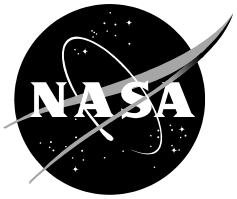
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Linear Technology LTC2054HVMP Operational Amplifier Low Dose Rate Total Ionizing Dose Test Report

Anthony M. Phan

Matthew B. Joplin

January 2022

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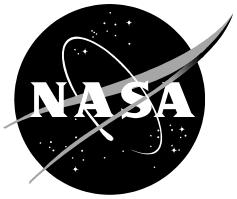
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Linear Technology LTC2054HVMP Operational Amplifier Low Dose Rate Total Ionizing Dose Test Report

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Report Date: 12/14/2021

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Space Administration

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Greenbelt, MD 20771

January 2022

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1. Introduction

The purpose of this test was to characterize the LTC2054HVMPS5 (LTC2054) parameter degradation for total ionizing dose (TID) response. In the test, the device was exposed to low dose rate (LDR) irradiations using gamma radiation to account for the effects of enhanced low dose rate sensitivity (ELDRS) on the bipolar device. The following device parameters were electrically tested before and after irradiation dose steps:

- input offset voltage (V_{OS})
- input bias current (I_B)
- input offset current (I_{OS})
- output high voltage swing (V_{OUT_H})
- output low voltage swing (V_{OUT_L})
- open loop gain (A_{OL})
- quiescent current (I_Q)
- slew rate (SR)

All parameters except A_{OL} exhibited TID effects in both the biased and unbiased irradiation conditions though many of these parameters remained within specification up to a dose of 100 krad(Si). Under the biased irradiation condition V_{OS} (exceeded between 80 krad(Si) and 90 krad(Si)) and I_Q (exceeded between 90 krad(Si) and 100 krad(Si)) degraded beyond the datasheet specification according to the calculated K-factor tolerance limits (KTL) [3].

2. Devices Tested

2.1. Part Background

LTC2054 is a low noise zero-drift operational amplifier available in the SOT-23 package. The LTC2054 operates on supplies from 2.7V to ±5.5V. The current consumption is 175µA (typical), 220uA maximum over temperature. Typical input offset voltage and offset drift are 10µV and 0.05µV/˚C.

2.2.Device Under Test (DUT) Information

Twelve (12) parts were provided for LDR TID testing. Five (5) devices were tested in a biased source follower configuration with a square wave input. Five (5) devices were tested in an unbiased configuration with all leads grounded. All specifications and descriptions are according to the datasheet [2] (document #20545fc) table labeled “LTC2054HVMP” which corresponds to the part number of the provided parts. More information can be found in Table 1.

Table 1 – Part Identification Information

Part Number	LTC2054HVMPS5
Manufacturer	Linear Technology
Lot Date Code	2034
Additional Case Markings	LTFFC
Quantity Tested	10 (5 biased, 5 unbiased)
Part Function	Operational Amplifier
Part Technology	Bipolar
Package	5-pin SOT-23

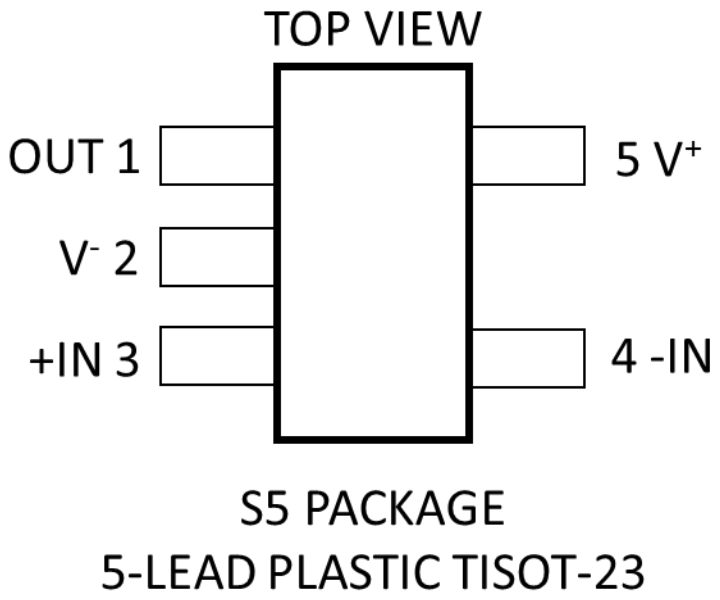


Figure 1 – Pinout of LTC2054

3. Test Setup

General test procedures were in accordance with MIL-STD-883, Method 1019, Condition D [1] for LDR testing of the bipolar circuit. Parts were serialized randomly. Electro-static Discharge (ESD) procedures were followed during test and transfer of the devices between irradiation chamber and characterization. Exposures were performed at ambient laboratory temperature.

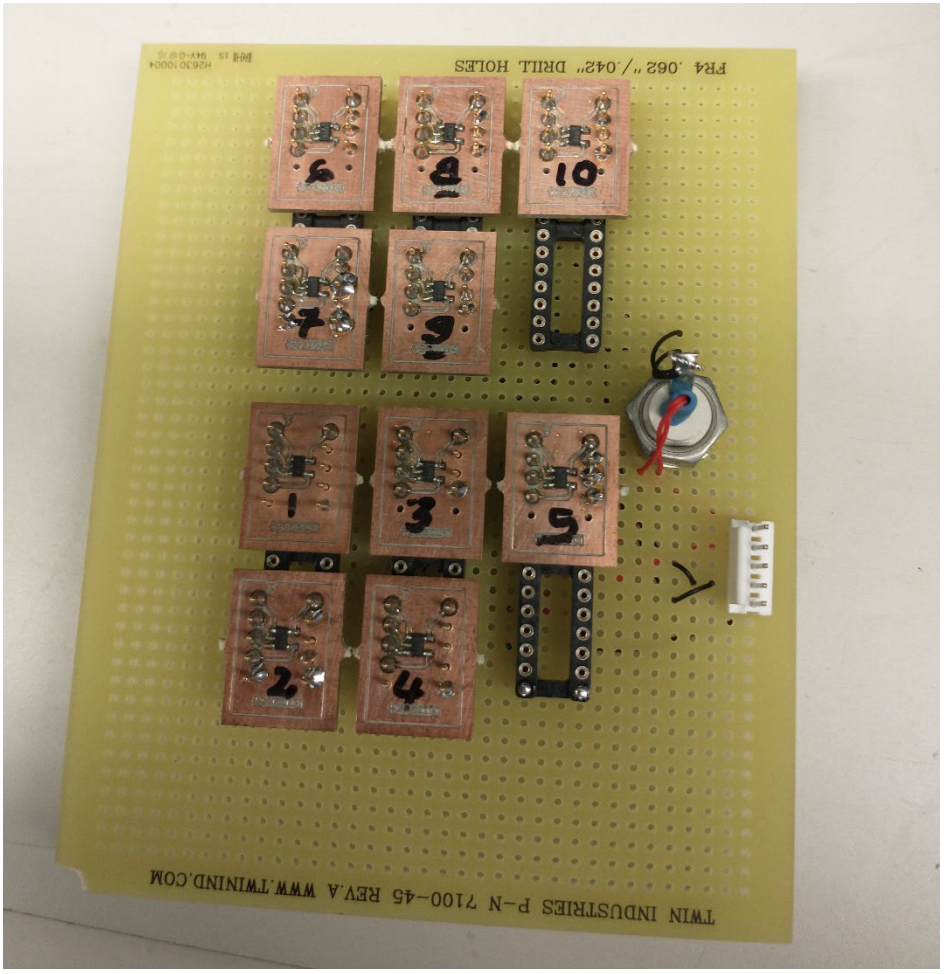


Figure 2 – Picture of 10 DUT daughter cards on the irradiation bias board

4. Test Description

4.1 Irradiation Conditions

Radiation testing was done by exposing the parts to gamma radiation at LDR of 10 mrad(Si)/s. Twelve (12) parts were provided for testing, Ten (10) parts were irradiated – five (5) biased, five (5) unbiased – and two (2) were used as control devices. Prior to the first radiation dose, all twelve (12) parts were electrically tested. After each gamma dose level was reached, the parts were tested again and returned to radiation within the time limits defined by MIL-STD-883, Method 1019 [1]. See Table 2 for more information.

Five (5) unbiased parts and five (5) biased parts were radiated over one hundred and eighteen (118) days. Dose steps 2.5 krad(Si), 5 krad(Si), 10 krad(Si), 20 krad(Si), 30 krad(Si), 40 krad(Si), 50 krad(Si), 60 krad(Si), 70 krad(Si), 80 krad(Si), 90 krad(Si), and 100 krad(Si) were exposed at a low dose rate of 10 mrad(Si)/s.

Table 2 – Device Grouping

Group	Qty	Bias	Dose Rate	Exposure Level Steps (krad(Si))
1	5	Unbiased	10 mrad(Si)/s	0, 2.5, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100
2	5	Biased	10 mrad(Si)/s	0, 2.5, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100
3	2	Control	-	-

The biased parts were connected to bias by 8-pin dual in-line package (DIP) adapter daughter cards on a wire wrapped board. During irradiation, V^+ was connected to +6.0V and V^- was connected to ground. Further, the LTC2054s were connected in a voltage follower configuration with an input signal of 0-5V square wave at 1kHz frequency on the non-inverting input.

4.2 Electrical Tests

Specification thresholds were set in accordance with the LTC2054 datasheet [2].

All data from the electrical tests in Table 3 were logged in Excel spreadsheet files. Parameter thresholds are defined in MAX and MIN columns of Table 3.

Table 3 – List of Electrical Tests Performed

Symbol	Parameter	MIN	TYP	MAX	Units	Test Conditions
V_{OS}	input offset voltage	-10		10	µV	V_{OUT}=0V
I_B	input bias current	-12	±3	12	pA nA	+IN = 0V, -IN = 0V
I_{OS}	input offset current	-5	±6	5	pA nA	V_{OUT}=0V
V_{OUT_H}	output high voltage swing, R_{Load}=5kΩ	4.675			V	V^+ = 5V
V_{OUT_L}	output low voltage swing, R_{Load}=5kΩ			10	mV	V^- = 0V
V_{OUT_H}	output high voltage swing, R_{Load}=100kΩ	4.965			V	V^+ = 5V
V_{OUT_L}	output low voltage swing, R_{Load}=100kΩ			10	mV	V^- = 0V
I_Q	quiescent current		175	220	µA	No Load
A_{OL}	open loop gain	115	140		dB	
SR	slew rate		0.5		V/µs	

5. Failure Criteria

The parameter limits are defined as those listed in the LTC2054 datasheet [2]. No device is to exceed parameter limits. Further, a device test condition confirmed to experience degradation with dose is compared to the KTL statistic 99% probability of survival with 90% confidence level survival threshold defined in MIL-HDBK-814 [3]. This survival threshold of test conditions observed to experience radiation-induced degradation are not to exceed the corresponding parameter thresholds defined in Table 3.

6. Source Requirements

The total dose source is in a room air source gamma ray facility, which is compliant with MIL-STD-883, Method 1019 [1]. Dosimetry is NIST traceable.

7. Results

For the biased and unbiased irradiation conditions the following device parameters were electrically tested between each dose step defined in Table 2:

- input offset voltage (V_{OS})
- input bias current (I_B)
- input offset current (I_{OS})
- output high voltage swing (V_{OUT_H})
- output low voltage swing (V_{OUT_L})
- open loop gain (A_{OL})
- quiescent current (I_Q)
- slew rate (SR)

A single part (SN1) was destroyed due to engineering error during electrical testing and the analysis of the remaining parts was adjusted to account for four (4) parts in subsequent dose steps.

The correlation coefficients comparing dose to change in observed parameter mean value and variance were calculated to elucidate whether any out-of-specification measurements are attributable to ionizing dose. Correlation values are computed according Pearson's correlation coefficient, r, with the CORREL function in Excel. Parameter variance values are lognormally distributed and therefore the values are analyzed by taking the natural log of the variance values prior to computing correlation coefficient.

Computed correlation coefficient is compared to the critical value of Pearson's r to determine statistical significance given α=0.05 with eleven (11) degrees of freedom corresponding to the thirteen (13) dose steps. One-tailed tests are used for specifications in Table 3 that have a MAX value only or a MIN value only. Otherwise, the two-tailed test is used. The critical value for the one-tailed test is 0.476 and the critical value for the two-tailed test is 0.553. The resultant calculations in Table 4 provide context to the subsequent figures of the measured data.

Table 4 – Table of dose-mean and dose-variance correlation coefficients for measured electrical parameters. Statistically significant correlations are in *italics*.

Parameter	Correlation Coefficient Critical Value (d.f. =11, α=0.05)	Biased Condition		Unbiased Condition	
		Correlation coefficient of dose to parameter mean	Correlation coefficient of dose to parameter variance	Correlation coefficient of dose to parameter mean	Correlation coefficient of dose to parameter variance
V_{OS}	0.553	-0.385	*0.934*	*-0.807*	0.200
V_{OUT_H}, 5k	0.476	*-0.835*	*0.976*	*-0.898*	*0.963*
V_{OUT_L}, 5k	0.476	0.318	*0.525*	0.339	*0.611*
V_{OUT_H}, 100k	0.476	*-0.915*	*0.777*	*-0.909*	-0.240
V_{OUT_L}, 100k	0.476	0.284	*0.488*	0.347	*0.589*
I_Q	0.476	*0.665*	*0.918*	*-0.968*	*0.965*
I_B	0.553	*-0.662*	0.412	*-0.724*	-0.132
I_{OS}	0.553	*0.806*	-0.143	*0.758*	-0.131
A_{OL}	0.476	-0.230	-0.384	-0.355	-0.175
SR	0.553	-0.086	*-0.577*	-0.223	*0.591*

Table 4 guides the interpretation of observed effects with respect to TID as well as the degree and direction of the correlation. All parameters have been affected by accumulated TID significantly except for open loop gain, A_{OL}. The effect of TID, in most cases, did not cause enough degradation to put the part outside of datasheet specifications. Major observations are as follows:

- No unbiased parameter KTL limits exceeded datasheet specifications due to TID effects up to a dose of 100 krad(Si)
- Biased condition V_{OS} KTL lower limit exceeded datasheet specification of -10 µV between 80 krad(Si) and 90 krad(Si)
- Biased condition I_Q KTL upper limit exceeded datasheet specification of 220 µA between 90 krad(Si) and 100 krad(Si)
- A_{OL} parameter KTL lower limit exceeded datasheet specification of 115 dB in both biased and unbiased conditions, but this cannot be correlated to TID per Table 4

7.1. Unbiased Condition

All unbiased parameters stayed within specification after 100 krad(Si) of TID at 10mrad(Si)/s dose rate except for open loop gain, A_{OL}, but this could not be attributed to TID because any change in gain could not be correlated to TID.

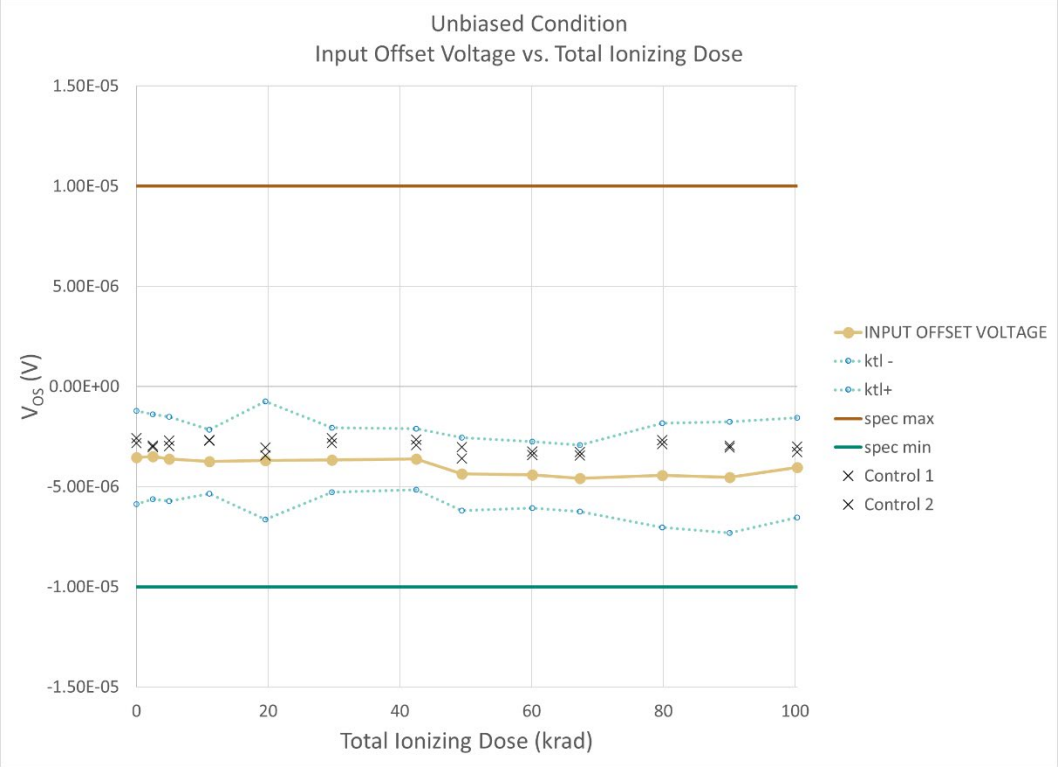


Figure 3 – Unbiased V_{OS} vs. TID. Mean value is negatively correlated to TID. ***(r_{mean} = -0.807)***

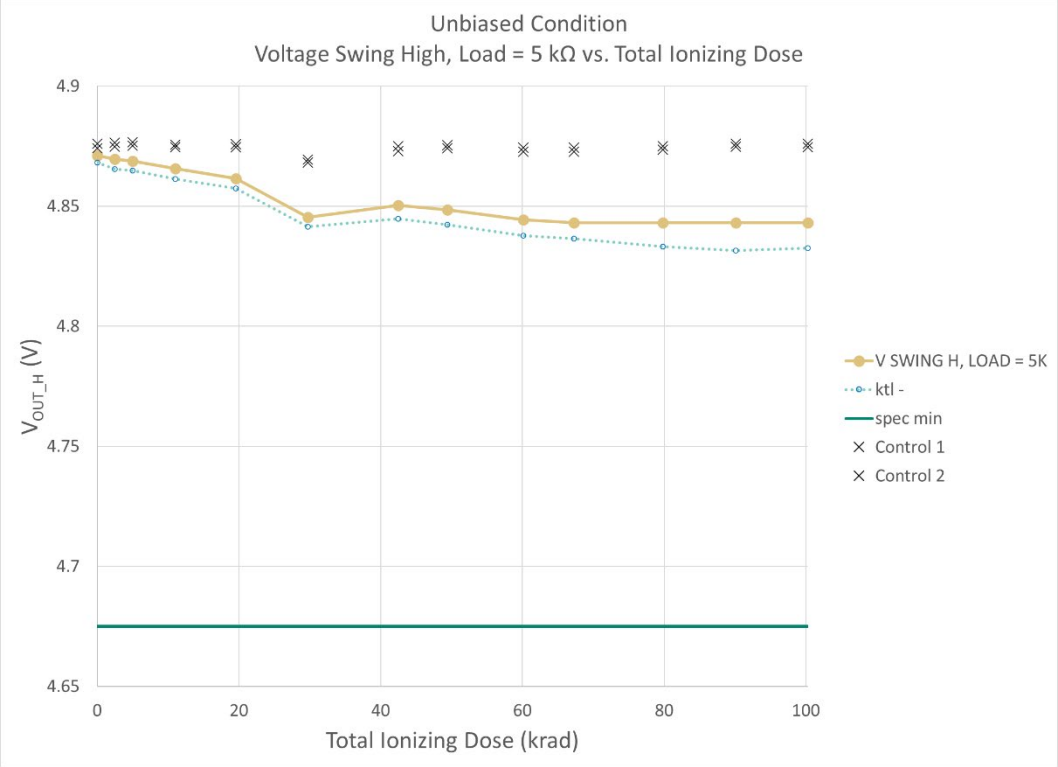


Figure 4 – Unbiased V_{OUT_H} at R_{LOAD} = 5 kΩ vs. TID. Mean value is negatively correlated to TID. Variance is positively correlated to TID. *(r_{mean} = -0.898, $r_{variance}$ = 0.963)*

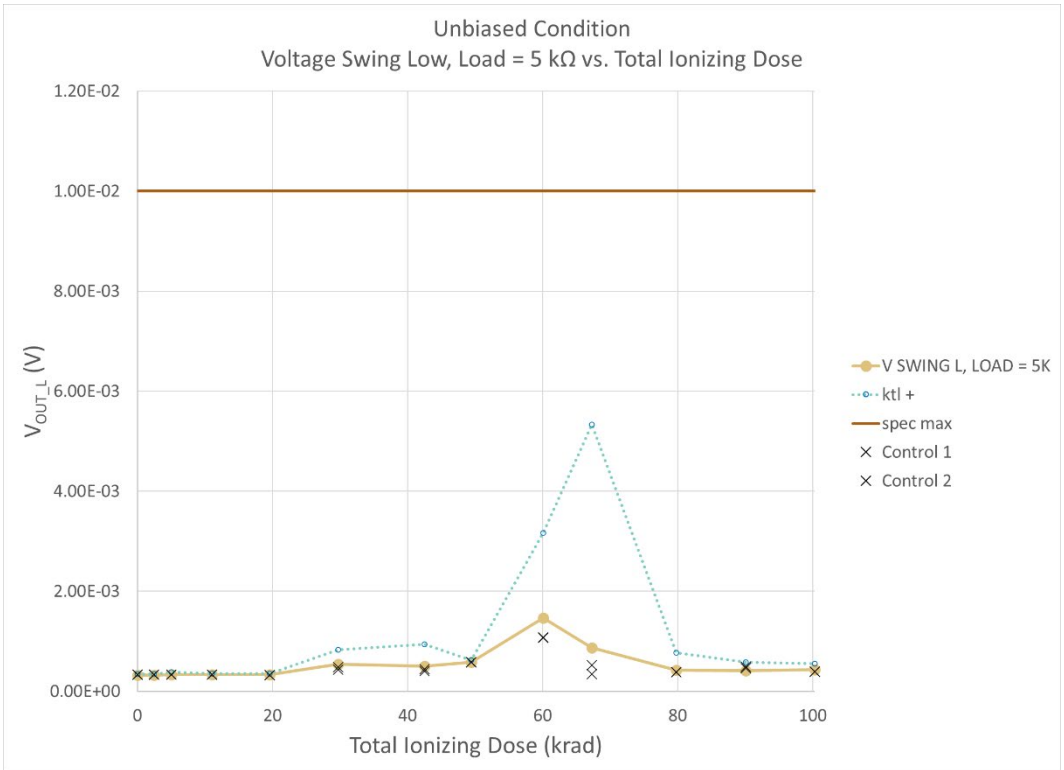


Figure 5 – Unbiased V_{OUT_L} at R_{LOAD} = 5 kΩ vs. TID. Variance is positively correlated to TID. *($r_{variance}$ = 0.611)*

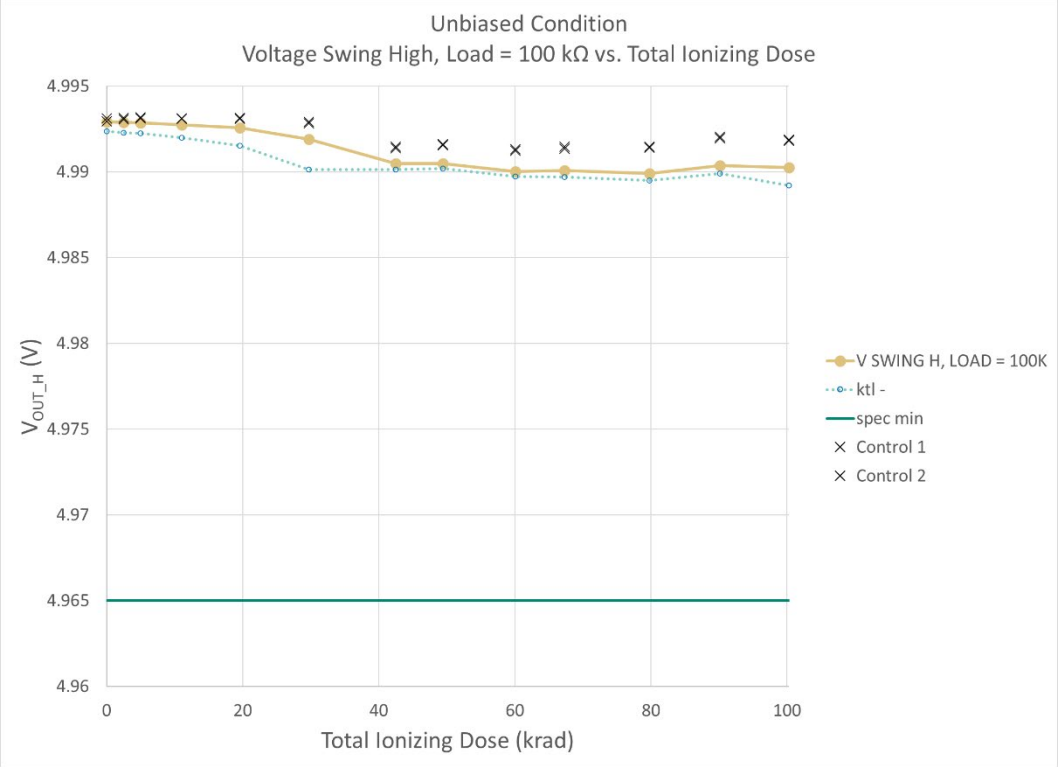


Figure 6 – Unbiased $V_{OUT\neg_H}$ at R_{LOAD} = 100 kΩ vs. TID. Mean value is negatively correlated to TID. *(r_{mean} = -0.909)*

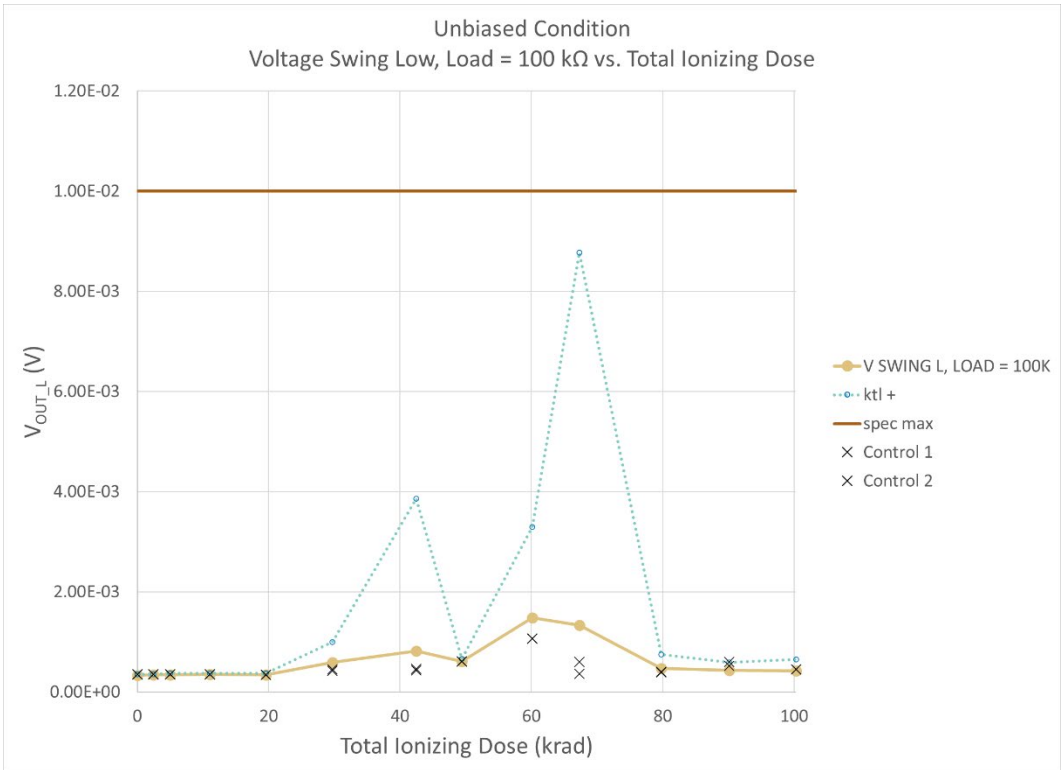


Figure 7 – Unbiased $V_{OUT\neg_L}$ at R_{LOAD} = 100 kΩ vs. TID. Variance is positively correlated to TID. *($r_{variance}$ = 0.589)*

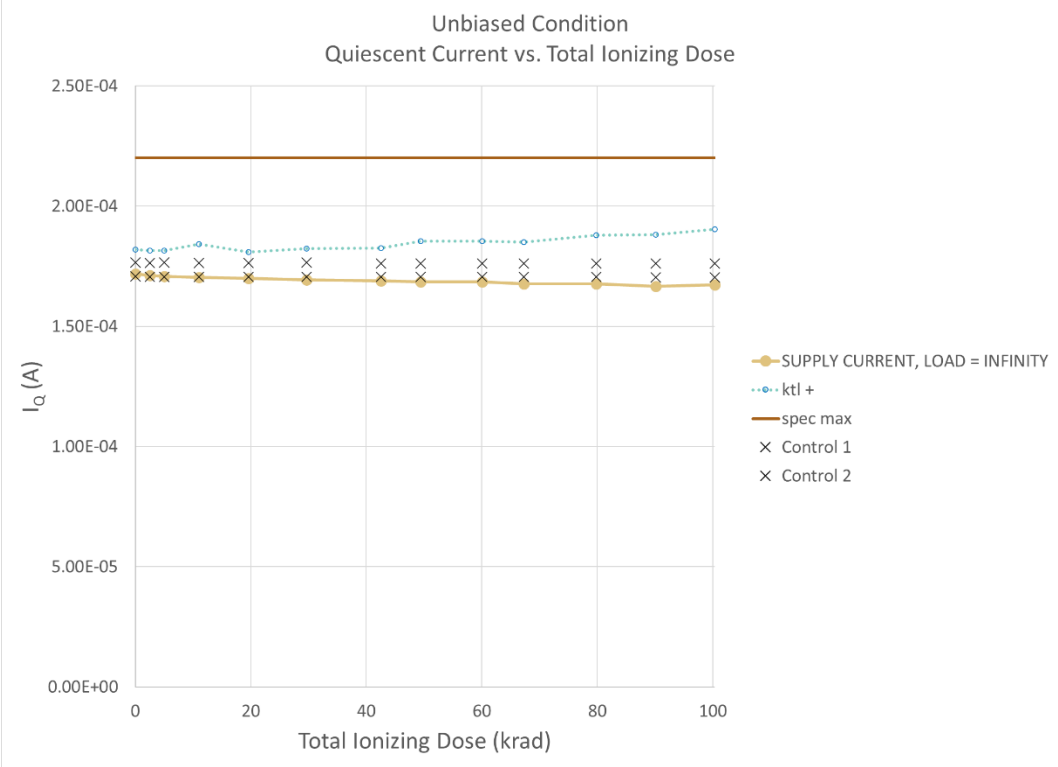


Figure 8 – Unbiased I_Q vs. TID. Mean value is negatively correlated to TID. Variance is positively correlated to TID. *(r_{mean} = -0.968, $r_{variance}$ = 0.965)*

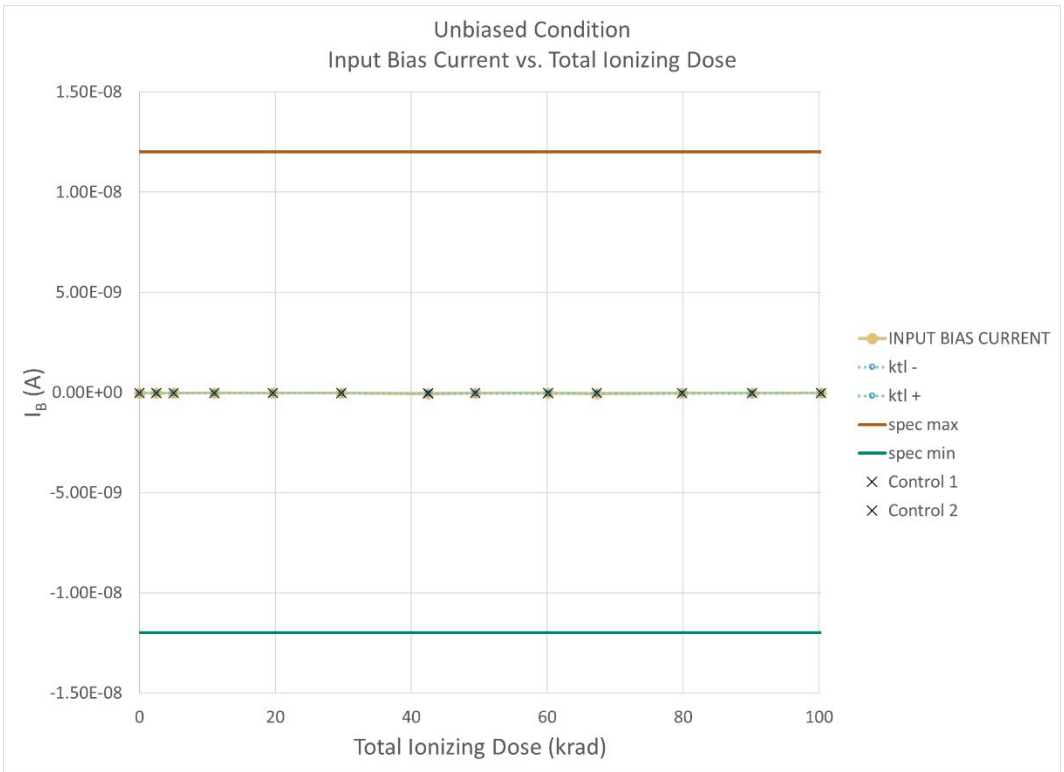


Figure 9 – Unbiased I_B vs. TID. Mean value is negatively correlated to TID. *(r_{mean} = -0.724)*

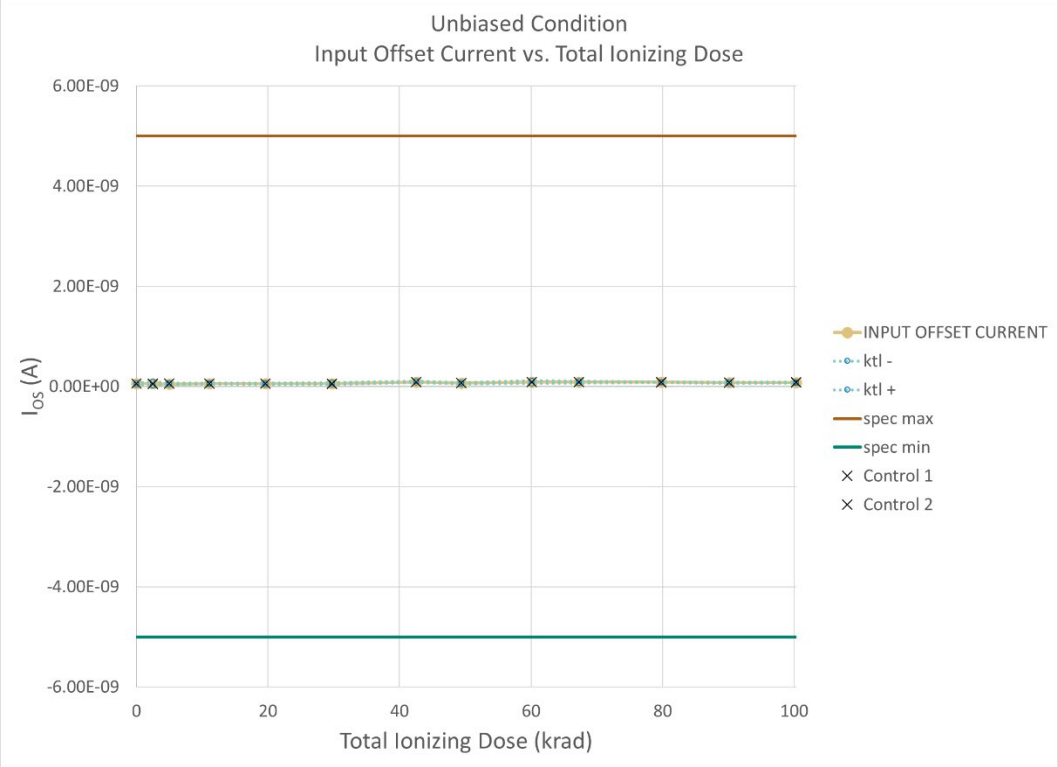


Figure 10 – Unbiased I_B vs. TID. Mean value is positively correlated to TID. *(r_{mean} = 0.758)*

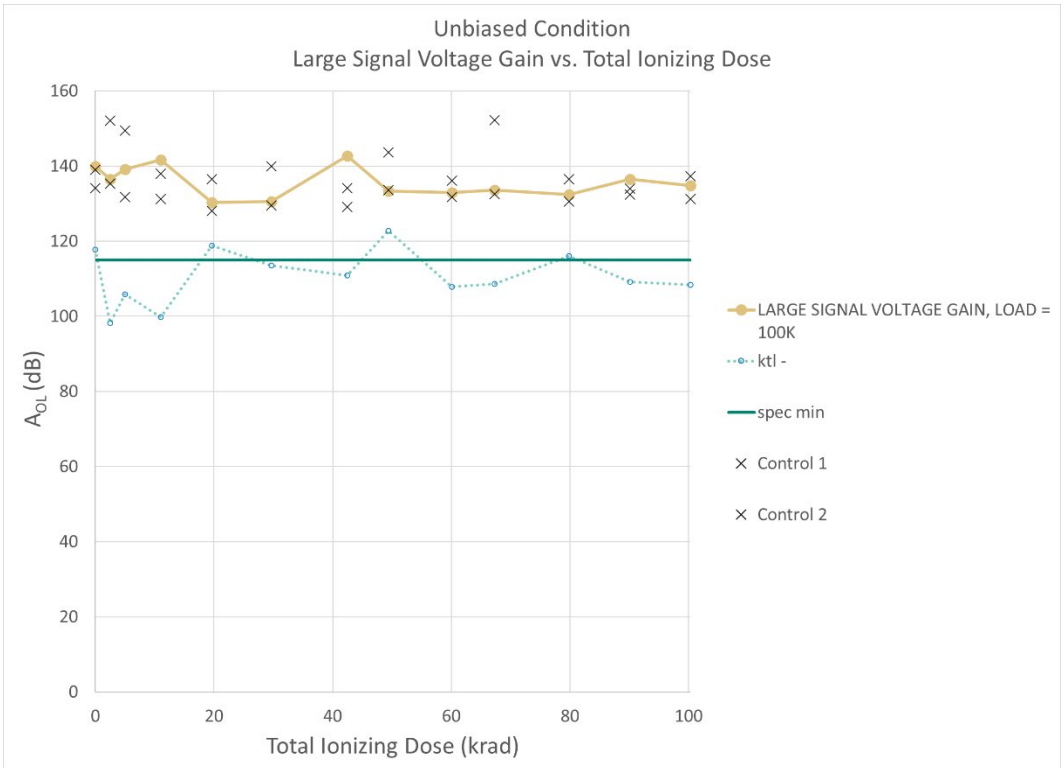


Figure 11 – Unbiased A_{OL} vs. TID. A_{OL} correlation to TID is not significant.

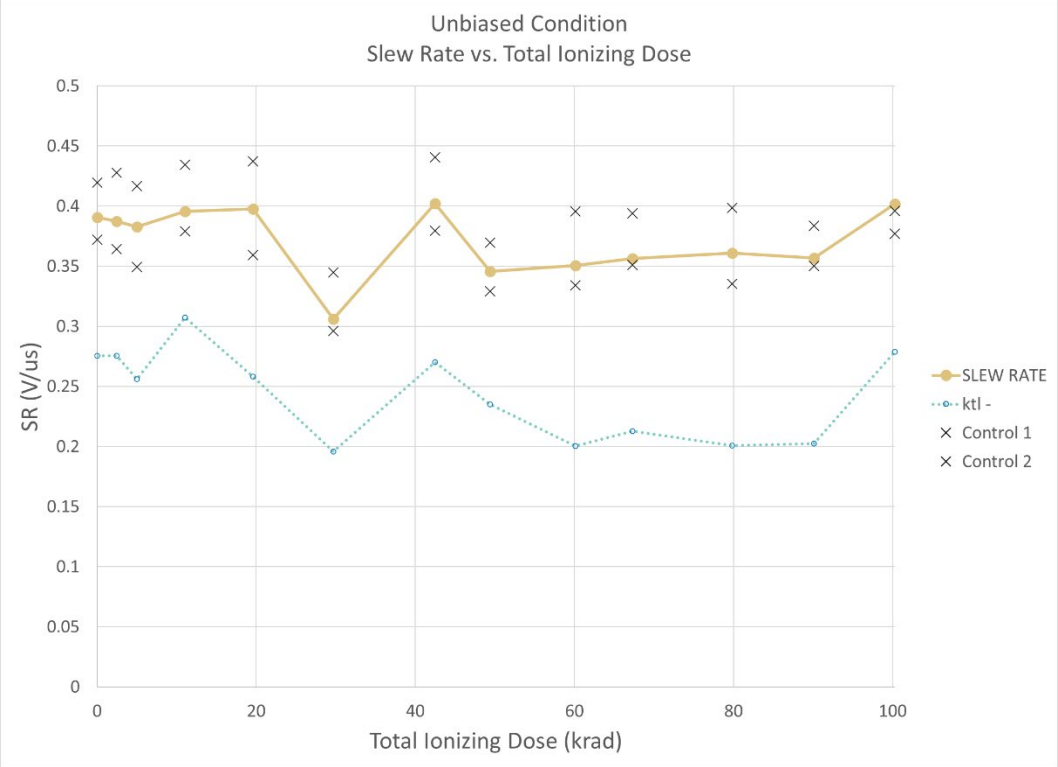


Figure 12 – Unbiased SR vs. TID. Variance is positively correlated to TID. ***($r_{variance}$ = 0.591)***

7.2. Biased Condition

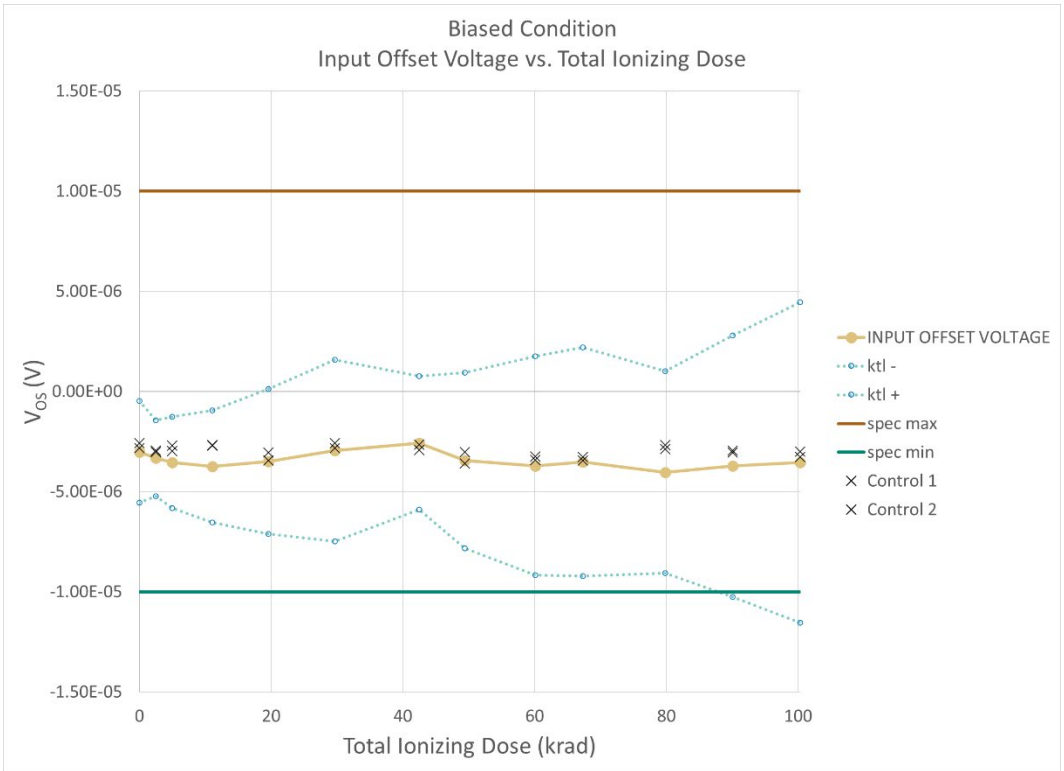


Figure 13 – Biased V_{OS} vs. TID. KTL Lower limit exceeds the specification between 80krad(Si) and 90krad(Si). Variance is positively correlated to TID. ($r_{variance}$ = *0.934)*

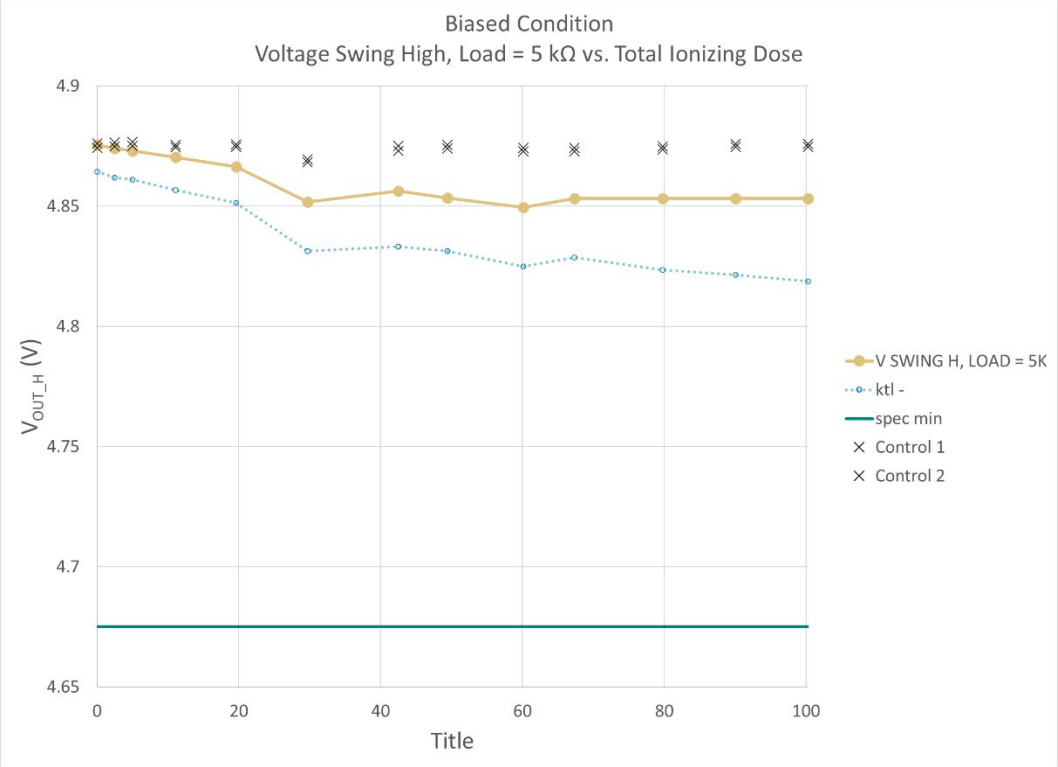


Figure 14 – Biased V_{OUT_H} with R_{LOAD} = 5 kΩ vs. TID. Mean value is negatively correlated to TID. Variance is positively correlated to TID. *(r_{mean} = -0.835, $r_{variance}$ = 0.976)*

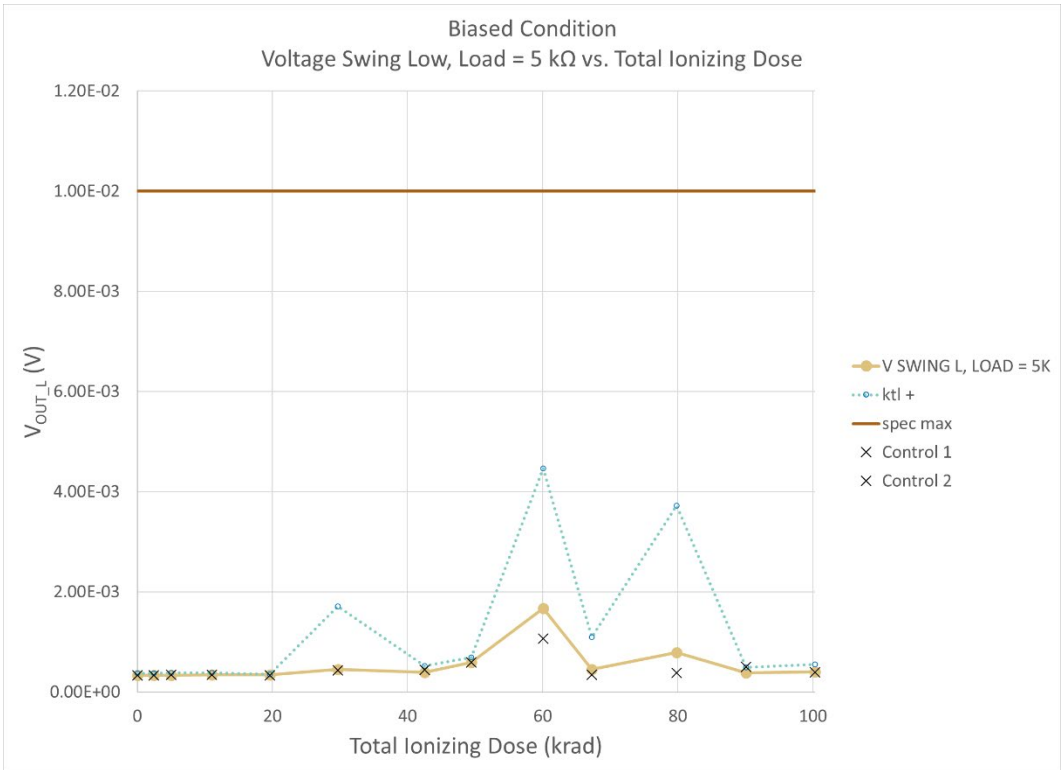


Figure 15 – Biased V_{OUT_L} with R_{LOAD} = 5 kΩ vs. TID. Variance is positively correlated to TID. *($r_{variance}$ = 0.525)*

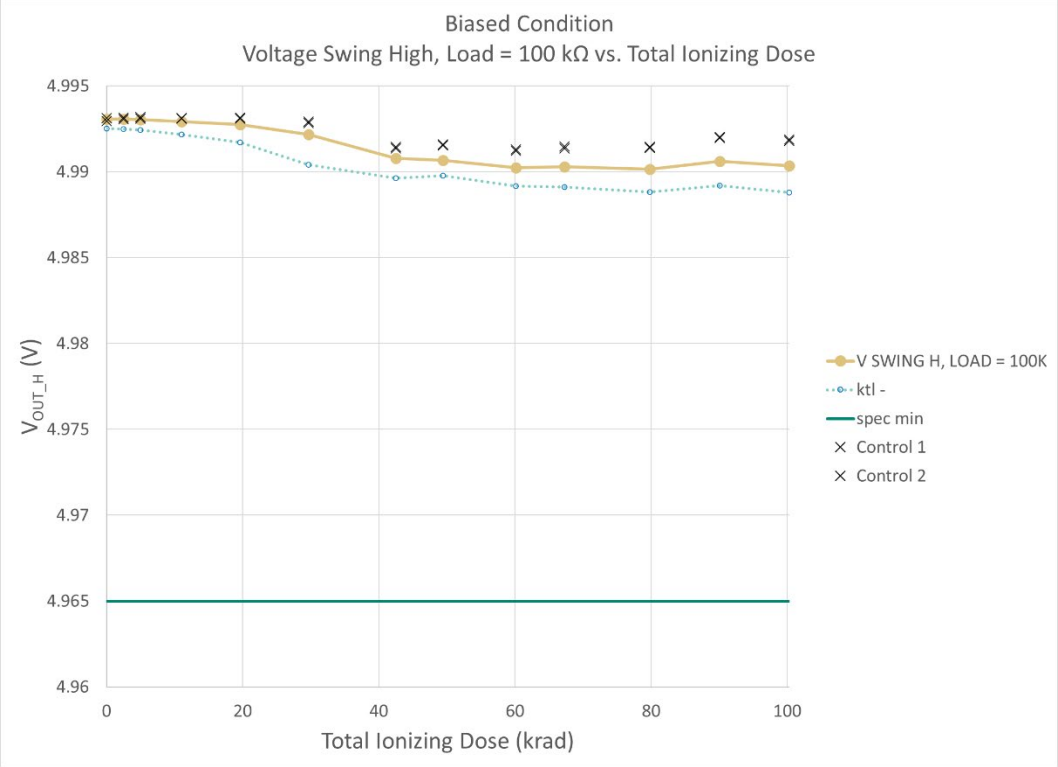


Figure 16 – Biased V_{OUT_H} with R_{LOAD} = 100 kΩ vs. TID. Mean value is negatively correlated to TID. Variance is positively correlated to TID. *(r_{mean} = -0.915, $r_{variance}$ = 0.777)*

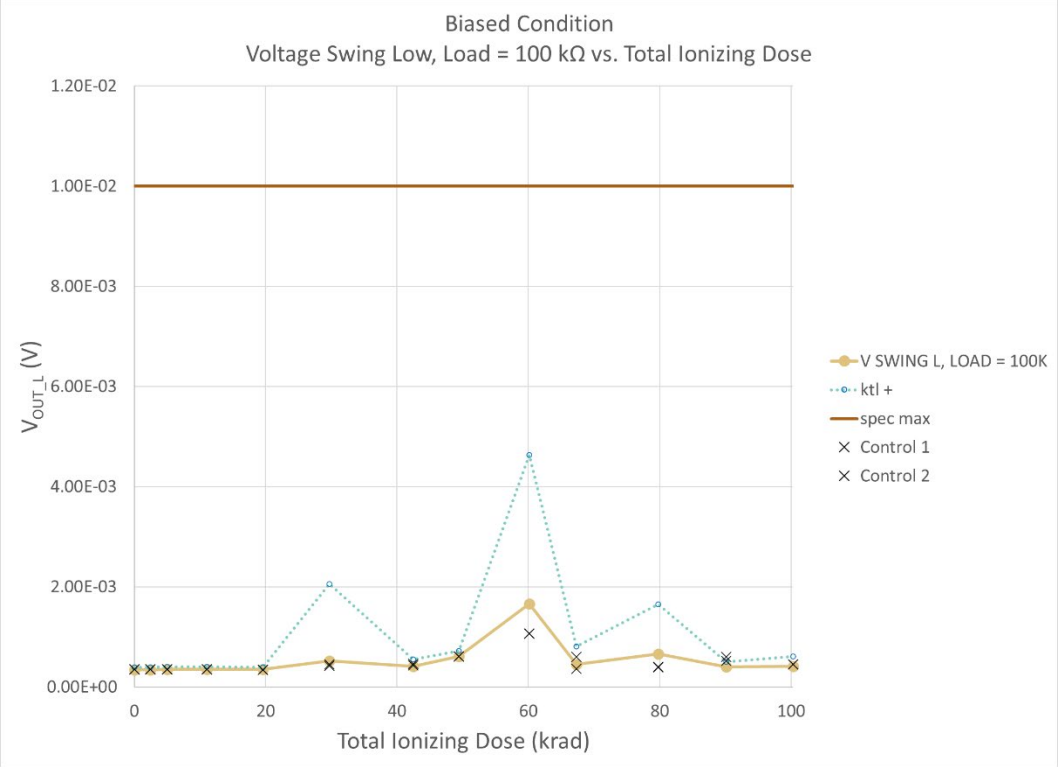


Figure 17 – Biased V_{OUT_L} with R_{LOAD} = 100 kΩ vs. TID. Variance is positively correlated to TID. *($r_{variance}$ = 0.488)*

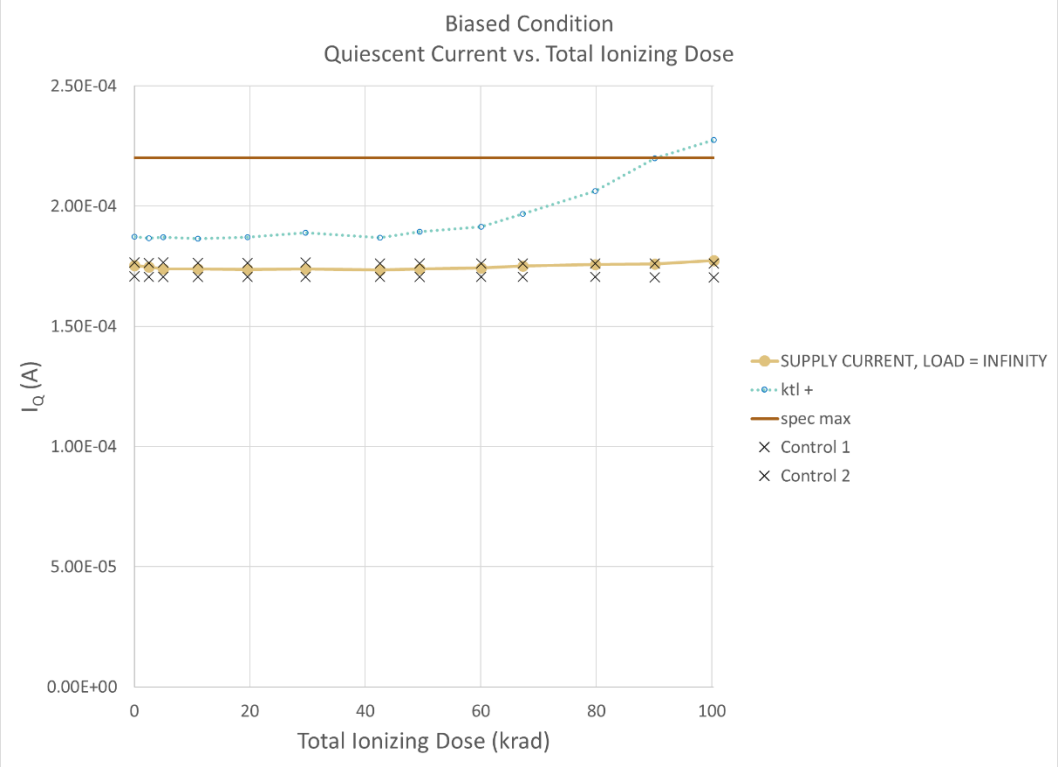


Figure 18 – Biased I_Q vs. TID. Mean value is positively correlated to TID. Variance is positively correlated to TID. *(r_{mean} = 0.665, $r_{variance}$ = 0.918)*

$r_{mean} = 0.665$, $r_{variance} = 0.918$

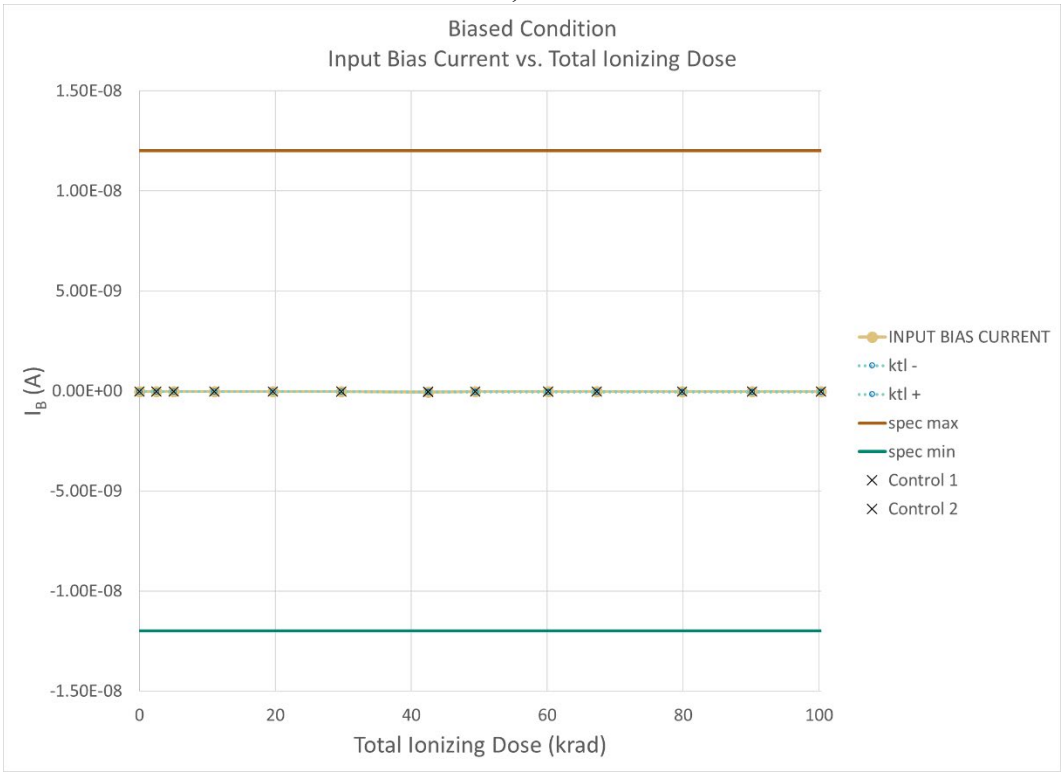


Figure 19 – Biased I_B vs. TID. Mean value negatively correlated to TID. *(r_{mean} = -0.662)*

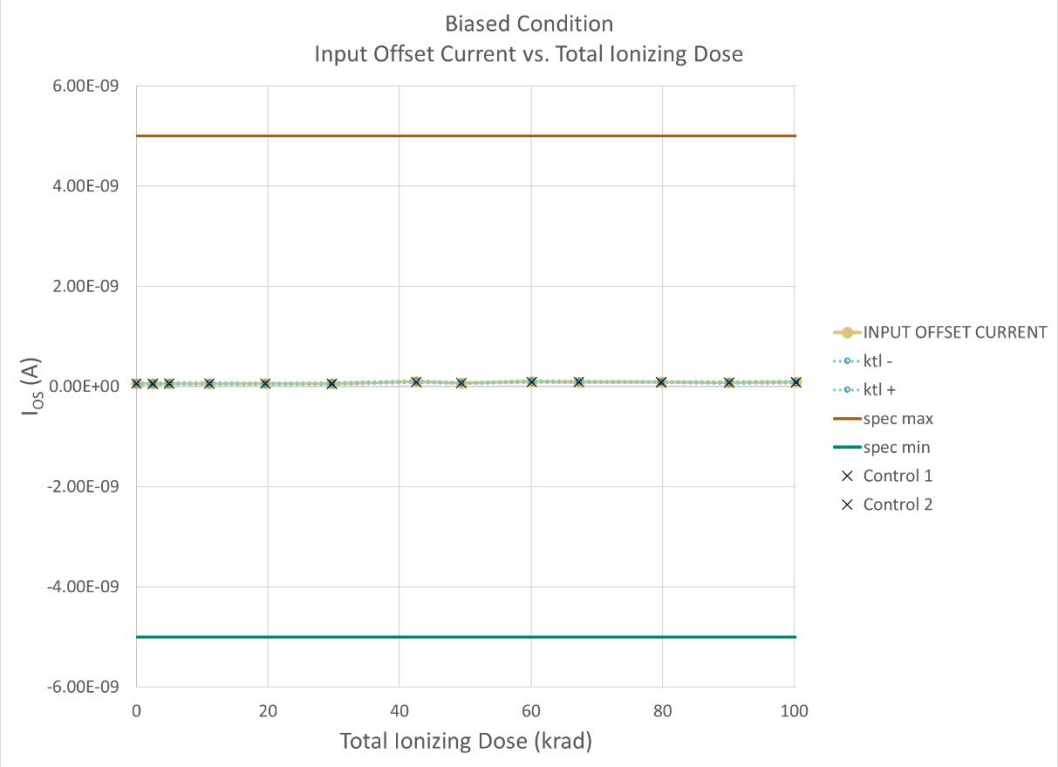


Figure 20 – Biased I_{OS} vs. TID. Mean value is positively correlated to TID. *(r_{mean} = 0.806)*

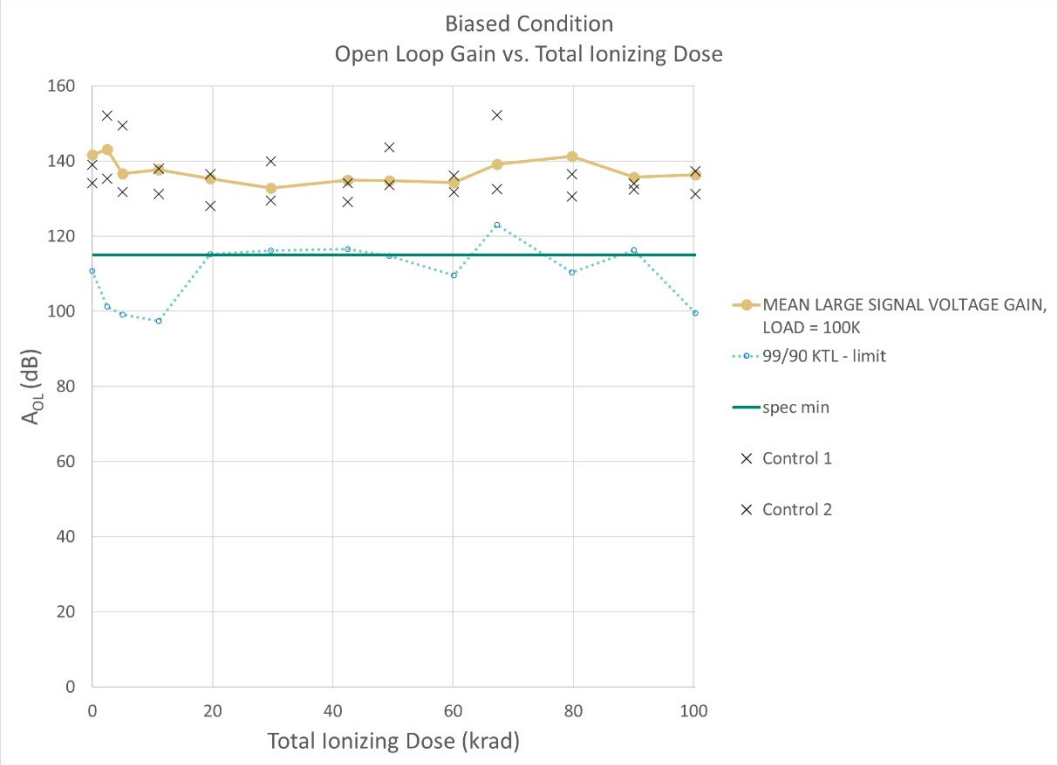


Figure 21 – Biased A_{OL} vs. TID. A_{OL} correlation to TID is not significant.

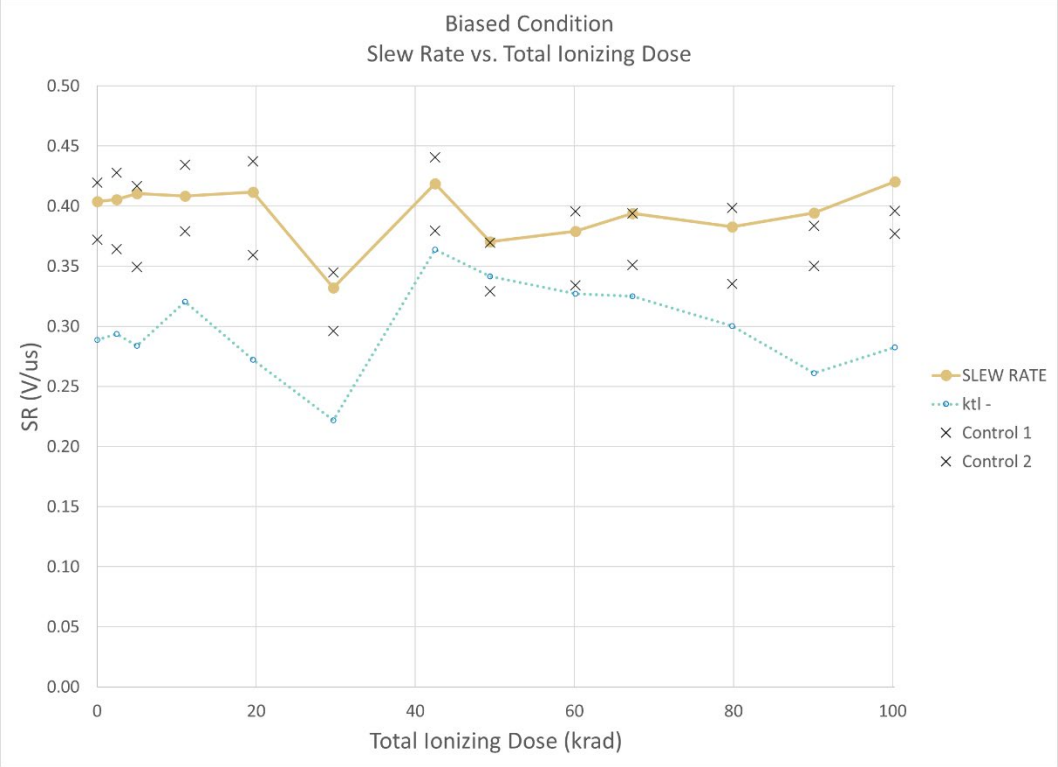


Figure 22 – Biased SR vs. TID. Variance is negatively correlated to TID *($r_{variance}$ = -0.577)*

8. Summary

Twelve (12) parts were provided for LDR TID test of the LTC2054HVMP operational amplifier of lot date code #2034. Ten (10) parts were irradiated: five (5) in the biased condition and five (5) in the unbiased condition. Two (2) parts were used as control samples. Electrical datasheet parameters were tested between each dose step up to 100 krad(Si) at LDR of 10 mrad(Si)/s. All parameters in both irradiation conditions experienced degradation due to TID except for A_{OL} which could not be determined to be significantly affected by TID. V_{OS} among the biased condition group was degraded to the point of the KTL lower limit exceeding the specification between 80 krad(Si) and 90 krad(Si). I_Q among the biased condition group was degraded to the point of the upper KTL limit exceeding the specification between 90 krad(Si) and 100 krad(Si). No parameters in the unbiased group exceeded datasheet specifications [2]. Open loop gain parameter KTL lower limit exceeded datasheet specification of 115 dB in both biased and unbiased conditions, but this cannot be correlated to TID per correlation coefficient values of open loop gain in Table 4.

9. Equipment

MFG and P/N	Function
Keithley 2425	Source Meter Unit
Keithley 2425	Source Meter Unit
Agilent 33220A	Function Generator
Tektronix MSO 5204	Oscilloscope
HP 34401A	Multimeter
Agilent N6700B	Power Supply
NI GPIB-USB	GPIB-to-USB adapter
Labview PC	Test Controller

10. References

1) Department of Defense "Test Method Standard Microcircuits," MIL-STD-883 Test Method 1019.9 Ionizing radiation (total dose) test procedure, June 7, 2013, https://landandmaritimeapps.dla.mil/Downloads/MilSpec/Docs/MIL-STD-883/std883.pdf.
2) LTC2054HVMP device datasheet, <https://www.analog.com/media/en/technical-documentation/data-sheets/20545fc.pdf>
3) Department of Defense "Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices," MIL-HDBK-814, February 8, 1994, https://landandmaritimeapps.dla.mil/Downloads/MilSpec/Docs/MIL-HDBK-814/hb814.pdf.

11. Acronyms

Acronym	Definition
A_{OL}	Open Loop Gain
DIP	Dual In-line Package
ELDRS	Enhanced Low Dose Sensitivity
ESD	Electro-static Discharge
I_B	Input bias current
I_{OS}	Input offset current
I_Q	Quiescent Current
KTL	K-factor Tolerance Limit
LDR	Low Dose Rate
SR	Slew Rate
TID	Total Ionizing Dose
V_{OS}	Input offset voltage
V_{OUT_H}	Output Swing High
V_{OUT_L}	Output Swing Low