Total Ionizing Dose (TID) Report

Low Dose Rate Test Results for National Semiconductor’s ELDRS-free LM136-2.5 Bipolar Reference

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Low Dose Rate Test Results for National Semiconductor's ELDRS-free LM136-2.5 Bipolar Reference

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***Abstract*— Low dose rate (LDR) and high dose rate (HDR) total ionizing dose (TID) test results, drift calculations and an Enhanced Low Dose Rate Sensitivity (ELDRS) characterization are presented for National Semiconductor's "ELDRS-free" bipolar reference, LM136-2.5 and compared to data from older versions of the product.**

I. Introduction

The LM136-2.5 is a bipolar shunt reference that was designed over 30 years ago and has been used in many different radiation environments, including space applications. The LM136-2.5 or variations of it have been manufactured by a number of different suppliers. Each supplier may have used a number of different product layouts, manufacturing locations and processes to produce these products over the years. Each combination of variables could result in a different radiation performance, with some failing Total Ionizing Dose (TID) testing as low as 20 krad(Si) and others passing above 100 krad(Si) [1]-[4].

It has been shown that some versions of the LM136-2.5 exhibit Enhanced Low Dose Rate Sensitivity (ELDRS). Although a part may pass TID testing at a high dose rate (HDR), it could fail at a low dose rate (LDR) that is closer to the dose rate seen in a space application [1].

Historically, TID testing has been done under HDR conditions, typically between 50 and 300 rad(Si)/s, as outlined in MIL-STD-883, TM1019 [5]. Testing under LDR conditions was not routine, due to the time constraints. It can take several months to years to test products at the same dose rates of some applications. It had been proposed that it might be possible to simulate LDR response by irradiating products at elevated temperatures at HDR [6] but later found that this method was not valid for all product types [7]. Later it was proposed using a dose rate of 10 mrad(Si)/s with a design margin of two for the parametric drift to qualify bipolar products for LDR environments [8]. This dose rate has been adopted for the LDR qualification in the latest revision of MIL-STD-883 (rev G) Test Method 1019 (rev. 7), released February 28, 2006 [5]. Also included in MIL-STD-883G, TM1019.7 is a characterization technique to determine if a product could be considered to have ELDRS.

National Semiconductor has released a new version of the LM136-2.5 (Table I) that has been put through the ELDRS characterization defined in MIL-STD-883G, TM1019.7. Per the test method, the product is qualified to 100 krad(Si) and could be considered to be "ELDRS-free" [5]. Unexpectedly, HDR is the worst case condition for most electrical parameters. The ELDRS characterization results, along with data and statistical analysis from a larger sample size across multiple lots, are presented here.

TABLE I
Product Number and Lot Used for ELDRS Characterization

National Part Number	DSCC SMD Number	Lot Number
LM136AH-2.5RLQV	5962R0050102VXA	JM046X24

II. Product Description

The LM136-2.5 is a precision 2.5 V shunt regulator diode. It can provide a precision 2.5 V reference over a wide operating range of 400 uA to 10 mA (Fig 1) [9].

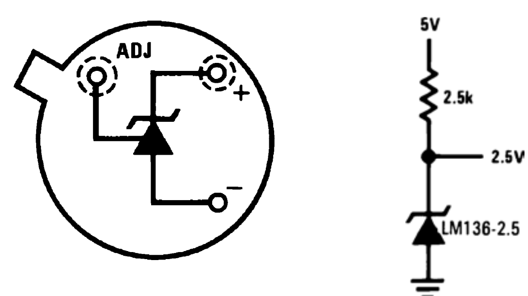

Fig. 1 Block diagram of the LM136-2.5 and schematic of the part in a simplified application.

The product tested in this study was manufactured in National Semiconductor's UK 6 inch bipolar wafer fab, using

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a unique process flow. The National Semiconductor part number and the Defense Supply Center Columbus (DSCC) Standard Microcircuit Drawing (SMD) number are listed in Table 1. The data presented here are applicable only to the part number listed, as the wafer process used is different from that used for other versions and assurance levels of this product.

III. Test Method

All units tested were assembled in the TO-46, three terminal metal can package and put through burn-in according to the V level flow of MIL-PRF-38535 [10].

Radiation testing was done using the ELDRS characterization in MIL-STD-883, Test Method 1019.7, section 3.13.1.1 as a guide [5]. A four way split was run on the lot listed in Table I with units biased and unbiased during HDR and LDR irradiation as shown in Table II. Additional units from 4 wafers from lot JM05CX20 and 5 wafers from lot JM05CX16 were tested at LDR with units biased and unbiased during irradiation and HDR with units biased during irradiation, with the sample sizes shown in Table IV.

TABLE II
ELDRS Characterization Test Matrix

Dose Condition	Dose Rate (rad/s)	Biasing	Sample Size
LDR	0.01	Biased	5
LDR	0.01	Unbiased	5
HDR	46	Biased	6
HDR	46	Unbiased	6

All irradiations were done using a Cobalt-60 gamma ray source. HDR irradiation was done at National Semiconductor's radiation facility in South Portland, Maine with a dose rate between 31 and 46 rad(Si)/s. The LDR irradiation was done at 10 mrad(Si)/s at White Sands Missile Range (WSMR).

The unbiased units had all leads tied to ground during irradiation. For the biased units, the positive pin was connected to 5 V through a 300 Ω resistor, with the negative pin connected to ground and the adjust pin left open.

Electrical testing was done with an LTX77 test system at National Semiconductor's South Portland radiation facility. All datasheet and SMD parameters were tested. At the time of the ELDRS characterization, the precision of the zener tests was 0.5 mV. For the testing of the second group of samples, the precision was improved to 1 µV. For the HDR experimental test legs testing was done at 0, 3, 10, 30, 50 and 100 krad(Si) total ionizing dose levels. The LDR legs were pulled at close to the same levels, but not always exactly at those levels. For the HDR legs, electrical testing was completed within an hour of being removed from the gamma radiation. The LDR legs were shipped overnight from the test facility at WSMR to National for testing, and shipped back overnight to WSMR to resume irradiation.

IV. Test Results

All test legs passed TID testing to a radiation level of 100 krad with all parameters inside the limits on the datasheet and SMD [9][11].

A. EDLRS Characterization

The parametric drift between 0 rad and 100 krad(Si) was analyzed for each of the test legs. Per MIL-STD-883G, Test Method 1019.7, section 3.13.1.1, the median parametric drift for each test condition was compared (Table III). If for any parameters, the ratio of the median LDR drift to the median HDR drift is greater than 1.5 and the parametric reading is outside the pre irradiation test limits, the "part is considered to be ELDRS susceptible". The worst case condition for the highest drift was HDR with the part unbiased during irradiation. No parametric readings were outside the pre irradiation limits, indicating the part does not meet the definition of being ELDRS susceptible.

TABLE III
Median Parametric Drift for Lot JMX046X24

			Parametric Drift 0 rad to 100 krad			
Test	Conditions	Units	LDR Bias	LDR Unbias	HDR Bias	HDR Unbias
Zener voltage	Vadj = 0.7 V	mV	0.0	0.0	-0.5	-1.0
Zener voltage	Vadj = 1.9 V	mV	1.0	0.0	-0.5	-0.5
Zener voltage	Vadj = Open	mV	0.0	0.0	-0.5	-1.0
Adjust current	Vadj = .0.7 V	uA	0.10	0.00	0.05	0.10
Delta zener voltage	400 uA < IR < 10 mA	mV	0.31	0.47	0.48	0.50

B. Drift Statistical Analysis

Table IV shows the average drift, standard deviation of the drift, the number of samples tested for the second group (lots JM05CX20 and JM05CX16) and the parametric limit spec range. With the improved precision of the test system it is possible to better discern the amount of drift due to the radiation damage. The standard deviation of the drift is about the same as the drift average, a reflection that many of the units showed no drift.

The within wafer, wafer to wafer and lot to lot parametric drift variations are shown in Table V for the LDR unbiased test condition. The first two data columns list the averages for the parametric readings at the 0 rad test point and the 0 rad to 100 krad(Si) average parametric drift for all 44 units tested from lots JM05CX20 and JM05CX16. The next three columns show the standard deviation of the drift for 5 units from one randomly chosen wafer, all of the units from one wafer lot and all units from the two wafer lots.

C. Parametric Drift Plots

The average parametric readings for all units in the ELDRS characterization (lot JM046X24) at all TID test points are plotted in Fig. 2 to 4. The average drift is greater than the median drift, as more than half of the samples showed little or no drift. The plots of the LDR drift show some nonlinearity that is due to the repeatability issues with the parametric test system that were not experienced with the HDR testing. The LDR testing takes over 4 months to complete, with several

TABLE IV
AVERAGE AND STANDARD DEVIATION OF THE DRIFT FOR THE SECOND GROUP OF SAMPLES (JM05CX20 AND JM05CX16)

			LDR				HDR		Spec
			Biased - 45 Samples		Unbiased - 44 Samples		Biased - 47 Samples		Range
Test	Conditions	Units	Drift	Std Dev	Drift	Std Dev	Drift	Std Dev	
Zener voltage	Vadj = 0.7 V	mV	-0.690	0.622	-2.197	0.649	-0.883	0.347	100
Zener voltage	Vadj = 1.9 V	mV	-0.765	0.824	-2.152	0.794	-0.635	0.253	100
Zener voltage	Vadj = Open	mV	-0.933	0.878	-2.896	0.880	-0.879	0.293	50
Adjust current	Vadj = .0.7 V	uA	0.059	0.087	0.138	0.068	0.062	0.072	250
Delta zener voltage	400 uA < IR < 10 mA	mV	0.373	0.45	0.746	0.067	0.399	0.145	6

TABLE V
WITHIN WAFER, WAFER TO WAFER AND LOT TO LOT DRIFT VARIATION FOR UNBIASED LDR

					Drift Sandard Deviation			
			Average	Average	Across	Across	Across	Spec
			reading	Drift	One	One Wafer	Two Wafer	Range
Test	Conditions	Units	at 0 rad	All Lots	Wafer	Lot	Lots	
Zener voltage	Vadj = 0.7 V	mV	2442.88	-2.197	0.010	0.010	0.649	100
Zener voltage	Vadj = 1.9 V	mV	2604.33	-2.152	0.009	0.010	0.794	100
Zener voltage	Vadj = Open	mV	2495.84	-2.896	0.010	0.010	0.880	50
Adjust current	Vadj = .0.7 V	uA	-10574.4	0.138	0.064	0.095	0.068	250
Delta zener voltage	400 uA < IR < 10 mA	mV	1915.88	0.746	0.209	0.068	0.067	6

days to weeks between each test point. The test system must be setup each time, resulting in some repeatability errors in the test system. The data plotted are the raw data and have not been normalized by the variation seen on the control (non irradiated) units. The HDR testing is completed within a few hours, in one session, requiring only one test setup, eliminating one source of test system variability.

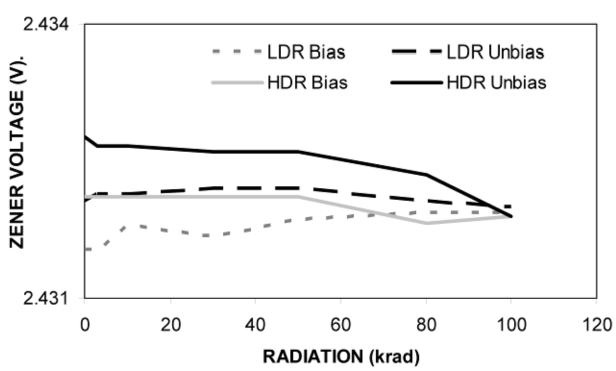

Fig. 2 Average zener voltage with the Adjust pin at 0.7 V vs. radiation level. Limits for this parameter are 2.39 to 2.49 V.

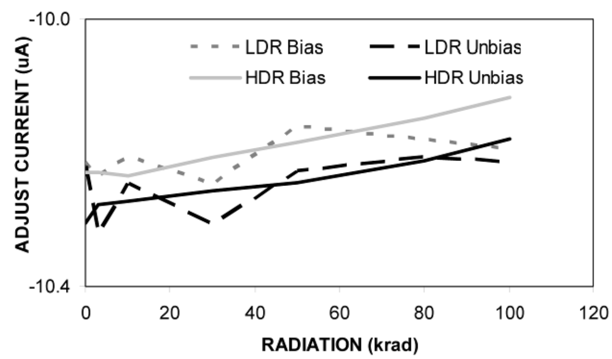

Fig. 3 Average adjust pin current with the Adjust pin at 0.7 V vs. radiation level. Limits for this parameter are -125 to +125 uA.

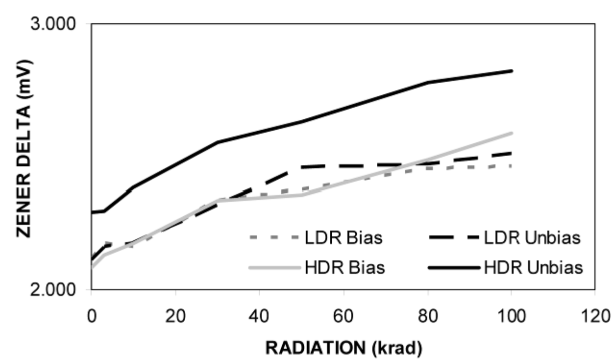

Fig. 4 Average zener voltage delta across the zener current range of 400 uA to 10 mA vs. radiation level. Maximum limit for this parameter is 6 mV.

V. Comparison to Other Versions of the LM136-2.5

Fig. 5 shows the zener voltage LDR and HDR drift for a B level (military grade) version of the LM136-2.5 manufactured by National Semiconductor in 1999 [1]. This version of the part shows more drift at both HDR and LDR, an ELDRS effect and greater sensitivity to bias conditions during irradiation.

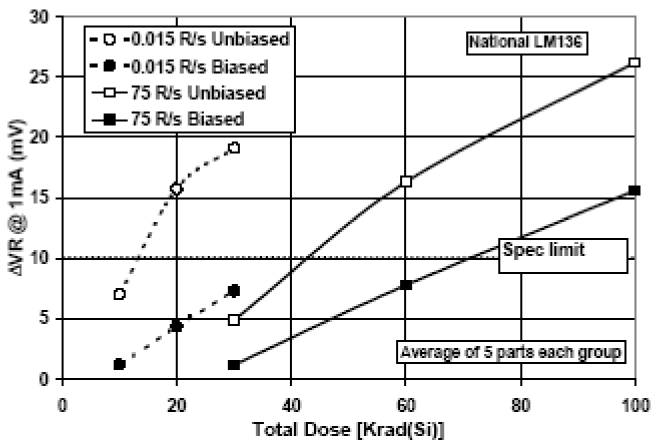

Fig. 5 Zener voltage drift vs. radiation level for a B-level (military grade) LM136-2.5, part number 5662-0050101QXA. Taken from [1].

VI. Conclusion

A characterization as outlined in MIL-STD-883G, Test Method 1019.7, section 3.13.1.1 has shown that National Semiconductor's LM136AH-2.5RLQV bipolar reference (DSCC SMD 5962R0050102VXA) does not exhibit ELDRS.

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