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NASA Goddard Space Flight Center's Compendium of Recent Total Ionizing Dose and Displacement Damage Dose Results

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Abstract: Total ionizing dose and displacement damage dose testing were performed to characterize and determine the suitability of candidate electronics for NASA spacecraft and program use.

Introduction

Long term radiation-induced failure modes play a significant role in determining space system reliability. In order to determine risk to spaceflight applications, the effects of total ionizing dose (TID) and displacement damage dose (DDD) need to be evaluated through ground-based testing.

The test results presented here were gathered to establish the sensitivity of candidate spacecraft electronics to TID and/or DDD. Proton-induced degradation, dominant for most NASA missions, is a mix of ionizing (TID) and non-ionizing damage. The non-ionizing damage is commonly referred to as displacement damage. For similar results on single event effects (SEE), a companion paper has also been submitted to the 2018 IEEE NSREC Radiation Effects Data Workshop entitled: "NASA Goddard Space Flight Center's Compendium of Recent Single Event Effects Results," by M. O'Bryan, et al. [1]

This paper is a summary of results. Please note that these test results can depend on operational conditions.

Proton Test Facility

Facility	Proton Energy (MeV)
University of California at Davis - Crocker Nuclear Laboratory (UCD - CNL)	63

PIs Coordinating Testing

Abbreviation	Principal Investigator (PI)
ADT	Alyson D. Topper
MCC	Megan C. Casey
MJC	Michael J. Campola

Acronyms

A = Amp
BiCMOS = Bipolar – Complementary Metal Oxide Semiconductor
CMOS = Complementary Metal Oxide Semiconductor
COTS = Commercial off-the-shelf
CTR = Current Transfer Ratio
DDD = Displacement Damage Dose
DUT = Device Under Test
FET = Field Effect Transistor
GSFC = Goddard Space Flight Center
HDR = High Dose Rate
h_{FE} = Forward Current Gain
I_{b+} = Positive Bias Current
I_{Con} = On-State Collector Current
I_{CE} = Collector-Emitter Current
I_{CP} = Charge Pump Current
IF = Intermediate Frequency
I_{io} = Input Offset Current
I_{os} = Offset Current
I_{OUT} = Output Current
JFET = Junction Field Effect Transistor
LDO = Low Dropout
LED = Light Emitting Diode
LDR = Low Dose Rate
MeV = Mega Electron Volt
mA = milliamp
n/a = Not Available
Op-Amp = Operational Amplifier
PCB = Printed Circuit Board
PI = Principal Investigator
REAG = Radiation Effects & Analysis Group
RF = Radio Frequency
SEE = Single Event Effects
SMD = Surface Mount Device
Spec = Specification(s)
TID = Total Ionizing Dose
UCD-CNL = University of California at Davis – Crocker Nuclear Laboratory
$V_{(BR)CEO}$ = Collector-Emitter Breakdown Voltage
V_{CESAT} = Collector-Emitter Saturation Voltage
VCO = Voltage Controlled Oscillator
V_{OH} = Output Voltage High

Test Results and Discussion

AD620SQ/883B, Analog Devices, Operational Amplifier

The AD620SQ/883B is an instrumentation amplifier featuring high accuracy and low noise. A gain range from 1 to 10,000 is programmable with an external resistor. Eight AD620SQ parts were irradiated for TID testing at 10 mrad(Si)/s to a total dose of 25 krad(Si). Four parts were biased during irradiation and four were unbiased with two parts reserved as controls. Input offset current increased beyond specification at 3.3 krad(Si). Positive input bias current exceeded specification after 5.4 krad(Si). Negative input bias current and both power supply rejection ratios (gain at 1 and 10) failed at 8.5 krad(Si). After irradiation, the parts were annealed at room temperature for 212 hours. All measurements returned to specification or near specification after the 212 hour annealing period. Fig. 1 shows the input offset current over dose step and annealing. Fig. 2 displays the gain error at gain equal to ten over dose step and annealing.

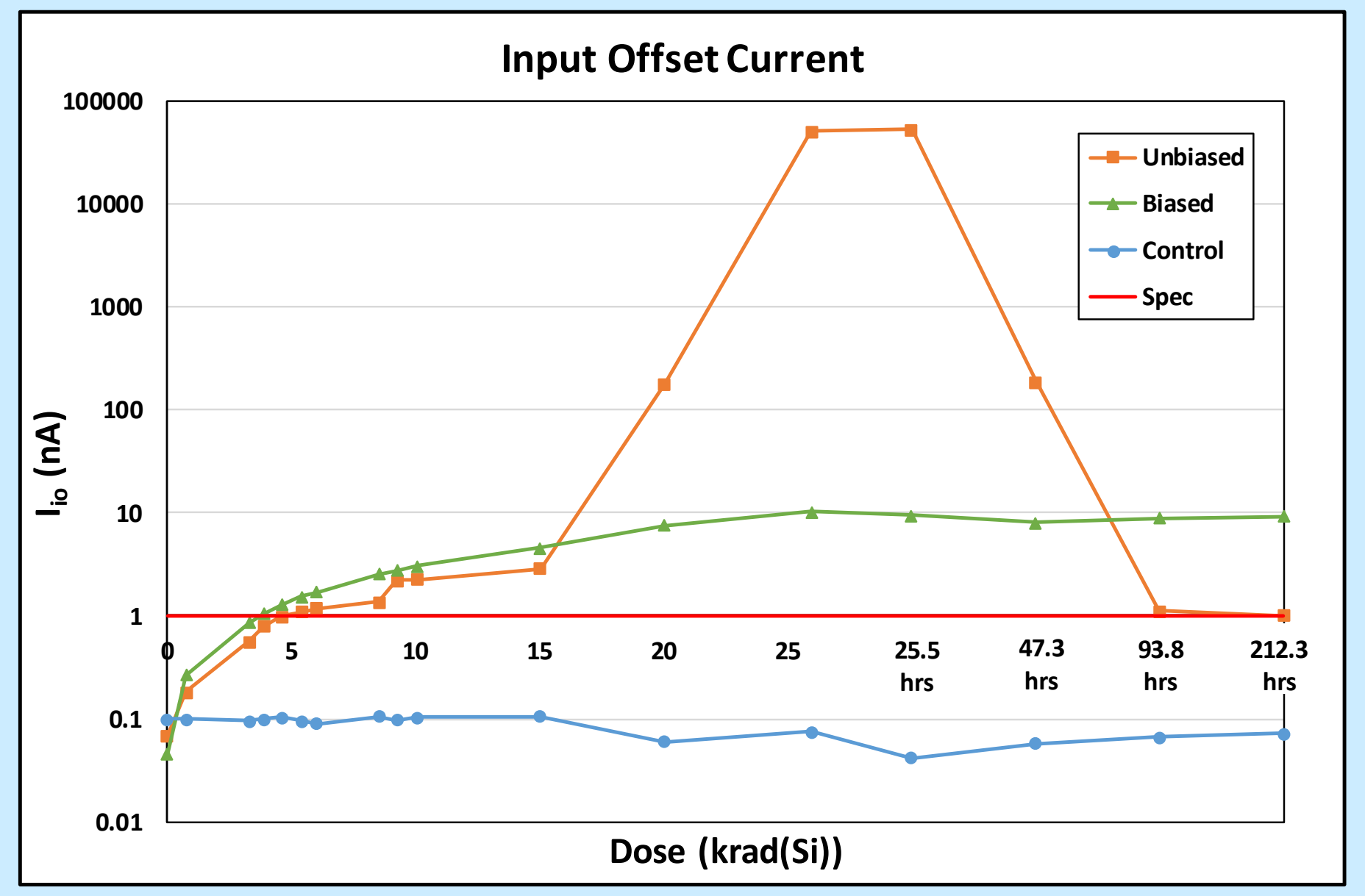

Figure 1. Input offset current vs. dose (krad(Si)) and annealing time.

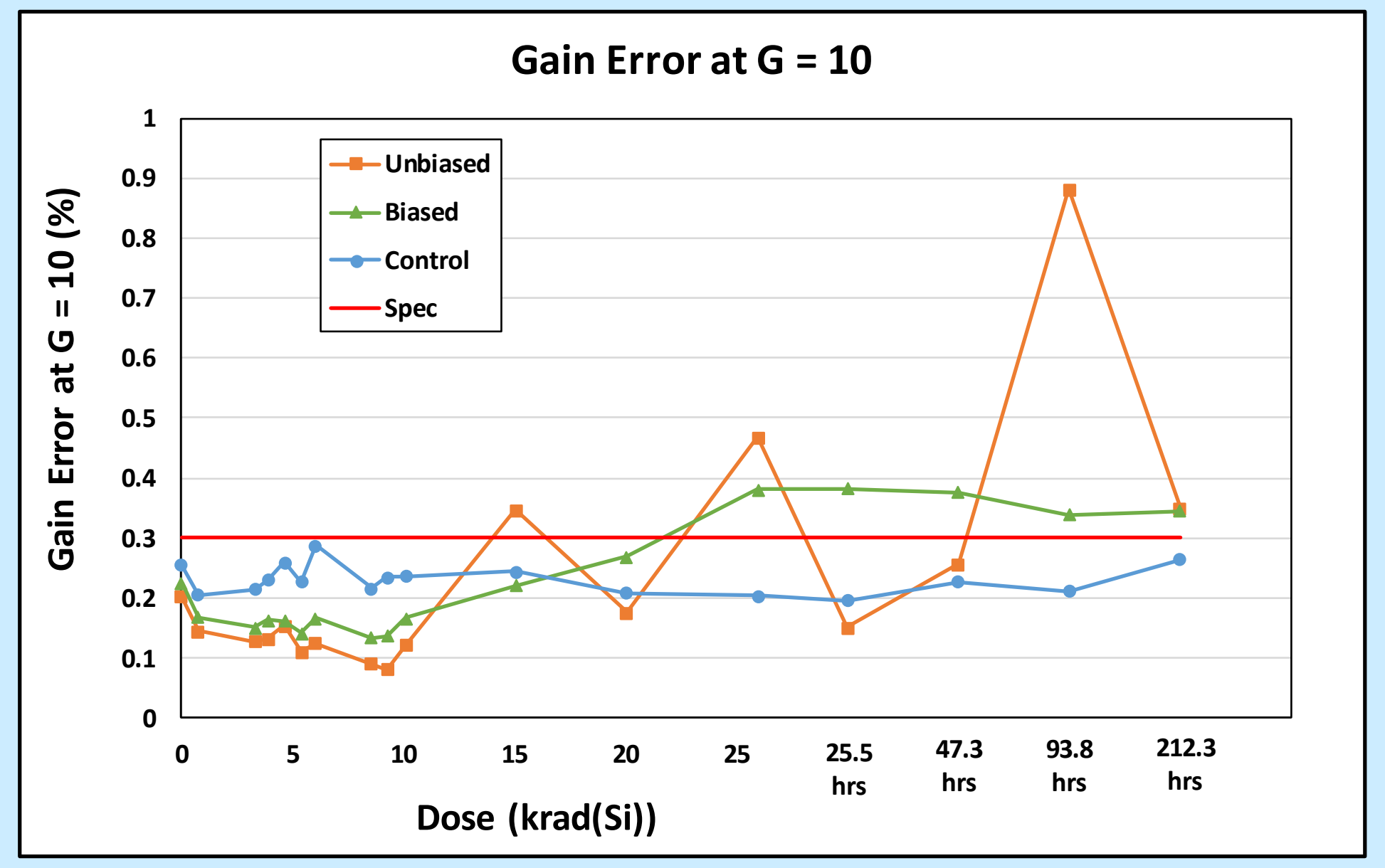

Figure 2. Gain error at gain = 10 vs. dose (krad(Si)) and annealing time.

OPB847, OPTEK Technology, Optical Switch

The OPB847 is a 110-V slotted optical switch with a gallium arsenide LED and silicon phototransistor. Ten parts were tested for DDD effects at Crocker Nuclear Laboratory at University of California at Davis (UCD-CNL). Five were biased and five were unbiased during irradiation, with two parts reserved as controls.

On-state collector current (Ic_{ON}) showed an immediate decrease after the first fluence step. This parameter exceeded the manufacturer's specification, consistently across all parts, at 2.18 x 10^{10} p^+/cm^2. Collector-Emitter Saturation Voltage ($V_{CE(SAT)}$) and Collector-Emitter Breakdown Voltage ($V_{(BR)CEO}$) increased with proton fluence. Six DUTs exceeded the $V_{CE(SAT)}$ limit at 9.29 x 10^{10} p^+/cm^2 and all remaining parts except one failed at the next fluence step. DUT 6 failed at the final irradiation step of 1.49 x 10^{11} p^+/cm^2. Fig. 3 displays the Current Transfer Ratio (CTR) over proton fluence. The unbiased parts were unmeasurable after 1.12 x 10^{11} p^+/cm^2 step.

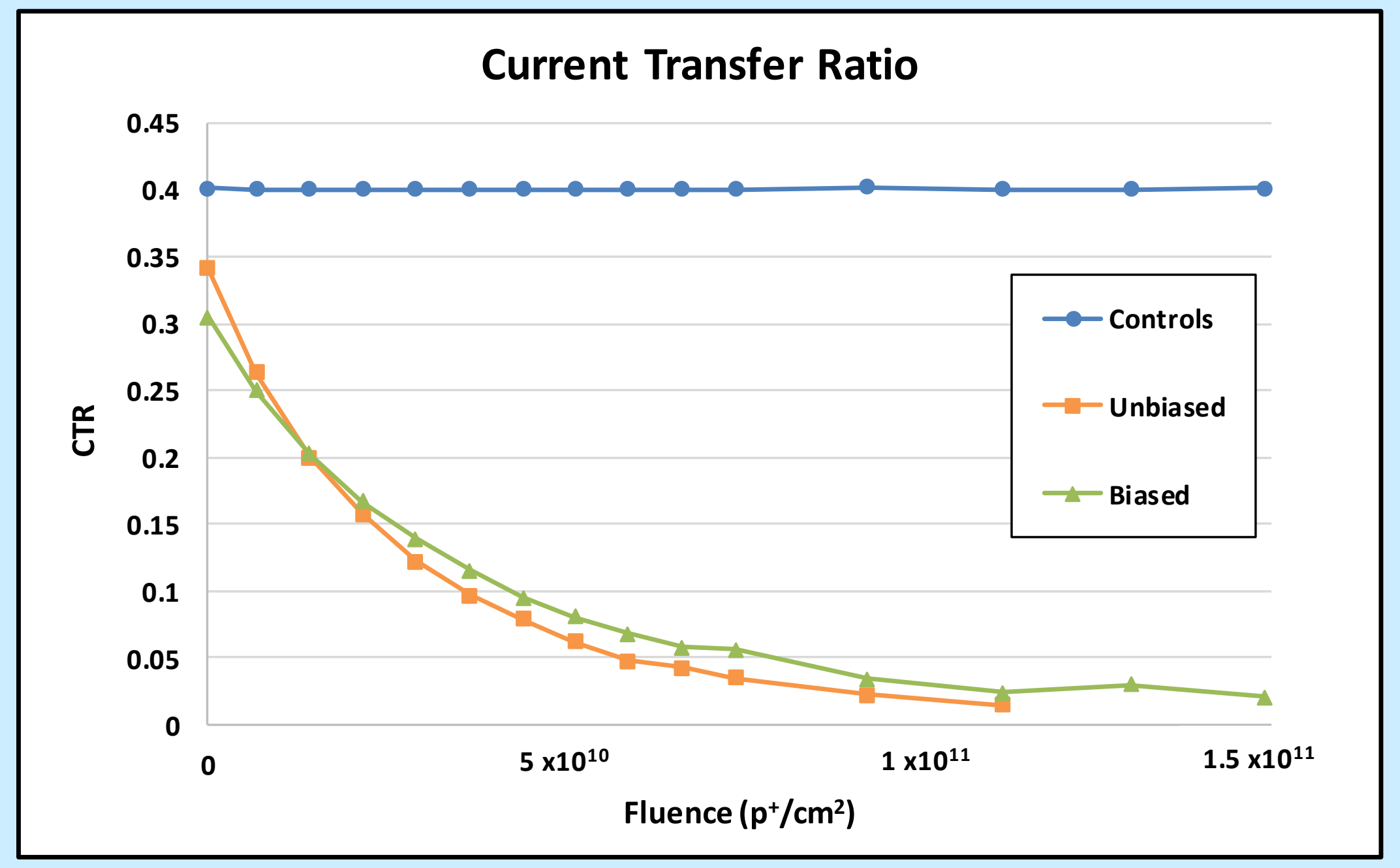

Figure 3. CTR (Collector current divided by forward diode current) vs. fluence (p^+/cm^2).

Total Ionizing Dose Test Results

Part Number	Manufacturer	LDC	Device Function	Technology	PI	Sample Size	Results	App. Spec (Y/N)	Dose rate (mrad(Si)/s)	Degradation Level (krad(Si))
Operational Amplifiers										
AD620SQ/883B	Analog Devices	1708D; (17-046)	Operational Amplifier	Bipolar	MJC	8	Input offset current out of specification at 3.3 krad(Si), positive bias current at 5.4 krad(Si), negative bias current at 8.5 krad(Si).	Y	10	$3.3 < I_{io} < 10$ $5.4 < I_{b+} < 9$ $8.5 < I_{b-} < 15$
OP484	Analog Devices	1553A; (17-072)	Operational Amplifier	Bipolar	MCC	10	All parameters within specification up to 50 krad(Si). V_{OH} dropped below the minimum specification at 75 krad(Si).	Y	10	$50 < V_{OH} < 75$
Comparators										
LM193	Texas Instruments	0624A; (17-054)	Comparator	Bipolar	ADT	6	All parameters remained within specification.	Y	10	> 20
ADCMP600	Analog Devices	1639; (17-067)	Comparator	BiCMOS	MCC	10	All parameters remained within specification.	Y	10	> 100
ADCMP604	Analog Devices	1551; (17-068)	Comparator	BiCMOS	MCC	10	All parameters remained within specification.	Y	10	> 100
Miscellaneous										
MT29F4G08ABADAWP-IT:D	Micron	1406; (16-034)	Flash Memory	CMOS	MJC	10	One unbiased part had block errors reading back after irradiation. No unrecoverable memory corruption.	Y	10 mrad(Si) and 15.5 rad(Si)	> 40
HS-4423BEH	Intersil	X1526ABBD; (17-071)	FET Driver	Bipolar	MCC	10	All parameters remained within specification.	Y	10	> 100
2N5154U3	Microsemi	E1624; (17-070)	NPN Transistor	Bipolar	MCC	10	h_{FE1} out of specification at 50 krad(Si).	Y	10	$h_{FE1} < 50$
ADF4252	Analog Devices	1637; (17-069)	Frequency Synthesizer	BiCMOS	MCC	10	Both RF and IF charge pumps failed at 92 krad(Si).	Y	10	$75 < I_{CP} < 92$
ISL71590	Intersil	1527; (17-073)	Temperature Transducer	Bipolar	MCC	10	Consistent linear decrease in output current. Maximum output value drift of 3.5°C at 100 krad(Si).	Y	10	0 < x < 50

Displacement Damage Dose Test Results

Part Number	Manufacturer	LDC	Device Function	Technology	PI	Sample Size	Results	App. Spec (Y/N)	Proton Fluence (/cm²)
OPB847	Optek Technologies	M1713A; (17-041)	Optical Switch	Hybrid	MJC	10	On-State Collector Current out of specification at 2.18x10^{10} cm^{-2}, Collector-Emitter Saturation Voltage out of specification at 9.29x10^{10} cm^{-2}.	Y	$I_{Con} < 2.18x10^{10} cm^{-2}$ $V_{CESAT} < 9.29x10^{10} cm^{-2}$
ACPL-785E	Avago	1649; (17-047)	Optocoupler	Hybrid	MJC	10	All parameters remained within specification.	Y	1.49x10^{11}
TUD69H1B	Sensor Electronics Technology, Inc.	n/a; (17-059)	LED	AlGaN	MCC	4	Glass darkening. No change in the forward I-V curve up to 9.4E^{11} cm^{-2}.	N	9.4x10^{11}
TUD89H1B	Sensor Electronics Technology, Inc.	n/a; (17-060)	LED	AlGaN	MCC	4	Glass darkening. No change in the forward I-V curve up to 9.4E^{11} cm^{-2}.	N	9.4x10^{11}
TCE49H1B	Sensor Electronics Technology, Inc.	n/a; (17-063)	LED	AlGaN	MCC	4	Glass darkening. No change in the forward I-V curve up to 3.3E^{13} cm^{-2}.	N	9.4x10^{11} 3 DUTs at 3.3x10^{13}

ADF4252, Analog Devices, Frequency Synthesizer

The ADF4252 is a dual RF/IF frequency synthesizer for wireless receivers and transmitters, capable of multiplying or dividing an input reference signal to fully implement a phase-locked loop when paired with an external voltage controlled oscillator (VCO). The ADF4252 is programmed with an SPI-compatible serial interface which configures the on-chip mode registers.

Due to the small package size and external component requirements, each device was soldered to a custom-designed PCB with a test circuit capable of measuring a typical set of performance and operational metrics. A total of twenty parts, with ten biased at nominal voltages and ten grounded, were irradiated at a rate of 10 mrad(Si)/s to a total dose of 100 krad(Si).

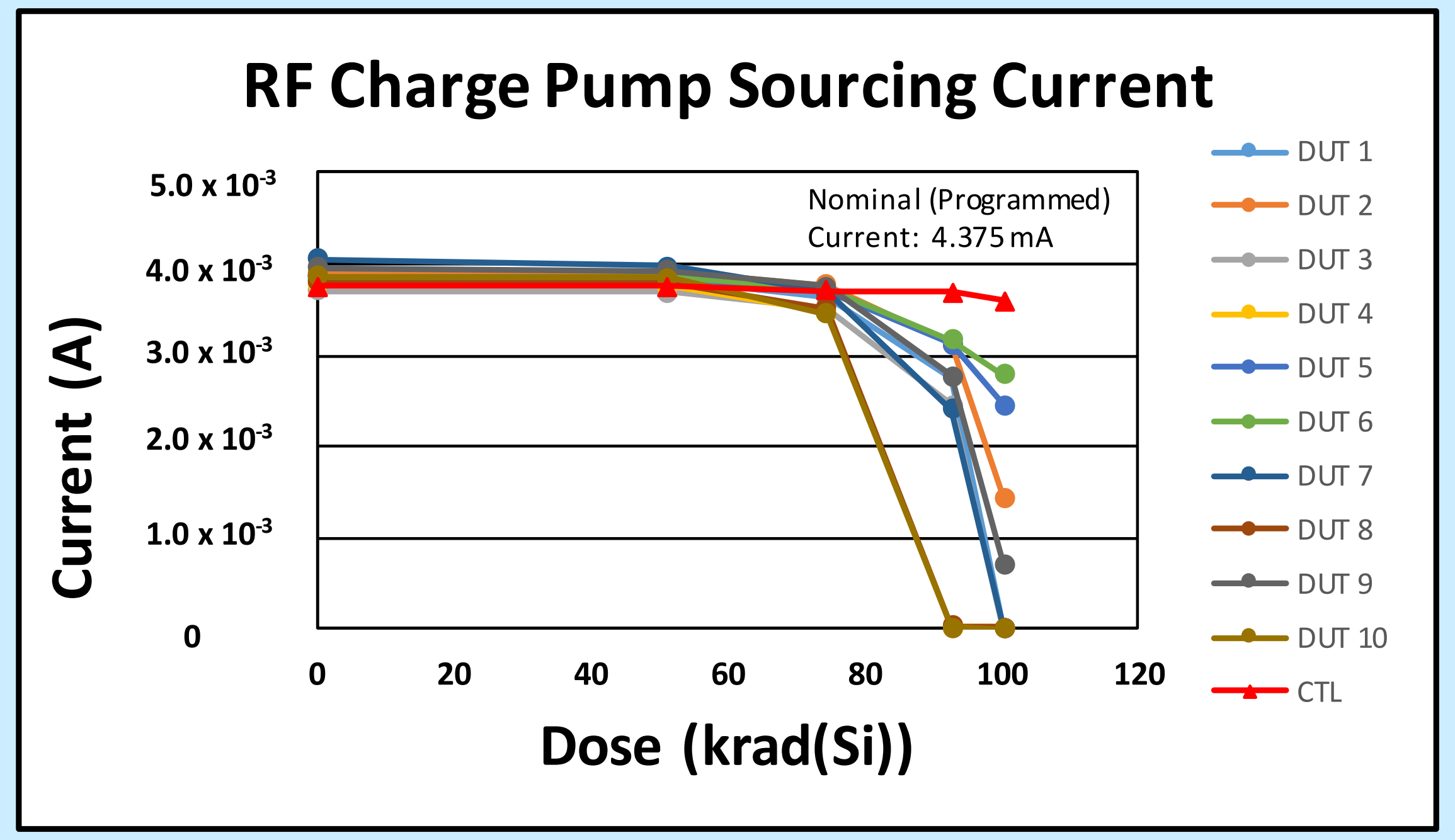

Figure 4. RF charge pump sourcing current (biased DUTs) vs. dose.

The logical high and low voltages, main supply voltage current, and the charge pump supply current showed no appreciable degradation during irradiation. Only degradation was seen during irradiation on the following parameters; quiescent supply current at 75 krad(Si) and charge pump supply current at 92 krad(Si).

Notably at 92 krad(Si), the charge pumps of the biased parts began to fail. By the 100 krad(Si) measurement, eight out of the ten biased DUTs were no longer functioning. Fig. 4 shows the sudden current drop over dose of the biased devices.

Summary

We have presented data from recent TID tests on a variety of devices. It is the authors' recommendation that this data be used with caution due to many application/lot-specific issues. We also highly recommend that lot testing be performed on any suspect or commercial device. 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, TID conditions/parameters, test results, and graphs of data [3] and [4].

References

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