specification by a factor of less than three. Unbiased devices at LDR are the worst case.

C. AD667

The AD667-713F is a 12-bit digital-to-analog converter manufactured by Analog Devices and packaged in a 28 pin flat pack. These devices with date code 0438 and were tested at HDR (25 rad(Si)/s) and LDR (0.01 rad(Si)/s). Since the device does not come in a radiation-hardened version, a radiation lot acceptance test (RLAT) was conducted to ascertain its radiation tolerance. All devices and parameters tested demonstrated a wide part-to-part variation that extended the 99/90 limits considerably, including but not limited to UZE LDR data UFS LDR data and BZE LDR data.

Devices at LDR exhibited consistently larger degradation than at HDR and devices irradiated unbiased are consistently the worst case and exhibited a significant ELDRS effect. An example of this can be seen in Figure 3 for the Unipolar Zero Error parameter. The ratio of HDR to LDR failure level was as large as three in some cases. Some divergent behavior was seen in comparison from LDR to HDR. Part-to-part variation, however, appears to drive the response to a great extent. Several of the parameter violated the manufacturer's lower specification limit of -2 LSB, but the devices were functional throughout the tested levels.

AD667 Unipolar Zero Error VCC= +/-12 Volts vs. Total Dose

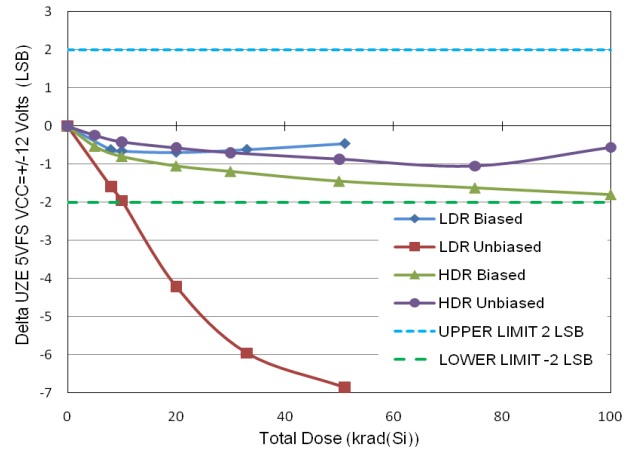


Figure 3 -AD667-Average values of 5 devices for each bias condition at HDR and LDR for Unipolar Zero Error vs. Total Dose. The LDR unbiased devices were first to exceed the manufacturer's lower specification limit of -2 LSB at the 8 krad level, and by the 20 krad level, all devices were out of specification. LDR unbiased devices exhibited a significant ELDRS effect.

IV. SUMMARY

This compendium provides a summary of recent TID test results on microelectronic devices tested at JPL from 2003-2009. This data is only intended to be used as a reference guide in consideration of devices for spacecraft applications with a radiation design margin (RDM) requirement or use in a possible radiation environment. Readers are encouraged to review individual final reports and data on JPL's Radiation Database [6]. The research described in this paper was carried out at JPL, California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA). References herein to any device, process, manufacturer or otherwise does not constitute or imply endorsement by the United States Government, JPL, NASA, or the California Institute of Technology [1].

V. REFERENCES

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TABLE 1

<u>JPL Log Num.</u>	<u>Generic Part Number</u>	<u>SMD Part Number</u>	<u>MFR</u>	<u>Description</u>	<u>Date Code</u>	<u>Technology</u>	<u>Test Type</u>	<u>Dose Rate krad(SiSec)</u>	<u>Dose for Parametric Failure</u>	<u>Dose for Functional Failure</u>	<u>Test Results</u>
Analog to Digital Converters											
2161	AD670	AD5670-INZ	ADI	8-Bit ADC	0626	Bipolar	TID - HDR / LDR	25, 0.01	6k < 10	8-10LDR, 10-20 HDR	LDR commercial lot exceeded Input Bias Current at 6 krad and functionally failed between 8 and 10 krad. LDR unbiased exhibited more degradation than all other conditions typical of an ELDERS effect.
2203	AD670	AD670-009	ADI	8-Bit ADC	0443A	Bipolar	TID - HDR	25	< 10	15-20k	Flight lot 2 nonfunctional between 15-20 krad.
2179	AD670	AD670-703D	ADI	8-Bit ADC	9851A	Bipolar	TID - LDR	0.01	< 10	13-17k	Flight lot 1 exhibits evidence of ELDERS effect.
2204	AD574	5962R8512701VXA	ADI	12-Bit ADC	0247A,0622	Bipolar	TID - HDR / LDR	25, 0.01	>10 HDR	50k LDR	HDR exceeded spec above 10 krad for differential and integral linearity. No functional failures at HDR. Functional failure at 50k at LDR. Unbiased are worst case.
2055	LTC1417	LTC1417	LTC	14-Bit ADC	0240	CMOS	TID - HDR / LDR	25, 0.01	20k	30k	Catastrophic Failure at 30 krad, not recommended above 20 krad.
2001	LTC1419	LTC1419AGC	LTC	14-Bit ADC	9926C/D	CMOS	TID - HDR	50	20-30k	30k	Recommended for use below 15 krad.
2092	LTC1604	LTC1604AIG	LTC	16-Bit ADC	0123	CMOS	TID - HDR	100	100k	100k	Functional failure accompanying parametric degradation up to 100 krad.
2243	LTC1608	LTC1608AIG	LTC	16-Bit ADC	0422	CMOS	TID - HDR	25	10k	50k	Significant functional failures in the Nap and Sleep mode below 50k and more than an order of magnitude out of specification at 100 krad. Unbiased remained within specification beyond 100 krad on for these same parameters.
2252 2244	AD8138	AD8138ARMZ-ND	ADI	Differential ADC Driver	8-Mar	CMOS	TID - HDR / LDR	50, 0.01	N/A	N/A	Devices at HDR remained functional to 3 Mega Rad while slightly remaining initially out of spec throughout test. LDR are functional to 500 krad.
2174	AD7714	AD7714YRU	ADI	24-Bit ADC	0543, 0539, 0543	CMOS	TID - HDR	50	7.5k	10-15k	Parametric degradation does not impact functionality.
Analog Switches											
N/A	LS2812D LS2805S LS2803RS	5962-0524001KXA 5962-0524101KXA 5962-0523901KXA	IR	Hybrid DC/DC Switching Converter	N/A	BiCMOS	TID - HDR / LDR	25, 0.01	N/A	N/A	Significant differences between LDR and HDR output voltage parameters implies ELDERS. Degradation up to 150mV efficiency on input voltage or load condition. Most DC parameters exhibited little to no degradation. Transient parameters and turn-on overshoot were degrading with total dose but remained within specification.
N/A	LS2805RS	5962-0524001KXA	IR	DC/DC 3.3 V Switching Power Converter	N/A	BiCMOS	LDR	0.01	15k	N/A	Out of specification at 50 krad. ELDERS evidence. Output voltage degradation as well as output rise time and turn on delay decreased. Overshoot voltage, max output Voltage, inhibit and efficiency good.
N/A	LS2805s	5962-0524101KXA	IR	DC/DC Switching Power Converter	N/A	BiCMOS	HDR	25	N/A	N/A	Unbiased exhibiting more degradation than biased to 100 krad. Output rise time and turn on delay time increased by more than 50%. No change in efficiency, output voltage, turn on overshoot, max output transient voltage, and stable recovery time.
N/A	LS2812D	5962-0524001KXA	IR	DC/DC 12V Switching Power Converter	N/A	BiCMOS	LDR	0.01	15k	N/A	Output voltage, output rise time and turn on delay decrease. Overshoot voltage increase, but max output voltage, inhibit and efficiency good.

JPL Log Num.	Generic Part Number	SMD Part Number	MFR	Description	Date Code	Technology	Test Type	Dose Rate krad(Si/sec)	Dose for Parametric Failure	Dose for Functional Failure	Test Results
Sample & Hold											
2215	LF198	5962-8760801QZA	NSC	Sample and Hold Amplifier	0422	Bipolar	HDR / LDR	25, 0.01	20k	N/A	Ileak and IIB out of specification at 20 krad at LDR, ELDRS response, biased worst case for most parameters, unbiased sensitivity exists.
2048 to 2051	2N3700UB	MRFC901	Semicon, ST Micro, New England Micro	NPN Transistor	P0241, 9736, 0147, 0022, 217A	Bipolar	TID - HDR	25	20k	N/A	All devices performed within specification for life up to 10 krad. Devices began to fail spec for life at Ic=0.1mA at 20 krad. Hfe at Ic = 10mA remained within specification beyond 50 krad, to eventually fail at 100 krad. Hfe at Vce = 80V performed somewhat better at the lower dose levels but was slightly worst than Hfe at Vce = 10V at 100 krad. Overall, this lot performed significantly better than Motorola lots tested in the early 1990's.
OpAmps											
2056	AD823	MD823AR0237K53484 AD823AR9821G63958	ADI	High Speed JFET-Op Amp	0237, 9821	JFET-Bipolar	TID - LDR	0.005	5k	5.4k	Catastrophic failure at levels greater than 5.4 krad, not recommended for use in space applications.
2137 2138	LTI211	LT1121CN8	LTC	Dual Op Amp	0422	Bipolar	TID - LDR	0.005	< 3.5k	N/A	Device tested up to 24 krad with parametric degradation, evidence of ELDRS present.
2163	LM124WR	5962R9950401VDA	NSC	Quad Op Amp	0434	Bipolar	TID - HDR / LDR	0.005	N/A	N/A	Little degradation seen up to 16 krad with all parameters within specification.
2131- 2134	OP97	5962-8954401PA	ADI	Op Amp	0419, 0501, 0504, 0506A	Bipolar	TID - LDR	0.005	7.5k	> 10k	Unbiased worst case. Device tested to 24.5 krad with severe parametric degradation and catastrophic failure at higher levels.
2178	OP484/NS5337	5962-R0051701VDA	GID	Quad Op Amp	0431A	Bipolar	TID - LDR	0.010	12k	N/A	Device tested to 55 krad with most parameters initially exceeding 99/90's, VOS and VOH parameters Out of specification at 12 krad.
2239 2241	AD648TQQMLV	5962-9753502VPA	ADI	Low Power BIFET-OpAmp	0747, 0629A	Bipolar	HDR / LDR	25, 0.01	<5k	50k	Input bias current out of specification <5 krad at LDR. Biased out of specifications at 50 krad for IOS, OLG, Slew Rate. Unbiased out of specifications at 50 krad for VIO, and IOUT.
2280	OP400	5962-8777101V3A	ADI	Bipolar Op Amp	0502	Bipolar	TID - HDR	25	10k	N/A	Input bias current out of spec at 10 krad, voltage gain out at 20 krad, slew rate out at 30 krad. VOS, IIO, Vout, CMRR, Is Sink/Source out at 50 krad. PSRR out at 100 krad.
2269	RH1498	RH1498MW	LTC	Dual Op Amp	0605	Bipolar	TID - HDR	25	0k	75k	99/90's initially failing AOL, offset voltage, CMRR. Functional failures above 75 krad for CMRR, and PSRR. Offset and bias current out of specification at 500 krad. Only tested biased.
2033	AD829SE	5962-9312901M2A	ADI	Video Op Amp	0005	Bipolar	TID - LDR	0.01	20k	30k	Unbiased devices within specification to 20 krad and failed marginally at 30 krad for both positive and negative input bias current.
2046	MC350272	8E505-K001-RB	Motorola	Dual Op Amp	B1-R13	Bipolar	TID - LDR	0.01	30k	N/A	Unbiased exhibited marginal parametric failures for input offset voltage, input offset current, output source current, and slew rate at 30 krad.
2276	RH1814	RH1814MW	LTC	Quad Op Amp	0414A	Bipolar	TID - LDR	0.01	30k	N/A	Parameter limits are exceeded in biased devices at 30 krad for Isink, and at 50 krad for AOL, as well as some +/-99/90's limits are out of spec.
2277	RH1078	RH1078MW	LTC	Dual Op Amp	0741A	Bipolar	TID - LDR	0.01	N/A	N/A	No parametric or functional failures to 50 krad with the exception of some +/- 99/90's out of specification.
Memory											
N/A	512 Mb SDRAM	EDS5104ABTA-75	ELPIDA	Memory Module	0639	CMOS	TID - HDR	50	N/A	N/A	No parametric or functional failures for biased and unbiased. Data retention measurements seen to indicate that temperature plays a significant role in retention time.
Voltage Comparators											
2162 2171	RH119	RH119W	LTC	Dual Comparator	0429A	Bipolar	HDR / LDR	25, 0.005	N/A	N/A	No failures to 15 krad, good part to part agreement. Input offset current exhibiting the greatest amount of degradation but all devices remained within specifications, generally biased worst case for most parameters, no evidence of ELDRS effect.
2011	LM193	M38510/11202BPA	NSC	Dual Voltage Comparator	9950G0551	Bipolar	TID - HDR / LDR	50, 0.01	3.6k	15k	Significant ELDRS effect observed. Unbiased worst case at LDR. Biased worst case at HDR, usable to 15-20 krad depending on parametric tolerance.
2278	PM139	5962R8773901VDA	ADI	Quad Voltage Comparator	0046A	Bipolar	TID - LDR	0.01	N/A	N/A	No parametric or functional failures to 50 krad.

JPL Log Num.	Generic Part Number	SMD Part Number	MFR	Description	Date Code	Technology	Test Type	Dose Rate krad(SiSec)	Dose for Parametric Failure	Dose for Functional Failure	Test Results
Linear Voltage Regulators											
2078	LP2951	LP2951WG883	NSC	Low Dropout Voltage Regulator	H9D0248D	Bipolar	TID - LDR	0.05	5k	8k	Unbiased worst case, at 5 krad the output voltage is greatly reduced at all loads. This device is not recommended for use in space applications.
2139 to 2141	LP2953	LP2953A	NSC	Low Dropout Voltage Regulator-300mA	0228, 0417	Bipolar	TID - HDR / LDR Protons	0.005	1.6k	2.96k	Biased devices degraded more severely than unbiased devices at higher currents as biased devices were pre-irradiated with protons and unbiased were not.
2067	LM2941	LM2941	NSC	Low Dropout Voltage Regulator-1A	0317, 0337	Bipolar	TID - HDR / LDR / Protons	0.05	N/A	17-24k LDR	Catastrophic Failure at very low total dose levels between 17 to 24 krad, lot to lot variability of failure level.
2167	RH117	RH117H	LTC	Positive Voltage Regulator	0527	Bipolar	TID - HDR / LDR	25, .005	N/A	N/A	Device tested up to 15 krad with very little parametric degradation, no indication of ELDRS at this level
2065	RH137	RH137	LTC	Negative Voltage Regulator	0211A	Bipolar	TID - LDR / Protons	0.005	N/A	N/A	Device tested up to 50 krad with very little parametric degradation, no indication of ELDRS. The initial proton irradiations caused relatively small changes in device properties.
2265	RH117	RH117H	LTC	Adjustable Positive Voltage Regulator	0750A	Bipolar	TID - LDR	0.04	150k	N/A	All devices were unbiased and first out of specifications at 150 krad for VREF, VOUT, Load/Line Regulation, Iadjust and Dropout.
2279	LM1577K	5962-9216601MXA	NSC	Boost Regulator	0725	Bipolar	TID - HDR / LDR	25, 0.01	1k LDR	2.5k LDR	All device at HDR have catastrophically failed between 1 and 2.5k. Unbiased devices at LDR are catastrophically failing output voltage at load for all input voltage conditions and have no switching action. Biased have similar trend and are showing increasing amounts of degradation in load and line regulation.
2283	LP2953AMWG	5962-9233601VXA	NSC	Low Dropout Voltage Regulator	0826	Bipolar	TID - LDR	0.01	N/A	5.5k	All devices functionally failing specification at 5.5 krad.
Power Supply Supervisors											
2136 2128	MAX708	5962-936270408PA	Maxim	Power supply supervisor	0420	Bipolar	TID - HDR	50	8k	11-12k	Catastrophic Failure between 11krad and 12 krad, possible lot to lot variability of failure level.
Pulse Width Modulators											
2127	UC1845	5962-8670408PA	TI	PWM	0420A	Bipolar	TID - LDR	0.005	~4k	N/A	Device tested to 26 krad with all parameters degraded. Vref and Osc freq most affected.
Bipolar Junction Transistors											
2129	FZ1458	FZ1458TA	ZETEX	NPN Bipolar Junction Transistor	0501	Bipolar	TID - HDR	50	N/A	N/A	Devices exhibited a super linear behavior with a cubic dependence on total dose up to max tested dose of 24.5 krad.
2135	FZ1958	FZ1958TA	ZETEX	PNP Bipolar Junction Transistor	0407	Bipolar	TID - HDR	50	N/A	N/A	Devices exhibited a sub linear behavior dependence on total dose up to max tested dose of 24.5 krad.
2044	MRF901	MRF901	Motorola	NPN Transistor	PH48217AW, 572731 W	Bipolar	TID - HDR / Protons	25	300k	N/A	Comparatively, the two krs degraded similarly.
2255	LS401	LS401 TO71-6L	LIS	JFET Transistor	0743	Bipolar	TID - HDR	25	200k	N/A	First parametric failure at 200 krad for biased for parameter IGSS @ VDS=-30V
2256	LSK398	LSK398ATO71-6L	LIS	JFET Transistor	0805	Bipolar	TID - HDR	25	100k	N/A	First parametric failure at 100 krad for biased for parameter IGSS @ VDS=-30V
2272	2N918	JANTX2N918	AEI	NPN Transistor	0824	Bipolar	TID - HDR	25	75-100k	N/A	Out of specification between 75-100 krad for IC OFF high/low
2275	2N3251A	JANTXV2N3251A	MSL	PNP Transistor	0645	Bipolar	TID - HDR	25	200k	N/A	All device are out of specifications at 200 krad through 1Mega Rad for HFE 0.1mA-10mA.
2270	2N4391	2N4391	LIS	JFET Transistor	0614	Bipolar	TID - HDR	25	200k	N/A	Biased devices are worst case and out of specification at 200 krad for Idoff, IGSS through 1Mega Rad. Unbiased device are out of specification at 500 krad for Idoff through 1Mega Rad.
2271	2N4393	2N4393	LIS	JFET Transistor	0246	Bipolar	TID - HDR	25	200k	N/A	Biased devices are worst case and out of specification at 200 krad for Idoff, IGSS through 1Mega Rad. Unbiased device are within specification through 1Mega Rad.

JPL Log Num.	Generic Part Number	SMD Part Number	MFR	Description	Date Code	Technology	Test Type	Dose Rate krad/Sec	Dose for Parametric Failure	Dose for Functional Failure	Test Results
Digital to Analog Converters											
2219 2216	AD667	AD667-713F	ADI	12-Bit DAC	0737, 0438	Bipolar	TID - HDR / LDR	25, 0.01	5k LDR 20k HDR	75-100k	LDR first parametric failure at 5k, ELDRS evidence and unbiased is worst case. No functional failures. HDR first parametric failure at 20k, functional failure at between 75-100k.
2080 2081	DAC8413	DAC8413BTC/883C	ADI	12-Bit DAC	0424F, 0333F	BiCMOS	TID - LDR	0.05	> 10k	14-20k	Gradual parametric degradation above 10krad for positive supply current, amp current, INL, DNL, positive, mid, and negative scale error. Catastrophic failure between 14 and 20k. Biased worst case.
Sensors											
2142	OMH3040	OMH3040B	Optek	Hall Effect Switch	M0348	Bipolar	TID - HDR / LDR	25, 0.005	N/A	N/A	Functionally and parametrically good to 5.8 krad, leakage current degradation.
Voltage to Frequency Converters											
2234 2235 2220	AD537	AD537SH883	ADI	Voltage to Frequency Converter	0719A, 0719B, 0740	Bipolar	TID - HDR / LDR	25, 0.01	10k LDR >30k HDR	N/A	Op Amp input bias current out of specification at LDR above 10 krad. Same trend seen at HDR above 30 krad for full scale error, and PSRR. Linearity out of specification above 50 krad at HDR.
EPGA											
1180	RTSX72SU	5962-0151507QXC	Actel	Field Programmable Gate Array	5T54SX725-1CQ208E	CMOS	TID - HDR	25	50k	60k	I/O leakage out of specification at 50 krad, functional failure at 60 krad.
Multiplexer/Demultiplexer											
2273	IDTQS4A210	IDTQS4A210	Integrated Devices Tech.	2 Channel Multiplexer/Demultiplexer	X507	CMOS	TID - HDR	25	10k	N/A	Parameters remained within manufacturer's specification for unbiased conditions only. Biased devices exceeded Ice specification > 10 krad and leakage current > 50 krad.
2040 2041	MAX306	MAX306-EW/CW1	Maxwell	16 Channel Analog Multiplexer	0206, 0143	CMOS	TID - LDR	0.01	>6k	>10k	All parameters remained within specification to 6 krad with only minor (not significant) increases in leakage currents and "on" resistance. Functional failures began at 16 krad with failure to measure a valid RDS(on).
Voltage References											
2058	AD590	5962-8757104XA	ADI	Temp Transducer	0145	Bipolar	TID - HDR / LDR	0.005	10k	12k	Unbiased worst case, dose rate sensitive, evident ELDRS effect.
2009	LT1019	LT1019CN8-2.5	LTC	Voltage Reference	0040	Bipolar	TID - HDR / LDR	50, 0.01	10k	30k	ELDRS exhibited, but within specification to 10 krad.
2164 2175	LM113	5962-9684302VXA	NSC	Voltage Reference	X8C0501A/64A B	Bipolar	TID - HDR / LDR	25, 0.01	30k	N/A	HDR within specifications up to 100 krad. LDR exhibiting parametric degradation starting at 30 krad and parametrically failing specification above 50 krad.
2047 2060	LM136	8E501-K001-RB	NSC	Voltage Reference	C1-R11	Bipolar	TID - LDR	0.005	> 20k	N/A	Device tested to 20 krad with moderate parametric degradation, no functional failure.
Sensors											
2224 2218	AD652	AD652SQ883B	ADI	Voltage to Frequency Converter	0745, 0740	Bipolar	TID - HDR / LDR	25, 0.01	5k LDR 10k HDR	N/A	Reference Voltage, Input Bias Current, Clock ILL out of specification above 5 krad at LDR. Out of spec at 10 krad at HDR. Unbiased worst case, no functional failures.
Logarithmic Amplifier											
2209 2213	AD606	AD606JZ	ADI	Logarithmic Amplifier	0650, 0732	Bipolar	TID - HDR / LDR	25, 0.01	N/A	N/A	All parameters at LDR within specification to 50 krad, as well as at HDR to 100 krad.
Motor Drivers											
2037	LMD18200	LMD18200	NSC	H-Bridge Motor Driver	0046	Bi-CMOS	TID - HDR / LDR	50, 0.01	7.6k	15k	Parametric failures began at 7.6 krad with the input voltage thresholds VIH and VIL, exceeding specifications. The device continued to remain functional through the 11 krad test level with functional failures beginning at 17 krad with the device not responding to inputs.
MOSFET Drivers											
N/A	TC4423	TC4423	Microchip	Dual MOSFET Driver	0346	Bipolar	TID - HDR	25	50k	N/A	Increasing levels of parametric degradation., yet no functional failures up to 50 krad.