Total Dose Bias Dependency and ELDRS Effects in Bipolar Linear Devices

C.C. Yui, S.S. McClure, B.G. Rax, J.M. Lehman, T. D. Minto, M.D. Wiedeman
Electronic Parts Engineering Office
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, USA
candice.c.yui@jpl.nasa.gov

Abstract—**Total dose tests of several bipolar linear devices show sensitivity to both dose rate and bias during exposure. All devices exhibited Enhanced Low Dose Rate Sensitivity (ELDRS). An accelerated ELDRS test method for three different devices demonstrate results similar to tests at low dose rate. Behavior and critical parameters from these tests are compared and discussed.**

Keywords - LM139, LM193, LT1019, LM185, LM134;

I. INTRODUCTION

The use of bipolar linear devices is prevalent in most satellite and some space applications. However, degradation as a result of low dose irradiations known as ELDRS (effects of enhanced low dose rate sensitivity) is a major concern when selecting flight hardware. The reason for this is because space programs receive low dose radiation over numerous months and years. Many studies and reports have been conducted on this phenomenon [1]-[5] as well as their responsible physical mechanisms [6].

The testing of five different bipolar linear circuits will be presented in this summary. They include a dual and quad voltage comparator, two voltage reference devices and a temperature transducer. Testing done include high dose rate and low dose rate testing for biased and unbiased conditions. In addition, medium dose rate testing at 100 C was conducted for three different device types as an evaluation of an accelerated ELDRS test methodology. The purpose of these tests was to characterize these parts for total dose environments and to assess suitability for use in space systems. Additionally, these tests assist in further understanding the effects of ELDRS under a wider range of conditions. A reminder must be made that the dose rates used here does not guarantee that device performance at low dose rates has been bounded. Additional testing should be done to study possible degradation at lower dose levels.

II. EXPERIMENTAL DETAILS

A. Device Descriptions

A list of tested devices is shown on Table I. The LM193 and LM139 are dual and quad comparators, the LM185 and LT1019 are voltage reference devices and the LM134-H is a 3 terminal adjustable current source, also used as a temperature transducer. All devices are fabricated on the manufacturer's standard bipolar process and are military standard 883 type parts. The one exception is the LM139, it is a space level QML, radiation hardened device, guaranteed up to 100 Krad (Si).

B. Total Dose Facilities

TABLE I. IDENTIFICATION OF PART TYPES

Generic	Part Number	Date Code	Die Manufacturer	Description	Procured as
LM193	M38510/11202BPA	9950G	National Semiconductor	Dual Comparator	Military grade "B" hermetic parts – ceramic 8 pin DIP
LM139	RM139AJRQMLV	HID0205A	National Semiconductor	Quad Comparator	Military grade ceramic 14 pin DIP
LT1019-2.5	LT1019CN8-2.5	0040	Linear Technology	2.5V Precision Reference	Military grade hermetic – plastic DIP
LM185-1.2	LM185WG-1.2	H9C0039F	National Semiconductor	1.2 Voltage Reference	Military grade hermetic -ceramic 10-pin gull wing
LM134	LM134-H	0142	National Semiconductor	Temperature Transducer	Military grade TO-46 metal can package

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Total dose irradiations for all parts were performed using the Cobalt-60 gamma ray source at the Jet Propulsion Laboratory, Pasadena, CA. High dose rate exposure was approximately 50 rad(SiO^2)/s, medium dose rate was approximately 0.20 rad(SiO^2)/s, and low dose rate exposure was roughly 0.01 rad(SiO^2)/s. All irradiations were compliant to Mil-STD-883, Method 1019 and NIST traceable. Lead and aluminum shields were used to absorb low energy gamma rays.

TABLE II. IRRADIATION BIAS CONDITIONS

	LM193	LM139	LT1019-2.5	LM185-1.2	LM134
LDR (0.01 r/s) Qty. Biased	3	3	5	3	3 0.02 r/s
LDR (0.01 r/s) Qty. Unbiased	3	4	3	3	3 0.02 r/s
MDR Qty. Unbiased	none	3 0.25 r/s	none	2 0.20 r/s	5 (5 Biased) 0.20 r/s
HDR (50 r/s) Qty. Biased	3	3	5	none	5
HDR (50 r/s) Qty. Unbiased	3	4	none	3	5
Bias	15V Input A – High Input B - Low	15V Input 1&2 – Low Input 3&4 - High[1]	$2.5V_{out}$ 1 KΩ	1.25mA through 10KΩ	Iset = 100 uA or 1mA

C. *Electrical Tests*

All parts were electrically tested with an LTS2020 mixed signal automated test system located adjacent to the Co-60 range source. Pre and post irradiation tests were performed at ambient temperature according to DC test parameters listed in the vendor or military specifications. Special precaution was taken to allow the temperature of the LM134 to stabilize before electrical testing was conducted.

D. *Procedure*

Samples of each part were tested at low and high dose rate for either or both biased and unbiased conditions. Of the three device categories – voltage comparator, voltage reference and temperature transducer, the LM139, LM185 and LM134 was selected for an accelerated ELDRS test at medium dose rate. Irradiated in an oven with a setting of 100 C, the medium dose test results will be further discussed in Section IV. Table II provides a comprehensive outline of the test conditions for the parts measured prior to irradiation and at step-levels thereafter. The time between irradiation steps for electrical tests occurred within one to two hours of each other. Also, low and high dose rate tests were conducted within a period of a month or less to ensure minimal errors due to equipment calibration changes. Parts in the unbiased group had all leads shorted.

III. TEST RESULTS AT HIGH AND LOW DOSE RATE

A. *LM193 Dual Comparator*

The LM193 is the counterpart of the LM139 quad comparator, also tested for this paper. For all test groups, the input bias current (Ib) degraded the most with respect to the specification, followed by the input offset current (Ios), and then input offset voltage (Vos). The change in Ib was far more rapid for the low dose rate groups than for the high rate groups and exceeded the specification between 3.6 and 6 Krad test levels. Bias condition did not have a significant effect on this parameter as indicated in Fig. 1 and 2.

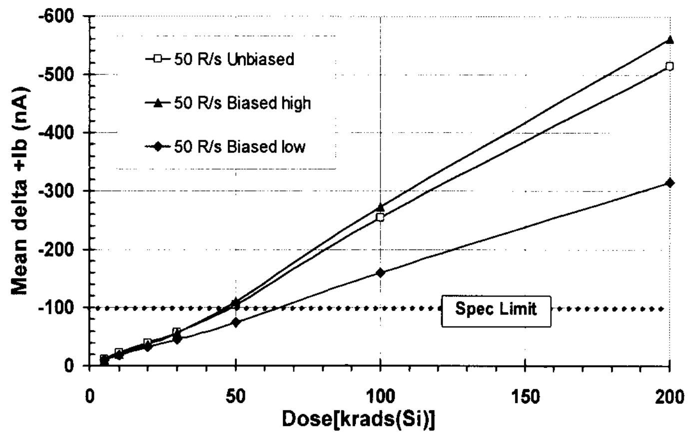
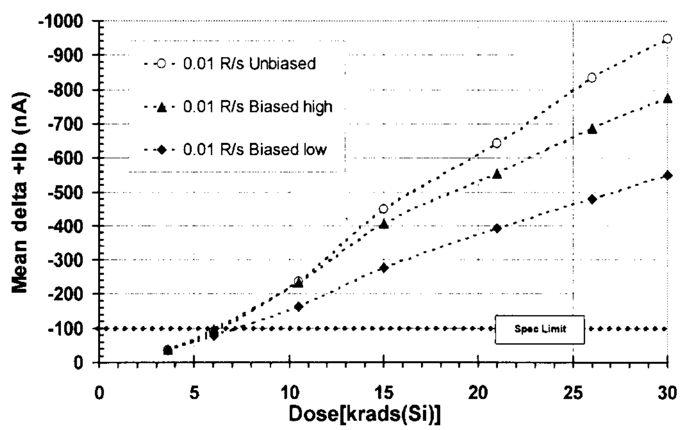


Fig. 1. High dose rate change in input bias current shows a mean difference of 250 nA between the biased high and low conditions.



[1] True bias conditions; different from future Data Workshop Record.

Fig. 2. Low dose rate results show large changes at earlier levels compared to high dose rate results. A mean difference in input bias current of 200 nA exists between biased high and low conditions.

Input offset current showed signs of degradation with dose rate dependence and some bias dependency for the high dose rate case (Fig. 3 & 4). Low dose rate degradation resembles the same pattern as high dose rate but at earlier dose levels. The one exception to this pattern is the unbiased case where the mean difference did exceedingly better in the high dose rate but demonstrated little bias difference in the low dose rate test. Although Vos remained within specification to the highest levels tested, this parameter exhibited both bias and dose rate dependence. It is interesting to note for Vos that while the unbiased case was worse at low dose rate, the opposite was true for the high rate case (Fig. 5 & 6). Furthermore, the parameter change was in opposite directions for the input high and input low conditions.

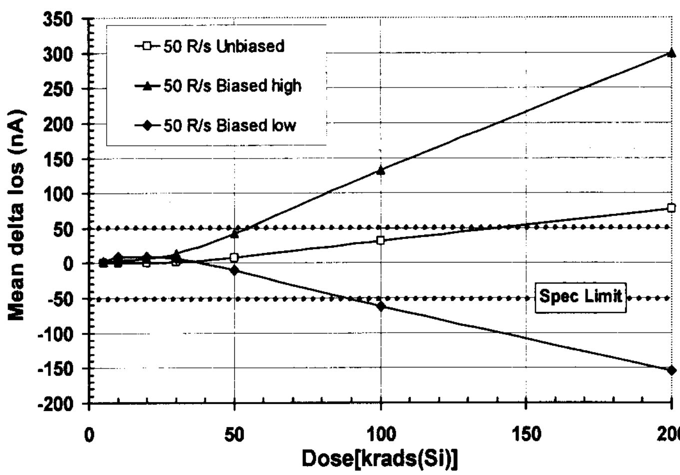


Fig. 3. High dose rate test for change in input offset current.

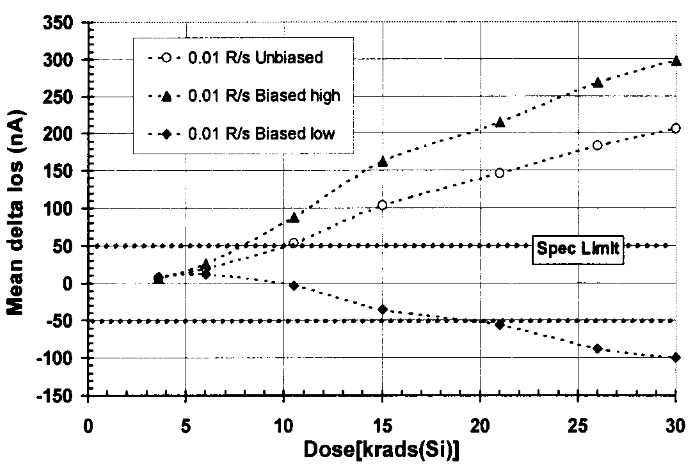


Fig. 4. Low dose rate change in input offset current exhibits ELDRS and dose rate dependency.

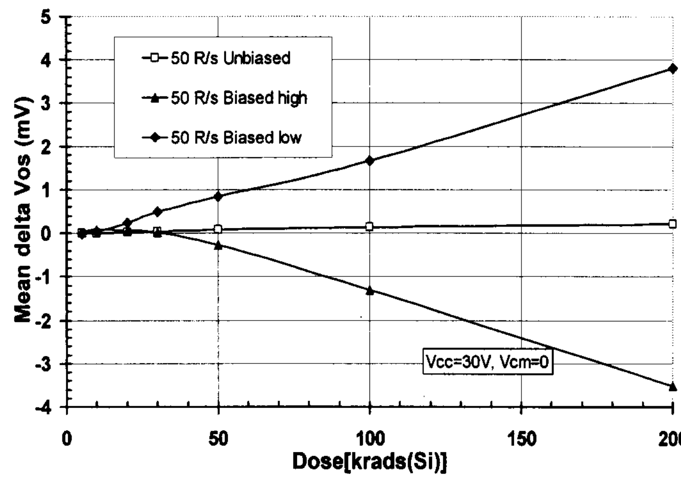


Fig. 5. High dose rate test of input offset voltage show little degradation out to 200 Krad. Unbiased case does better compared to biased cases. Biased low has a positive change.

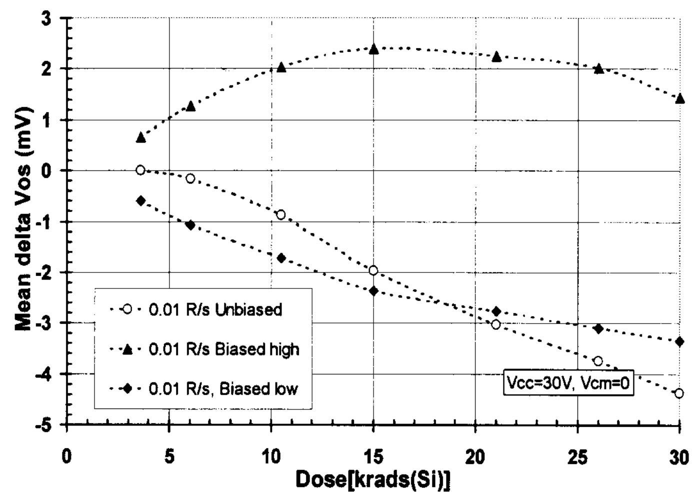


Fig. 6. Unbiased case was worse for this low dose rate test. Biased low has a negative change.

B. LM139 Quad Comparator

The LM139 low power, low offset voltage quad comparator exhibits dose dependency, having earlier failures for low dose rate tests than for high dose rate tests. Failures were determined for this device using the specifications listed under NSC's MNLM139A-X-RH data sheet. The main parameters of interest are input offset voltage and input bias current, both of which showed signs of degradation at 5 Krad for low dose rate biased parts. A slight bias dependency is only apparent for the high dose rate. In both parameters at high dose rate, unbiased devices did better than biased devices whereas biased devices did only slightly better for low dose rate tests (Fig. 7-9). Unbiased parts did not show signs of failure until the last tested level of 200 Krad. Also, all other test parameters -supply current, saturation voltage, and output sink current stayed within or near the specified limits. More mention of the medium dose rate, high temperature test will be made in Section IV, Accelerated Temperature Test.

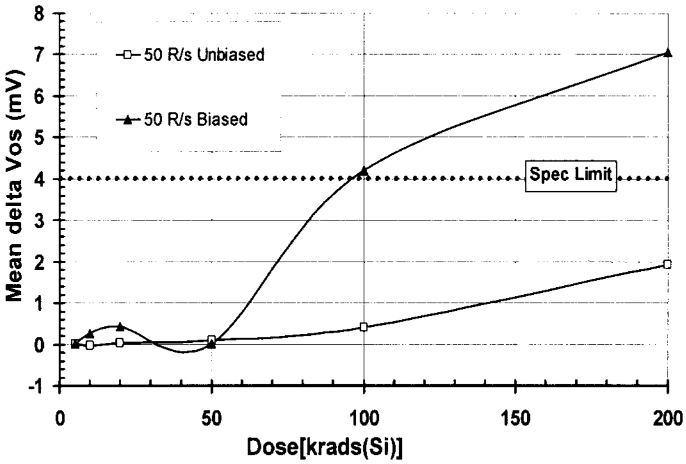


Fig. 7 Change is input offset voltage for high dose rate, biased parts - degrades at a faster rate than unbiased parts.

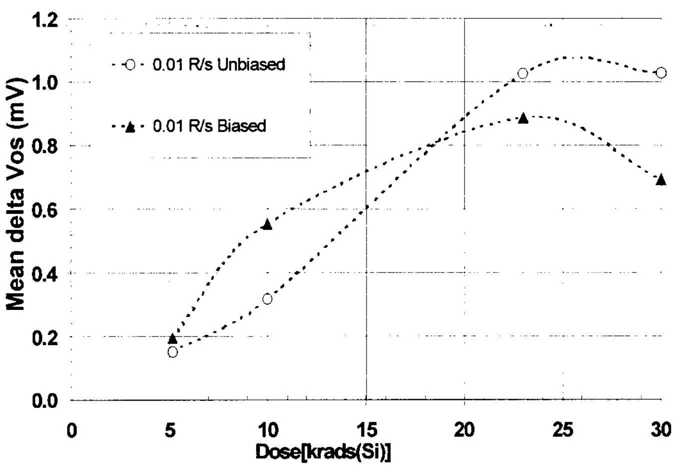


Fig. 8 Low dose rate change in input offset voltage exhibit failures at 5Krad.

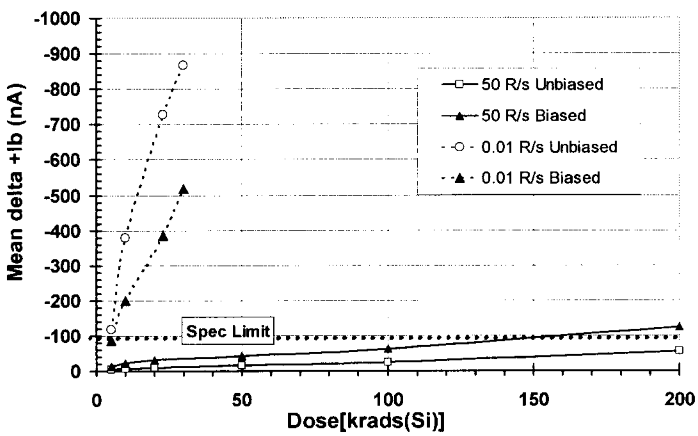


Fig. 9. Dose rate dependency is apparent for input bias current. Degradation for low dose devices show at 5 Krad.

C. LT1019-2.5 Voltage Reference

This device exhibited enhanced low dose rate sensitivity (ELDRS) with output voltage for the biased low dose rate case degrading approximately four times faster than the biased high dose rate case. A slight bias dependency is indicated with the biased case being slightly worse (Fig. 10 and 11). The low dose rate groups performed within the manufacturer's pre-radiation specification to greater than 10 Krad while the biased group remained within specification to greater than 30 Krad. Output voltage and line regulation failures occurred at the 17 Krad test level for the low dose rate case. In contrast, these failures did not occur until 50 Krad for the high dose rate case. The remaining test parameters were within specification at all test levels. Parts in the high dose rate group recovered about 40% after a one-hour biased anneal for line regulation.

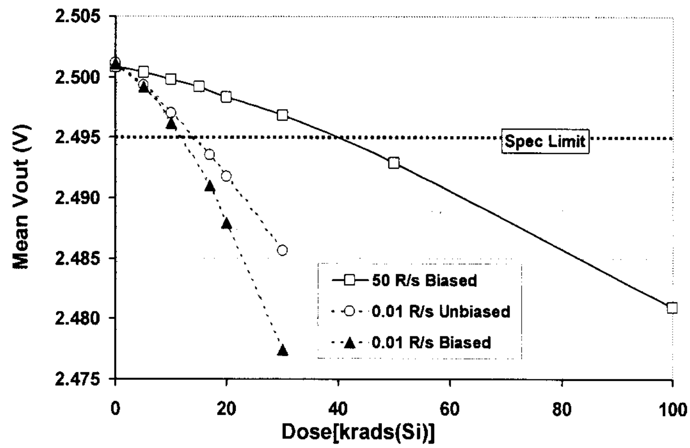


Fig. 10 Output voltage for the biased low dose rate case degrading approximately four times faster than the biased high dose rate case.

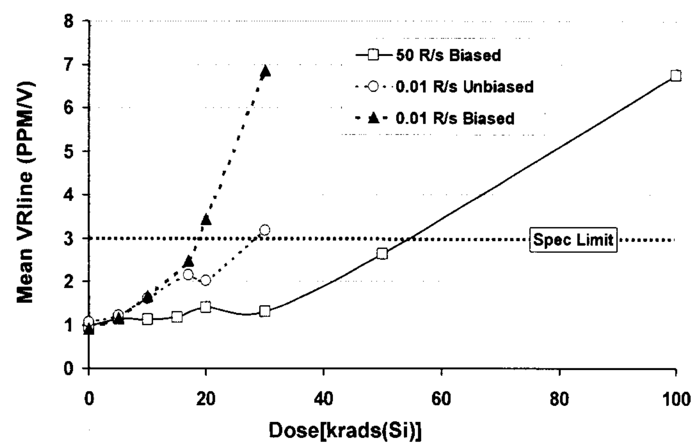


Fig. 11 Similar to Vout, Vrline demonstrates the same bias and dose dependency, with low dose rate biased devices doing the worst followed by low dose rate unbiased.

D. LM185-1.2 Voltage Reference

For all test groups, reverse breakdown voltage was the primary parameter of interest. Though degradation was also found for breakdown voltage change with current, these failures were due to large changes in the breakdown voltage alone. The device exhibited enhanced low dose rate sensitivity (ELDRS) with the reverse breakdown voltage (reference voltage) for the low dose rate case degrading far more than for the unbiased high dose rate case. For the low dose rate case, the unbiased condition degraded faster than the biased case with the reference voltage going out of specification between 5 and 10 Krad. The initial tendency of reference voltage for the low rate groups was to first decrease then increase after 20 Krad. In contrast, the high dose rate group had very little degradation out to the highest level tested, 100 Krad.

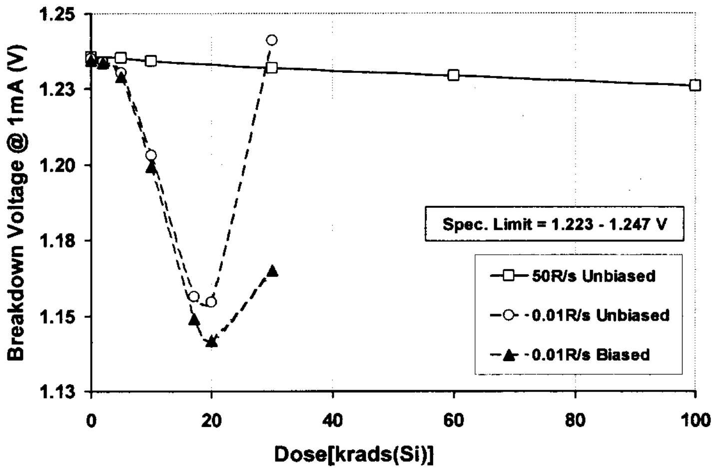


Fig. 12. Dose rate dependency is much more severe in low dose rate testing than high dose rate testing.

E. LM134-H Temperature Transducer

The LM134 demonstrated both ELDRS and severe bias dependency. Under low dose rate conditions, unbiased devices went beyond listed specifications at 16 Krad for parameters set error and temperature error (Iset = 100uA or 1mA, Vcc=1.5V-15V, Fig. 13). Set ratio parameter also showed signs of failure beginning at 10 Krad for unbiased parts and at 16 Krad for biased ones. Failures for high dose rate did not appear until roughly 50 Krad for set error and temperature error (Iset = 100 uA for Vcc= 1.5-20V) for both biased and unbiased parts (Fig. 14). One interesting note is the fact that as Vcc voltages continued to increase after 7.5 V, little to none biased parts exceeded limits for these two parameters at Iset = 1 mA (Fig. 15). Set current ratio indicates failures at 20 Krad for some biased devices and all unbiased devices. PSRR also depicted ELDRS as it began to degrade as early as 3.4 Krad for low dose rate biased and unbiased devices and at 5-10 Krad for high dose rate unbiased and biased devices.

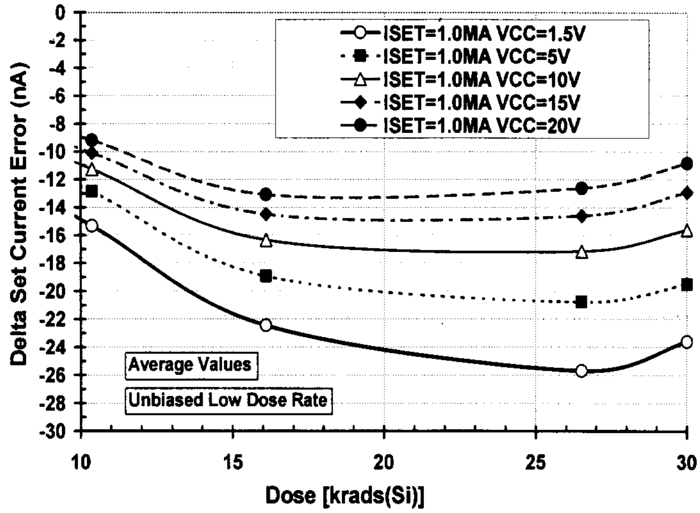


Fig. 13. Degradation for delta set current error increases with decreasing Vcc.

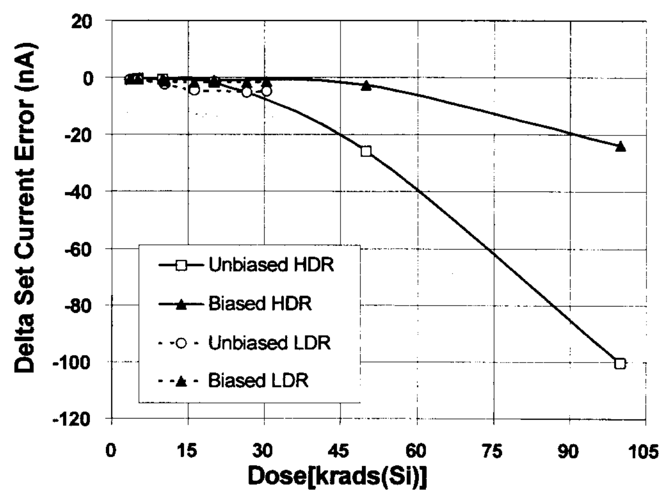


Fig. 14. Comparison of high dose and low dose test results for delta set current error.

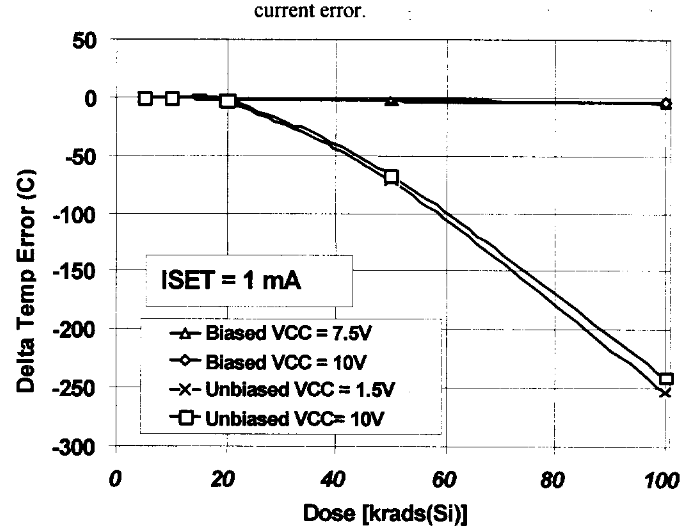


Fig. 15. Peformance of biased devices improve as Vcc increases past 7.5V for high dose rate test.

IV. ACCELERATED TEMPERATURE TEST

The accelerated temperature test was conducted for the LM139, LM185 and LM134 at approximately 0.20 R/s in an oven set at 100 C. Previous studies indicate that elevated temperature testing at 100 C to be effective in indicating and bounding ELDRS performance [7]. Subsequent studies have shown that the typical dose rate of 1 rad/s may still be too fast to adequately simulate some degradation mechanisms [8]. Our dose rate of 0.20 R/s was chosen as an optimum rate that meets this requirement as well as provides convenience for testing purposes. Test results from the following three devices simulate low dose test responses.

A. LM139

The main parameters of interest are input bias current, saturation voltage and output sink current. These parameters began to degrade at levels relatively close to that of the low dose rate test. For input bias current, this accelerated temperature test at 0.25 rad/s and 100 C resembles low dose, unbiased results up until approximately 25 Krad (Fig. 16). Both began to show signs of degradation at 5 Krad. One interesting note is input voltage offset. The test results show that for this device, the high temperature condition of 100 C may have aided in the delayed degradation of input voltage offset to 100 Krad instead of the 23 Krad failure level for the low dose, unbiased condition. The last two parameters, saturation voltage and output sink current, fail at 20 Krad and 14 Krad respectively, similar to the 23 Krad and 10 Krad failure levels exhibited by the low dose unbiased case.

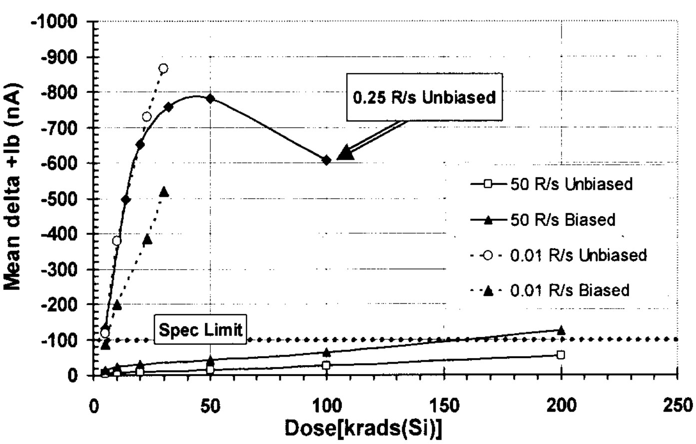


Fig. 16. Medium dose rate (0.25 R/s) for input bias current indicate similar results to low dose unbiased results.

B. LM185

The accelerated temperature test for this device resulted in degradation of breakdown voltage at all current levels (0.01 – 20 mA) beginning after 5 Krad and demonstrating failures at the next tested level of 17.5 Krad. Low dose rate failures for the same parameters were first noticed at 10 Krad. The initial tendency of reference voltage for the low rate groups was to decrease then to increase after 20 Krad. The medium rate group showed the same tendency but at an earlier point, between 5 and 17 Krad and the degradation for this group was significantly more than for the low rate group in general (Fig. 16). Although this accelerated temperature test exhibited ELDRS and dose dependency, a direct comparison to the low dose rate group is unavailable as tested dose levels were not the same.

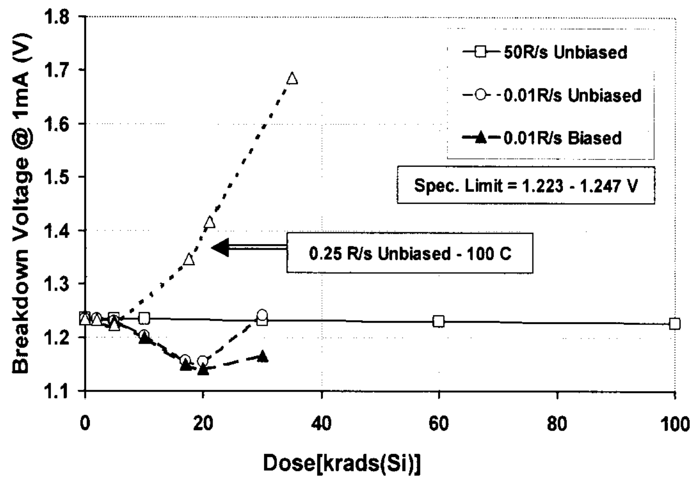


Fig. 17. Medium dose rate (0.25 R/s) begin to exhibit degradation between 5 – 17.5 Krad.

C. LM134

Findings for the LM134 medium dose rate are similar to that of the low dose test group. Failures for the unbiased devices begin at the 17 Krad test level for set error and temperature error (Fig. 17). However, when Vcc increases past 7.5V for Iset = 100 uA, more and more biased devices begin failing at an earlier level of 39 Krad for both parameters. Set ratio degradation only appeared for unbiased devices at 17 Krad. PSRR, like low dose devices, fail at the early level of 2.5 – 5 Krad for all devices.

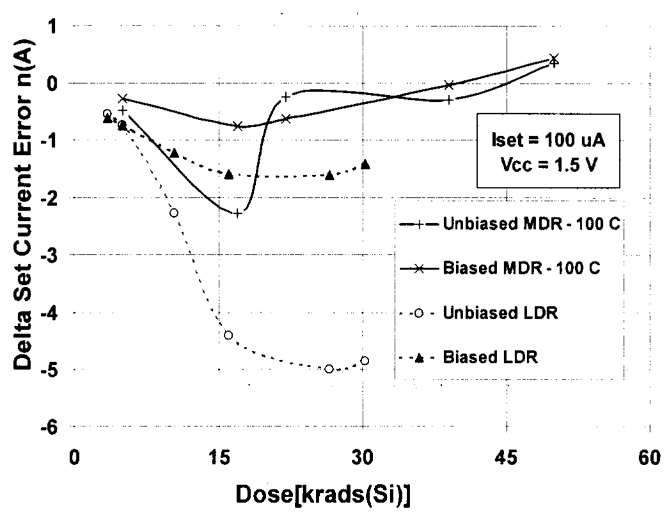


Fig. 18. Both medium and low dose rate test groups begin showing degradation at 17 Krad.

V. CONCLUSION

ELDRS is an effect common to all of the above tested devices. In each case, failures seen for low dose are evident again at higher dose levels or even not at all. Bias dependency exists for a number of the parameters tested. For the voltage comparators, both LM193 and LM139 demonstrated a bias dependency with unbiased devices doing better in high dose rate tests and worse for low dose rate tests. However, voltage reference devices behaved differently, with the LT1019 unbiased devices performing much better for both dose rate conditions and the converse being true for LM185 low dose rate. The LM134 temperature transducer only exhibited bias dependency at certain test parameters.

As a result of differing bias dependency for each of the three device type categories, a generalization cannot be made among them. However, each device should be tested at high and low dose rates according to their intended application to more fully characterize their behavior. The accelerated temperature test in this study demonstrated results similar to that of low dose rate testing. The similarity suggests a good bound of ELDRS performance to the levels tested.

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