Single Event Transient (SET)

ELDRS Characterization Test Results for LM4050QML 2.5V Precision Reference

Literature Number: SNAA178

Single Event Transient and ELDRS Characterization Test Results for LM4050QML 2.5V Precision Reference

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***Abstract*—National Semiconductor's 100 krad(Si) low dose rate qualified, 2.5V precision reference, LM4050WG2.5RLQV, was put through heavy ion testing and an enhanced low dose rate sensitivity (ELDRS) characterization. The results are presented here.**

I. Introduction

NATIONAL Semiconductor's LM4050WG2.5RLQV (DSCC SMD 5962R0923561VZA) is a precision shunt voltage reference with a 2.5 V fixed reverse breakdown voltage (Fig. 1) [1]. It has an accuracy of 0.1% at 25°C and an operating temperature range of -55°C to +125°C. It has an operating current range of 60 µA to 15mA, which is set by the resistor Rs in Fig. 1. A functional block diagram of the part is shown in Fig. 2.

The LM4050WG2.5RLQV is manufactured using National Semiconductor's LFAST process, which is a standard, junction isolated bipolar structure on a lightly doped substrate. Many bipolar references have been shown to degrade when exposed to ionizing radiation. Many bipolar products experience Enhanced Low Dose Rate Sensitivity (ELDRS), where the product performance degrades more when exposed at a low dose rate (LDR), similar to the dose rates seen in a space application, than when exposed at a high dose (HDR), for the same total ionizing dose (TID) [2]-[5]. In addition, a reference can experience a single event transient (SET) where the output is disturbed by a single ion strike from a cosmic ray. It has been shown that the SET performance of a bipolar product can be highly dependent upon the operating conditions of the product [6].

The LFAST process is also used for National Semiconductor's DS16F95QML RS-485 transceiver [7], which will have single event transient (SET) and total ionizing dose (TID) data presented at the NSREC 2010 Data Workshop [8]. Although the products share the same process, the functions of the products are significantly different which may result in significantly different radiation responses. SET test results under different operating conditions and TID test results at both high dose rate (HDR) and low dose rate (LDR) for the LM4050WG2.5RLQV will be presented here.

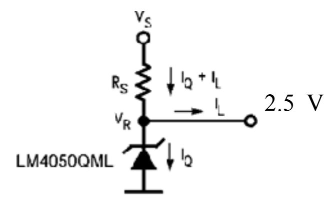

Fig. 1. LM4050WG2.5RLQV application diagram.

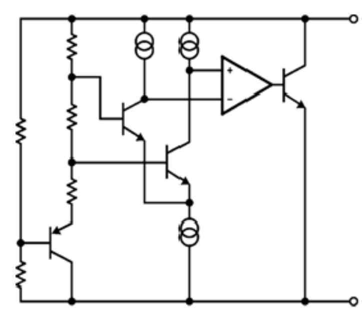

Fig. 2. LM4050WG2.5RLQV block diagram.

II. Test Method

A. ELDRS Characterization

TID testing was done using the ELDRS characterization in MIL-STD-883, Test Method 1019.7 section 3.13.1.1 as a guide [9]. A four way split was run with units biased and unbiased during irradiation at low dose rate (LDR) and high dose rate (HDR). HDR irradiation was run at 152 rad(Si)/s at National Semiconductor's radiation facility in Santa Clara, California. The LDR irradiation was done at 10 mrad(Si)/s at Radiation Assured Devices (RAD) in Colorado Springs, Colorado. The unbiased units had all pins grounded during irradiation. For the biased units, the negative pin was connected to ground and the positive pin (V_S) was connected to 15 V though an 866 Ω resistor for a supply current of 15 mA.

Electrical testing was done with an Eagle ETS500 test

Manuscript received July 14, 2010.
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system at National Semiconductor's Santa Clara radiation facility. All datasheet parameters were tested. For the HDR legs testing was done at 0, 3, 10, 30, 50, 80, 100 and 150 krad(Si) 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 RAD to National for testing, and shipped back overnight to RAD to resume irradiation. Testing time limits were in accordance with MIL-STD-883G, TM1019.7.

B. SET Testing

SET testing was done under several different biasing conditions and at two different heavy ion facilities. The first round of testing was conducted at Lawrence Berkeley National Laboratory (LBNL) using the 10 MeV/nucleon beam with a minimum ion penetration of 90 µm [10]. The second round of testing was conducted at the at the Radiation Effects Facility at the Texas A & M University Cyclotron Institute (TAMU), using the 15 A MeV beam with a minimum ion penetration of 106 µm [11]. At LBNL, heavy ion exposure is done inside a vacuum chamber. All testing was performed with the beam at a 0° incident angle.

Test boards were designed to accommodate two devices under test (DUT 1 and DUT 2 in Fig. 3) and several different operating conditions. For a clean input, each DUT was supplied by an LM4050WG5.0RLQV 5 V reference. The 5 V output of the LM4050WG5.0RLQV was connected to the input of the DUT through a resistor to set the operating current. The 5V references were powered by an external 7.5 V supply through a 100 Ω resistor and using an RC network to reduce the input noise.

The output of DUT could be connected to different filters consisting of a filter resistor (R_F) and capacitor (C_F) by switching jumpers on the board (see Fig. 4). All capacitors are tantalum unless otherwise noted. The output load (R_L) was controlled by an external decade resistor box. The output was monitored by connecting it directly to a Tektronix DPO 7354 oscilloscope. The scope termination was 1 MΩ, so that if R_L was open, the load current would be 2.5 µA and most of the operating current would be dissipated through the DUT. At LBNL, the scope capture window was set to 8 µs with the trigger set at 0.8 µs. The maximum length of a transient recorded was 7.2 µs and if a transient was longer than that, the total length of the transient is unknown. 500 data points were collected at each scope capture, for a time resolution of 16 ns. The DUT output was relatively noisy due to feeding the signals through a vacuum chamber wall. The scope trigger limits were set at 2.35 to 2.75 V. At TAMU, the scope capture window was increased to 20 µs, with the trigger set at 2 µs for a maximum transient capture of 18 µs. 1000 data points were collected at each scope capture, keeping the resolution at 16 ns. A cleaner output was achieved at TAMU and the scope trigger limits were tightened to 2.44 to 2.60 V. To be consistent, data analysis on the TAMU data was done with limits widen to 2.35 to 2.75 V.

For testing at LBNL, the board set up was as depicted in Fig. 3. The operating current was set at 12.0 mA for both DUTs. R_F was shorted and R_L was open for all testing and the C_F value and ion linear energy transfer (LET) were the only variables. At TAMU, the operating current for DUT 1 was set at 14.3 mA and for DUT 2 at 0.89 mA. All testing was done with the Au ion for an LET of 87.1 MeV-cm^2/mg.

Each DUT was decapped to expose it to the ion beam. For the flatpack package, the lid seal is on the same plane as the bottom of the die, making decapping a challenge. It took several attempts to remove the lid without damaging the leadframe or bond wires. For DUT 1 tested at LBNL, the leadframe was damaged during decapping (Fig. 4). The "no connect" leads (Fig. 2) were broken off. The two active leads were epoxied to hold them in place. Due to the limited number of samples available at test time, this damaged part was used in the testing.

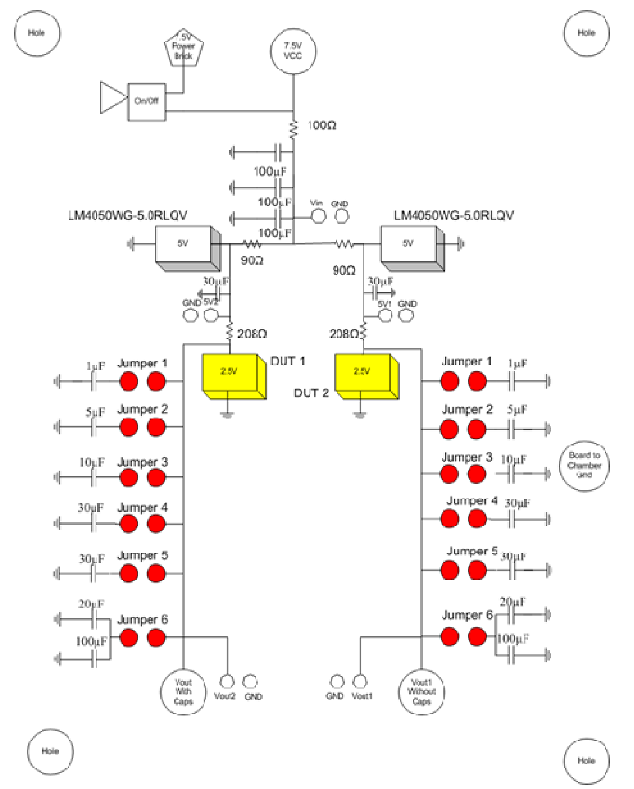

Fig. 3. SET test board. This configuration was used for the testing at LBNL. At TAMU, the board was modified so that DUT 1 operating current was 14.3 mA and DUT 2 was 0.89 mA. The capacitor values were changed, and an optional resistor was added between the DUT and the capacitors.

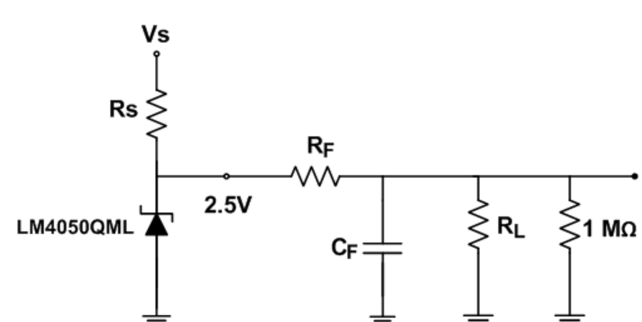

Fig. 4. Schematic of the filter and load options.

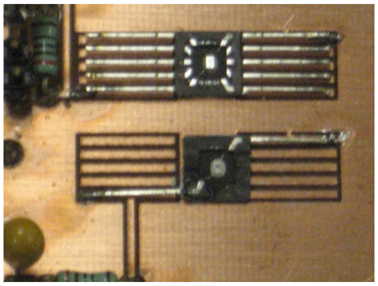

Fig. 4. DUT 1 (bottom part) was damaged during decapping but was used for the testing due to the lack of available units at the time of the testing.

III. ELDRS Characterization Results

The parametric drift between 0 rad and 100 krad(Si) was analyzed for each of the test splits. The LM4050WG2.5RLQV is a simple shunt reference and there are only 2 parametric tests: minimum operating current and reference voltage at various current loads (Table I). The minimum operation current, which has a specification limit of 60 µA did not show any significant drift through irradiation. For TID qualification, the reference voltage is expressed in terms of percentage drift from the 0 rad reading. Measureable drift was detected on this parameter through irradiation (Table I and Fig. 5). As the load current increased there was a slight amount of increase in the parametric drift, with the 15 mA load current being the worst case. The worst case irradiation condition resulting in the most parametric drift was at LDR with the units biased during irradiation. The condition with the least amount of drift was HDR biased.

Per the ELDRS characterization method in MIL-STD-883G, TM1019.7, section 3.13.1.1, the median parametric drift for each test condition was compared (Table I). If any parameters show significant drift and the ratio of the median LDR drift to the median HDR drift is greater than 1.5, the "part is considered to be ELDRS susceptible". With the units biased during irradiation, the reference voltage LDR/HDR drift ratio was 1.8, indicating that the LM4050WG2.5RLQV has ELDRS under the definition in MIL-STD-883.

To qualify a part defined as having ELDRS for low dose rate environments, MIL-STD-883 TM1019 requires that the part is tested at a dose rate of 10 mrad(Si)/s and an overtest factor of 1.5X is used. For the LM4050WG2.5RLQV to be qualified to 100 krad(Si), it must pass qualification testing to 150 krad(Si) at a dose rate of 10 mrad(Si)/s with all parameters inside the post irradiation test limits. The post irradiation drift limit for reference voltage is 1.5%. Fig. 5 shows a plot of the median parametric drift, along with the post irradiation limit for the reference voltage with a 15 mA load. The maximum, average, minimum and the standard deviations of the drift are shown in Table II.

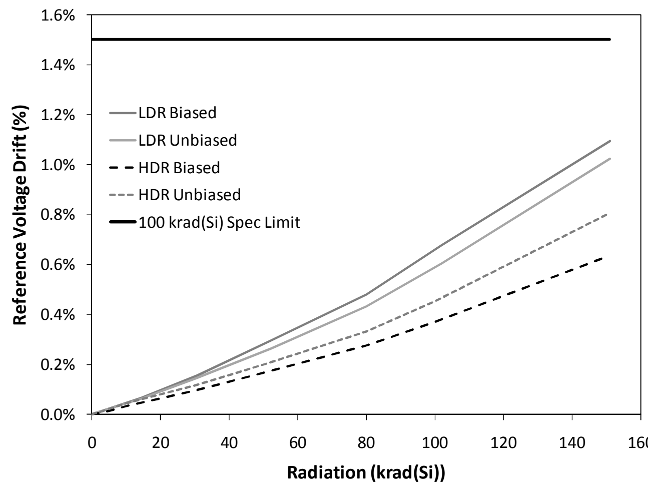

Fig. 5. Reference voltage parametric drift with the load current at 15 mA, which was the worst case showing the most amount of parametric drift.

TABLE II
Reference Voltage Drift at LDR with Load Current at 15 mA. Units Are % Drift from 0 Rad Reading

TID Level krad(Si)	30.6	52.3	102	151.7
Biased				
Maximum	0.167	0.316	0.712	1.138
Average	0.149	0.288	0.656	1.060
Minimum	0.129	0.252	0.577	0.945
Standard Deviation	0.00018	0.00030	0.00061	0.00087
Unbiased				
Maximum	0.150	0.286	0.654	1.082
Average	0.144	0.270	0.615	1.022
Minimum	0.137	0.257	0.589	0.975
Standard Deviation	0.00006	0.00012	0.00025	0.00041

TABLE I
ELDRS Characterization Table Listing the Median Parametric Drift

Parameter	Conditions	Units	Median Drift LDR Bias	Median Drift LDR Unbias	Median Drift HDR Bias	Median Drift HDR Unbias	LDR/HDR Drift Ratio Bias	LDR/HDR Drift Ratio Unbias
Minium Operating Current		µA	-0.802	-0.989	-0.709	-0.758	1.13	1.31
Reference Voltage	I_L=60 µA	% drift	0.671	0.591	0.366	0.436	1.83	1.36
Reference Voltage	I_L=100 µA	% drift	0.672	0.592	0.367	0.437	1.83	1.35
Reference Voltage	I_L=1 mA	% drift	0.672	0.592	0.368	0.441	1.83	1.34
Reference Voltage	I_L=10 mA	% drift	0.675	0.601	0.373	0.448	1.81	1.34
Reference Voltage	I_L=15 mA	% drift	0.678	0.605	0.375	0.453	1.81	1.33

IV. SET Test Results

Both positive-going and negative-going SETs were detected. For larger amplitude transients, the recovery could take several microseconds and overshoot the nominal output up to two times before settling (Figs. 6 and 7). No oscillation or ringing was seen.

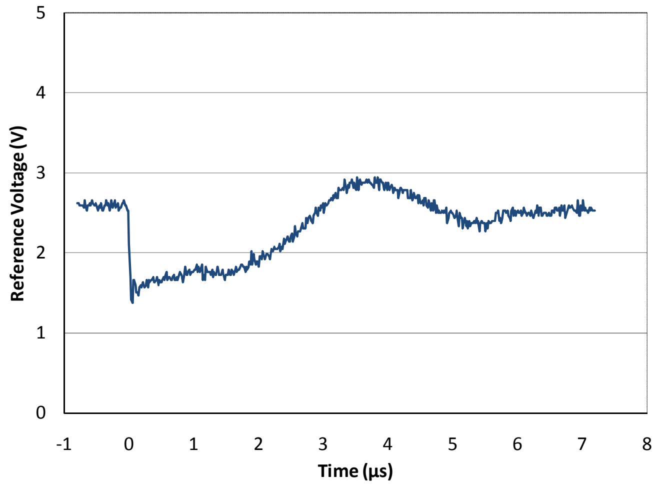

Fig. 6. Example of a negative-going SET.

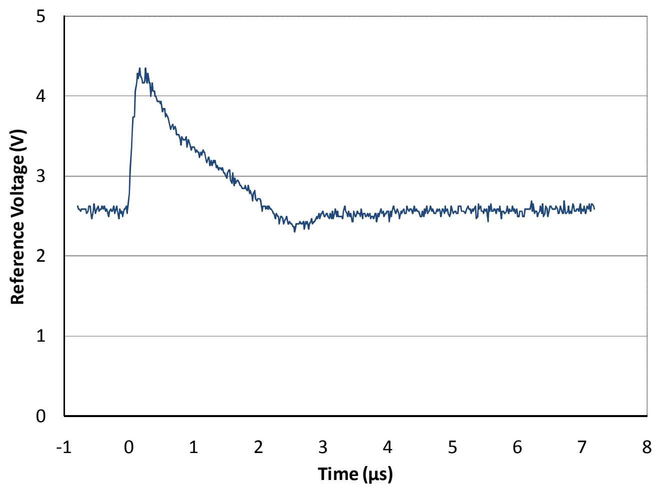

Fig. 7. Example of a positive-going SET.

The maximum SET amplitude and duration and the SET cross section were dependent upon operating conditions. The TAMU data are summarized in Table III. The cross section is a relative indication of the probability of an SET. It is calculated by dividing the number of SETs by the fluence from the ion runs at a specific LET. With no load on the output, a higher operating current resulted in as slight shift upward on the SET amplitude (Fig. 8). The maximum duration of the negative transients was 9.8 µs at the high operating current but was greater than 18 µs at the lower operating current (the actual maximum duration is unknown as the scope could only capture 18 µs).

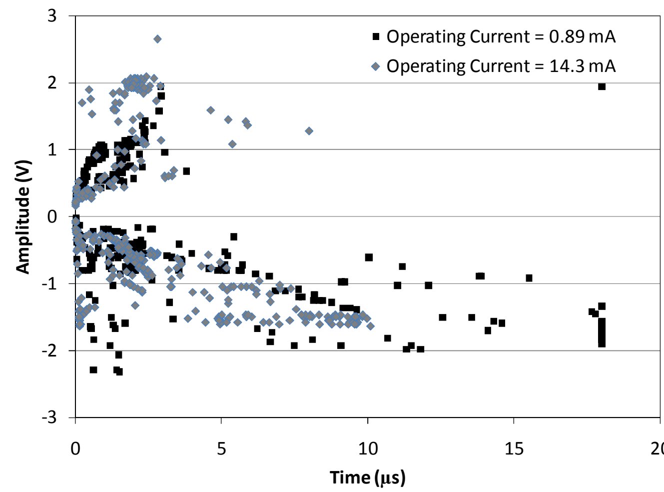

Fig. 8. SET amplitude vs. pulse width with a 2.5 µA load current. Data are from TAMU with an LET of 87.1 MeV-cm^2/mg.

Increasing the load current had a significant impact on reducing the SET amplitude. With the operating current at 14.3 mA and the load current at 10 mA, the maximum SET amplitude was 0.5V, while it was 2.6 V when the load was just the 2.5 µA from the scope termination (Fig. 9 and Table III).

The output filters may attenuate the SETs, depending upon the size of the filter capacitor. The output filters using a capacitor value of 220 pF or lower had little impact at high operating currents (Table III), but had a minor impact at the lower operating current (Table III and Fig. 10). These data are

TABLE III
SET Results From TAMU, LET=87.1 MeV-cm^2/mg

Operating Conditions				SET Results			
Operating Current (mA)	Load Current (mA)	Filter Resistor (Ω)	Filter Capacitor (pF)	Max Amplitude (V)	Min Amplitude (V)	Max Duration (µs)	Cross Section (cm^2)
14.3	0	None	None	2.62	-1.69	9.8	1.27E-03
14.3	10	None	None	0.49	-1.80	14.3	8.35E-04
14.3	0	50	80	2.54	-1.52	9.5	1.33E-03
14.3	0	50	220	2.65	-1.50	9.8	1.48E-03
14.3	0	100	220	2.62	-1.49	9.9	1.49E-03
14.3	10	100	220	0.52	-1.55	13.6	9.12E-04
0.89	0	None	None	1.94	-2.31	18+	1.29E-03
0.89	0	50	220	1.29	-1.68	18+	8.80E-04
0.89	0	100	200	1.36	-1.77	18+	9.74E-04

from TAMU testing, using the gold ion beam with an LET of 87.1 MeV-cm^2/mg. A 30 µF capacitor had a significant impact attenuating the SETs and no SETs were detected when a 60 uF capacitor was used (Table IV). There was one anomaly in that DUT 1, which was damaged during decapping, had some SETs with 120 µF output capacitance using a 20 µF tantalum capacitor and a 100 µF aluminum capacitor, while it did not have any SETs with a 60 µF tantalum capacitor. DUT 2 did not have any SETs with either 60 or 120 µF output capacitance. These data are from the LBNL testing using the xenon ion beam with an LET of 58 MeV-cm^2/mg. No filter resistor was used, the operating current was 12.0 mA and the load current was 2.5 µA.

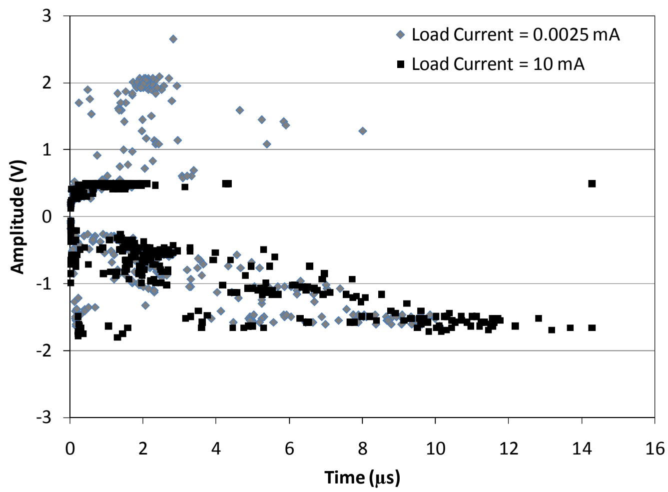

Fig. 9. SET amplitude vs. pulse width with the operating current set at 14.3 mA. Data are from TAMU with an LET of 87.1 MeV-cm^2/mg.

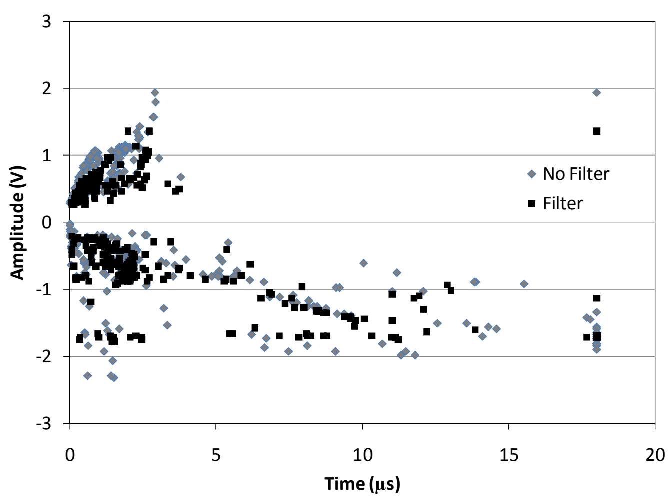

Fig. 10. SET amplitude vs. pulse width with the operating current set at 0.89 mA and a load current of 2.5 µA. Data are from TAMU with an LET of 87.1 MeV-cm^2/mg.

With no load on the output and a high operating current, the magnitude of the negative-going SETs was dependent upon LET up to 30 MeV-cm^2/mg (Fig. 11). The magnitude of the positive-going SET continued to increase with LET. The data plotted are from LBNL, with a 12.0 mA operating current, except the point at 87.1 MeV-cm^2/mg, which comes from the testing at TAMU with an operating current of 14.3 mA. Some of the increase in the amplitude may also be due to the increased operating current. The maximum duration of the SETs increases with LET up to at least 30 MeV-cm^2/mg (Fig. 12). These data are from LBNL. Since the scope window could only capture 7.2 µs, the relation between duration and LET is unknown beyond this point.

TABLE IV
TEST RESULTS FROM LBNL, LET=58.8 MEV-CM^2/MG, OPERATING CURRENT=12.0 MA, LOAD CURRENT=2.5µA

Output Capacitor	Cross Section (cm^2)	Maximum SET Amplitude Positive (V)	Negative (V)	Maximum SET Duration (µs)
No Cap	1.0E-03	1.76	-1.72	7.2+
30 µF	1.4E-05	0.33	-0.44	0.06
60 µF	None	None	None	None

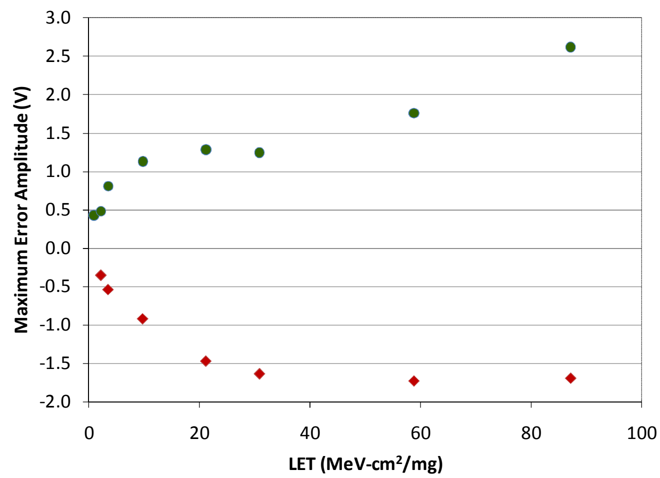

Fig. 11. SET amplitude vs. LET. Data are from LBNL, with an operating current of 12.0 mA, except for the last points at 87.1 MeV-cm^2/mg, which came from the testing at TAMU with an operating current of 14.3 mA.

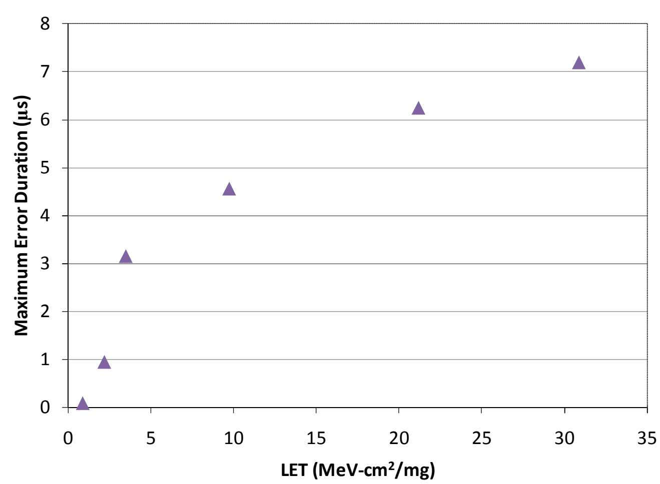

Fig. 12. SET duration vs. LET. Data are from LBNL.

A threshold LET (LETth) was not determined, as 1 event was detected at a fluence of 1 x 10^7 ions/cm^2 at the lowest LET tested (0.89 MeV-cm^2/mg). A saturated cross section of 1 x 10^{-3} cm^2 was determined during the testing at LBNL. The

SET cross section versus LET to 58.8 MeV-cm^2/mg for the LBNL data is plotted in Fig. 13. This testing was done with the operating current at 12.0 mA. Also plotted on Fig. 13 at an LET of 87.1 MeV-cm^2/mg is the cross section data from TAMU with an operating current of 14.3 mA. The increase in cross section may be due to the operating current. A Weibull fit [12] based on the LBNL data only is also plotted. The Weibull parameters are listed in Table V.

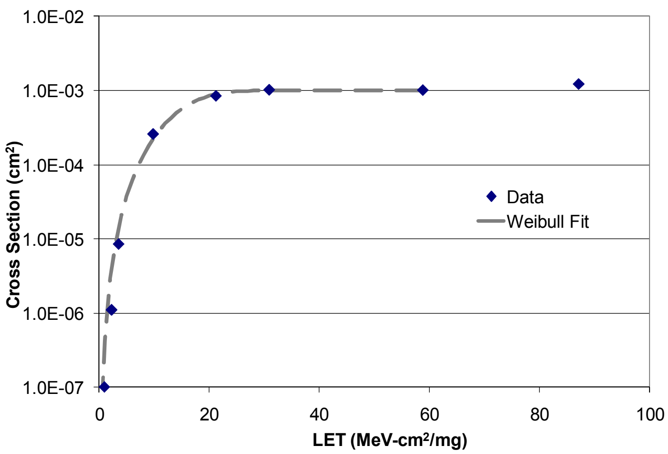

Fig. 13. SET cross section vs. LET. Data for 0.89 to 58.8 MeV-cm^2/mg are from the testing at LBNL with an operating current of 12.0 mA. The point at 87.1 MeV-cm^2/mg is from the testing at TAMU with an operating current of 14.3 mA.

TABLE V
WEIBULL FIT PARAMETERS FOR THE LBNL DATA

A	Lo	W	s
1.00E-03	0	16	2.8

V. CONCLUSION

The LM4050WG2.5RLQV is considered to have ELDRS under the strict definition in MIL-STD-883 TM1019. To qualify the product at 100 krad(Si) for low dose rate environments, the part is tested at a dose rate of 10 mrad(Si)/s to a TID of 150 krad(Si), with all parameters inside the specification limits at 150 krad(Si).

SET performance of the LM4050WG2.5RLQV is dependent upon operating conditions. Positive-going SETs can be greatly mitigated by carefully matching the operating current close to the load current. An output filter capacitor can attenuate or eliminate SETs.

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