ELDRS Characterization of Texas Instruments LM185, 1.2V Precision Reference: Retrograde Behavior Demonstrates Why Taking Interim Test Points Is Important

Kirby Kruckmeyer, *Member, IEEE* and Thang Trinh

***Abstract*—The LM185 1.2V reference voltage degraded through total ionizing dose radiation, but began to recover at around 70 krad. The recovery curve was different for high and low dose rates and biased and unbiased test conditions.**

I. Introduction

THE LM185H-1.2RLQV, 5962R8759461VXA 1.2 V precision reference [1] was put through the Enhanced Low Dose Rate Sensitivity (ELDRS) characterization as described in MIL-STD-883 Test Method 1019 [2], with some modifications. This characterization consists of irradiating units with gamma rays at high and low dose rates and comparing the parametric degradation at the two dose rates. During the irradiation, some units will be biased as they would be in an application and other units have all the leads grounded. Per TM1019, test points are taken at the rated total ionizing dose (TID) level for the part and half the rated dose. In this study, the test method was modified so that additional test points were taken. Because the extra test points were taken, a retrograde behavior of the reference voltage drift through irradiation was discovered. The reference voltage drift and recovery was different depending upon the dose rate, the bias conditions of the test units during irradiation and the operating conditions of the units post irradiation.

II. Product Description

Texas Instruments' (TI) LM185H-1.2RLQV is a 1.2V, two terminal band gap regulator diode, also known as a shunt reference (Fig. 1) [1]. It has an operating current range of 10 µA to 20 mA. It has a precision of ±1% at room temperature and ±2.5% over the full operating temperature range of -55°C to +125°C.

The wafers are fabricated at TI's facility in Scotland using a classic junction isolated bipolar process. It is assembled in a 2 lead TO metal can.

It is manufactured per MIL-PRF-38535 [3] and is available as SMD PIN 5962R8759461VXA [4].

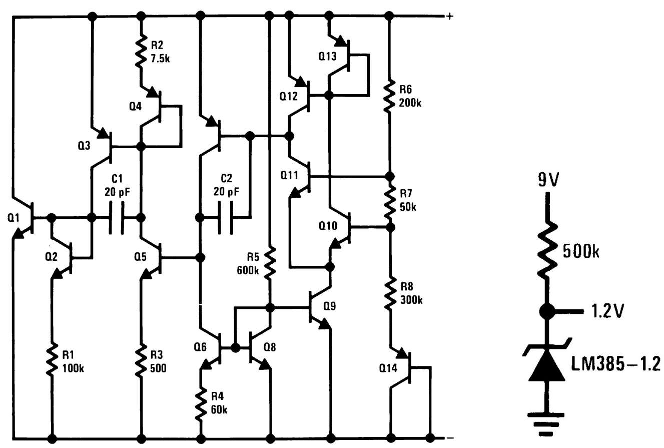

Fig. 1 LM185H-1.2RLQV simplified schematic and aspplication diagram.

III. Test Method

Units from two wafers from the same wafer lot were used for this characterization.

TID testing was done using the ELDRS characterization in MIL-STD-883, Test Method 1019 section 3.13.1.1 as a guide [2]. A four way split was run with units biased and unbiased during irradiation at low dose rate (LDR) and high dose rate (HDR). Five units from each of the two wafers were used for a total of 10 units per test split. The unbiased units had both pins grounded during irradiation. For the biased units, the negative pin was connected to ground and the positive pin (VS) was connected to 5.5 V though a 300 Ω resistor for a supply current of 14 mA. Electrical testing was done with an LTX80 test system at TI's Santa Clara radiation test facility. All datasheet and SMD parameters were tested.

HDR irradiation was run at 89 rad(Si)/s at TI's radiation facility in Santa Clara, California. All units were irradiated to 300 krad (Si) with interim test points taken at 3, 10, 30, 50, 80, 100, 150 and 200 krad(Si). At each test point, the units were tested within an hour of being removed from the radiation chamber and were returned to the radiation chamber

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Kirby Kruckmeyer is with Texas Instruments, Santa Clara, CA 95052 USA (telephone: +1 669 721 3548, e-mail: kirby.kruckmeyer@ti.com).

Thang Trinh is with Texas Instruments, Santa Clara, CA 95052 USA (e-mail: thang.trinh@ti.com).

within 2 hours. The LDR irradiation was run at 10 mrad(Si)/s at White Sands Missile Range (WSMR) in New Mexico. LDR units were irradiated to 150 krad(Si) with interim test points taken close to but not exactly the same level as the HDR test points. The TID levels for the interim test points are shown in Table I. At each test point, units were shipped overnight to TI's Santa Clara test facility for testing, and then shipped back to WSMR overnight to be returned to the radiation chamber, except at the 100 krad(Si) test point. At this test point, the units were still tested the day after being removed from the radiation chamber, but the units were not returned to the radiation chamber until 10 days later. After the 150 krad(Si) test point the units were retested again 10 days later to determine if time out the chamber would have any impact on the test results.

IV. ELDRS CHARACTERIZATION

For products with bipolar and linear elements, an ELDRS characterization is run to determine how radiation lot acceptance testing (RLAT) will be performed, per TM1019. If a product is determined not to have ELDRS, RLAT can be performed at either LDR or HDR to the TID rated level. If the part is determined to have ELDRS, RLAT must be done at an LDR of 10 mrad/s, with a 1.5X overtest. For a lot to be qualified to 100 krad(Si), it must be tested at 10 mrad(Si)/s and pass testing at 150 krad(Si).

To determine if a product has ELDRS per the definition in TM1019, the median parametric drift at each TID level tested is compared at LDR and HDR for each electrical parameter in the datasheet. If at the rated TID level or one half the rated TID level the parametric drift is significant and the drift at LDR is greater than 1.5 times the drift at HDR, the part is considered to have ELDRS. Significant parametric drift is defined as an electrical parameter drifting outside the pre irradiation datasheet limit.

The TI radiation test facility has an automated script for evaluating an ELDRS characterization. A sample output from one test, reference voltage (Vref) at 20 mA operating current, is shown in Table I. For each test split, at each TID test point, the median delta drift for the test units in the test leg is calculated as shown in the fifth column. The last column shows the ratio of the parametric drift at LDR and HDR.

V. ELDRS CHARACTERIZATION RESULTS

As shown in Table I, with the units unbiased during irradiation, the Vref drift at 20 mA is 1.6 times greater at LDR than it is at HDR at 50 krad(Si). The lower pre irradiation test limit for this parameter is 1.223 V and some units had readings below this limit at 50 krad, so the parametric drift is considered significant. Since there was one test that met both criteria of the LDR/HDR ratio being greater than 1.5 and the drift was significant at half the rated TID level, the product is considered to have ELDRS.

Typically, on most products, the post irradiation test limits are fixed limits. For this product, the post irradiation limits are listed in terms of per cent drift from the 0 krad reading. This is to allow for easy and meaningful worst case analysis. The post irradiation limits are listed in Table II. Because this product is considered to have ELDRS, the parametric drift at 150 krad(Si) must be less than these limits for the part to be rated at 100 krad(Si).

TABLE I
VREF AT 20 MA OPERATING CURRENT

TEST_BIAS	Dose (krad)	AVG (V)	MAX (V)	MIN (V)	SIGMA (V)	Median Delta from 0 rad (V)	Delta Ratio to HDR (V)
LDR_BIASED	0.0	1.2376	1.2421	1.2319	0.0038		
LDR_BIASED	3.2	1.2371	1.2411	1.2316	0.0036	-0.0004	0.62
LDR_BIASED	11.7	1.2358	1.2402	1.2307	0.0032	-0.0014	0.96
LDR_BIASED	32.0	1.2317	1.2375	1.2270	0.0030	-0.0049	1.46
LDR_BIASED	47.7	1.2288	1.2349	1.2241	0.0031	-0.0080	1.39
LDR_BIASED	76.1	1.2245	1.2303	1.2199	0.0030	-0.0125	1.37
LDR_BIASED	100.6	1.2219	1.2273	1.2175	0.0030	-0.0152	1.42
LDR_BIASED	150.0	1.2191	1.2236	1.2147	0.0030	-0.0182	1.53
LDR_UNBIAS	0.0	1.2348	1.2407	1.2296	0.0040		
LDR_UNBIAS	3.2	1.2346	1.2404	1.2294	0.0040	-0.0002	0.50
LDR_UNBIAS	11.7	1.2339	1.2396	1.2286	0.0039	-0.0010	0.86
LDR_UNBIAS	32.0	1.2305	1.2362	1.2246	0.0041	-0.0046	1.57
LDR_UNBIAS	47.7	1.2274	1.2330	1.2214	0.0040	-0.0076	1.65
LDR_UNBIAS	76.1	1.2242	1.2294	1.2190	0.0037	-0.0106	1.57
LDR_UNBIAS	100.6	1.2258	1.2302	1.2212	0.0035	-0.0091	1.20
LDR_UNBIAS	150.0	1.2372	1.2411	1.2307	0.0034	0.0023	-0.35
HDR_BIASED	0.0	1.2356	1.2419	1.2298	0.0042		
HDR_BIASED	3.0	1.2349	1.2412	1.2294	0.0041	-0.0007	
HDR_BIASED	10.0	1.2341	1.2399	1.2285	0.0040	-0.0014	
HDR_BIASED	30.0	1.2321	1.2365	1.2270	0.0036	-0.0033	
HDR_BIASED	50.0	1.2299	1.2341	1.2251	0.0035	-0.0057	
HDR_BIASED	80.0	1.2266	1.2315	1.2220	0.0034	-0.0091	
HDR_BIASED	100.0	1.2251	1.2305	1.2205	0.0035	-0.0107	
HDR_BIASED	150.0	1.2237	1.2294	1.2185	0.0035	-0.0118	
HDR_BIASED	200.0	1.2254	1.2312	1.2191	0.0039	-0.0102	
HDR_BIASED	300.0	1.2368	1.2477	1.2267	0.0064	-0.0007	
HDR_UNBIAS	0.0	1.2364	1.2401	1.2322	0.0024		
HDR_UNBIAS	3.0	1.2359	1.2396	1.2318	0.0023	-0.0004	
HDR_UNBIAS	10.0	1.2353	1.2389	1.2312	0.0023	-0.0011	
HDR_UNBIAS	30.0	1.2335	1.2370	1.2296	0.0022	-0.0029	
HDR_UNBIAS	50.0	1.2319	1.2353	1.2281	0.0021	-0.0046	
HDR_UNBIAS	80.0	1.2298	1.2332	1.2261	0.0021	-0.0067	
HDR_UNBIAS	100.0	1.2289	1.2322	1.2252	0.0021	-0.0076	
HDR_UNBIAS	150.0	1.2301	1.2337	1.2255	0.0028	-0.0067	
HDR_UNBIAS	200.0	1.2360	1.2441	1.2299	0.0044	-0.0013	
HDR_UNBIAS	300.0	1.2610	1.2814	1.2513	0.0094	0.0216	

TABLE II
PRE AND POST IRRADIATION TEST LIMITS

TEST NAME (PARAMETER)	SYMBOL	CONDITIONS	PRE RAD LIMITS		POST RAD LIMITS		
			MIN	MAX	MIN	MAX	Unit
Reverse Breakdown Voltage	V_{ref}	I_R = 10uA	1.223	1.247	±3 % Drift		%
		I_R = 1mA	1.223	1.247	±3 % Drift		%
		I_R = 20mA	1.223	1.247	±2.5% Drift		%
Reverse Breakdown Voltage Change with Current	$\Delta V_{ref}/\Delta IR$	10uA < I_R < 1mA	-1	1	-15	15	mV
		1mA < I_R < 20mA	-10	10	-25	25	mV
Forward Bias Voltage	VF	IF = 2mA	-1	-.4	-1	-.4	V

VI. RETROGRADE DRIFT BEHAVIOR

The average Vref measurements at the various TID levels tested are plotted in Figs. 2 through 5. Depending upon the test conditions, the parametric drift direction began to change at around 75 krad(Si) from negative to positive.

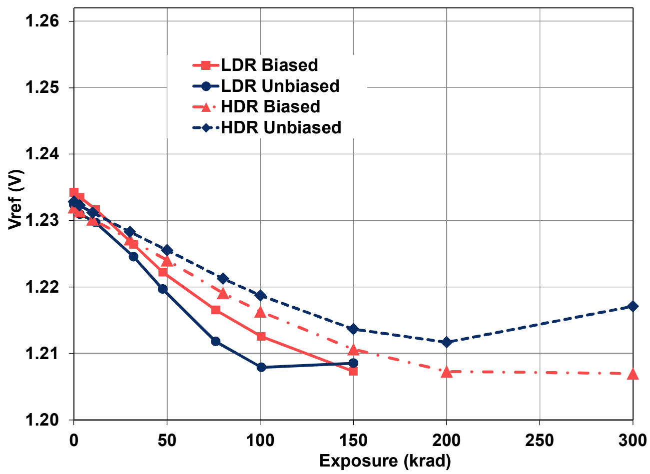

Fig. 2 Reference voltage at 10 µA operating current.

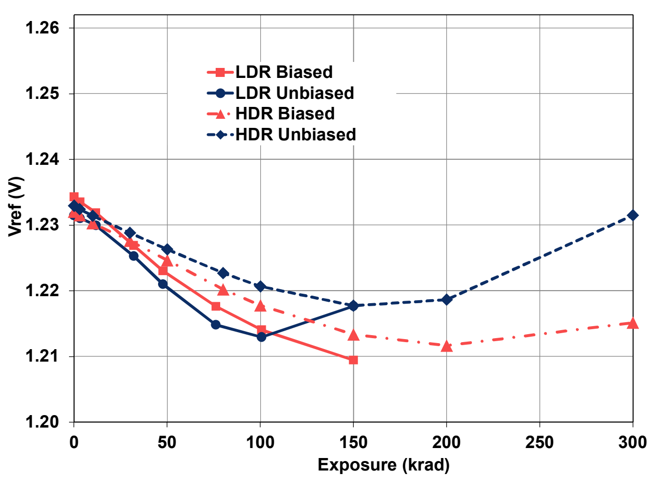

Fig. 3 Reference voltage at 1 mA operating current.

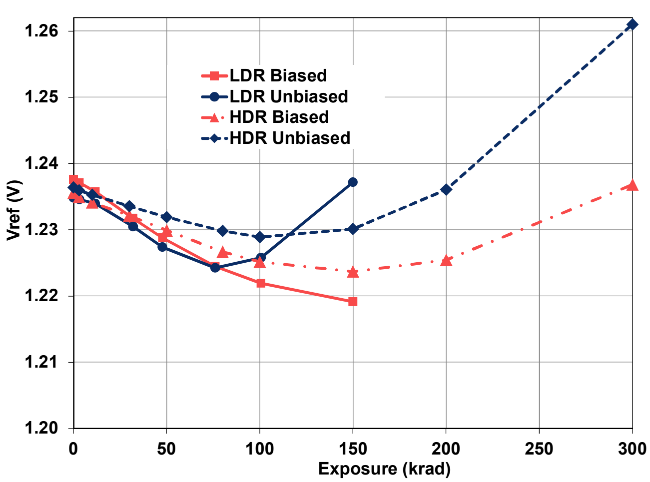

Fig. 4 Reference voltage at 20 mA operating current.

If the only test taken during TID testing was the rated TID level, the retrograde behavior of the Vref drift would not have been seen. Even testing at the rated dose and half the rated dose as required by TM1019 may not show the worst case drift as demonstrated in Fig. 6.

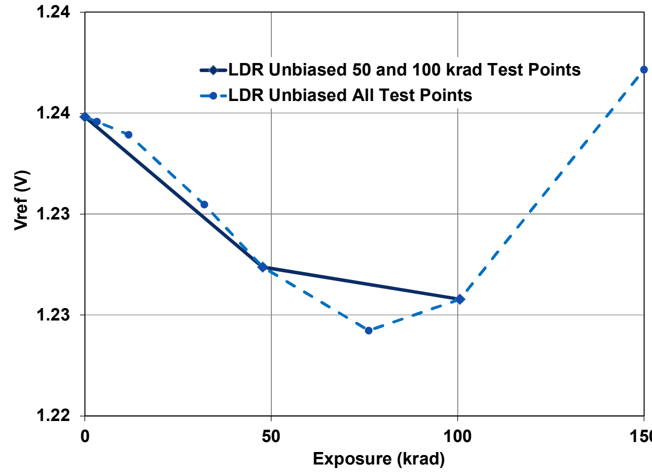

Fig. 6 Reference voltage at 20 mA operating current, LDR with units unbiased during irradiation. The dashed line shows the curve for all test points measured. The solid line represents what might be assumed about the TID drift in test points were only take at the rated value and half the rated value.

VII. Change in Drift after Irradiation

For LDR testing, TM1019 requires that units are returned to the radiation chamber within 5 days when the units are removed for electrical testing at interim test points. At the 100 krad(si) test point, the units were out of the chamber for 10 days. After the 150 krad(Si) test point, the units were again after 10 days to determine if there were any time delay effects (TDE) that could have impacted the validity of the 150 krad(Si) test results.

The worst case parameter, showing the most relaxation was Vref at 20 mA operating current (Table III). The worst case relaxation was 7% of the drift limits.

TABLE III
VREF AT 20 MA TESTED AFTER 150 KRAD AND 10 DAYS LATER (V)

	Vref @ IR = 20 mA (V)									
Wafer			6					1		
Units	9	10	11	12	13	9	10	11	12	13
Biased										
150 krad	1.2207	1.2236	1.2193	1.222	1.2224	1.2184	1.2147	1.2167	1.2159	1.2173
10 days later	1.2212	1.2242	1.2196	1.2223	1.2227	1.2188	1.2152	1.2171	1.2164	1.2176
Delta	0.0005	0.0006	0.0003	0.0003	0.0003	0.0004	0.0005	0.0004	0.0005	0.0003
Delta %	0.04%	0.05%	0.02%	0.02%	0.02%	0.03%	0.04%	0.03%	0.04%	0.02%
Unbiased										
150 krad	1.2411	1.2329	1.2397	1.2358	1.2398	1.2378	1.2402	1.2307	1.2375	1.236
10 days later	1.2397	1.2316	1.2381	1.2336	1.2379	1.2362	1.2386	1.2293	1.2359	1.2344
Delta	-0.001	-0.001	-0.002	-0.002	-0.002	-0.002	-0.002	-0.001	-0.002	-0.002
Delta %	-0.11%	-0.11%	-0.13%	-0.18%	-0.15%	-0.13%	-0.13%	-0.11%	-0.13%	-0.13%

VIII. Conclusions

The LM185H-1.2RLQV, 5962R8759461VXA has ELDRS as defined in MIL-STD-883 TM1019. To qualify the part at 100 krad(Si), the part should be irradiated to 150 krad(Si) at a low dose rate of 10 mrad(Si)/s and remain within the post irradiation limits for 100 krad(Si).

Post irradiation limits are based on percentage drift, allowing for meaningful worst case analysis.

Testing the units 10 days after the 150 krad test point demonstrated that the extended test window for the LDR units at the 100 krad(Si) did not impact the validity of the product qualification. If the delta in relaxation after 10 days is added to the parametric drift, the test results still remain within the specified test limits.

The reference voltage experienced a retrograde drift, where it would change direction around 75 to 100 krad(Si) depending upon the operation conditions and dose rate during irradiation and the operating current post irradiation testing. Because of this behavior, Texas Instruments will continue to take interim test points when performing RLAT.

IX. References

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