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Total Ionizing Dose (TID) Final Report for Cypress Semiconductor CYRS16B256 Serial NOR Flash 256-Mbit

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Prepared By: ______________________ 20 Nov 2020
JD Instruments Date

1.0 Test Overview

These parts are 256Mb NOR Flash Floating Gate devices packaged in 36 pin, ceramic flat-packs.

Total Ionizing Dose (TID) radiation testing was performed on Oct 20 and 29, 2020 at the AFRL ^{60}CO facility located on Kirtland AFB, NM.

On Oct 20th we performed exploratory testing with different dose rates. Test results with 10 rad/s dose rate did not result in a significant improvement of the TID performance which would warrant qualification testing outside the required 50 -300 rad/s window as outlined in MIL-STD-883 TM1019. All irradiations in this report were performed at a dose rate of 54.1 rad(Si)/sec.

Vt distributions of memory bits erased/programmed to “1” or “0” states were measured at various dose levels along with functionality and power supply currents. Vt distributions are known to degrade with TID radiation. These Rad Tolerant parts use slightly different ERASE/WRITE parameters than their commercial equivalents to give wider separation between the erased/programmed populations, so it was important to understand the change in distributions with TID.

These parts behaved as expected with radiation. When under bias they were fully functional up to a dose of 20K rad(Si) and could be read correctly at 30K rad(Si). When irradiated in an unbiased condition they remained fully functional to 50K rad(Si) and could be read correctly at 125K rad(Si).

Standby and Deep Power Down power supply currents passed the specified datasheet limits up to 30K rad(Si) biased and 125K rad(Si) unbiased.

In addition to the above biased and un-biased operating modes we also evaluated a 10% duty cycle mode (biased on 10% of the exposure time – on 10s / off 90s) and the parts passed 125K rad(Si) with full read functionality.

2.0 Test Procedure

All irradiations were performed with these parts in static mode since this is how they would normally be operated in space applications. Further, some parts were irradiated in an unbiased state since this might also be the way the parts would be biased for most of their life during some missions (e.g. boot ROM powered up occasionally).

Parts were programmed with a checkerboard pattern prior to being irradiated and pre-radiation measurements were recorded. They were then irradiated to various levels and measurements were recorded.

Figure 1 shows the block diagram for these parts. The parts are packaged in 32 pin ceramic flat-packs which are contained in plastic frames for ease in handling. Pictures of the front and back side of these parts in their carriers are shown in figure 2.

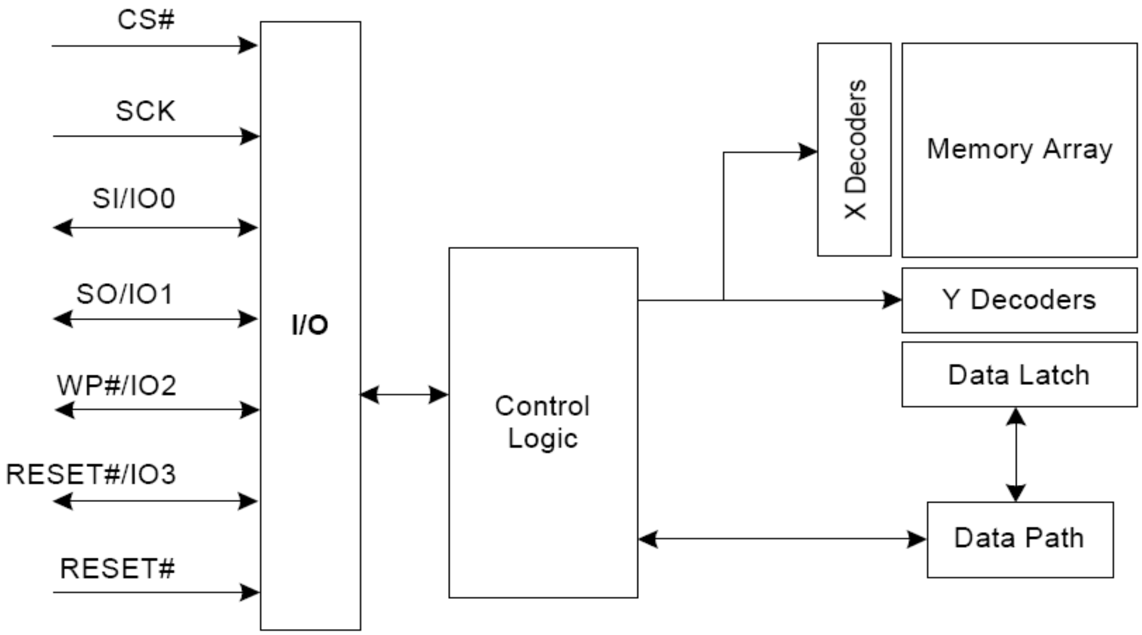

Figure 1. Cypress CYRS16B256, 256Mb SNOR

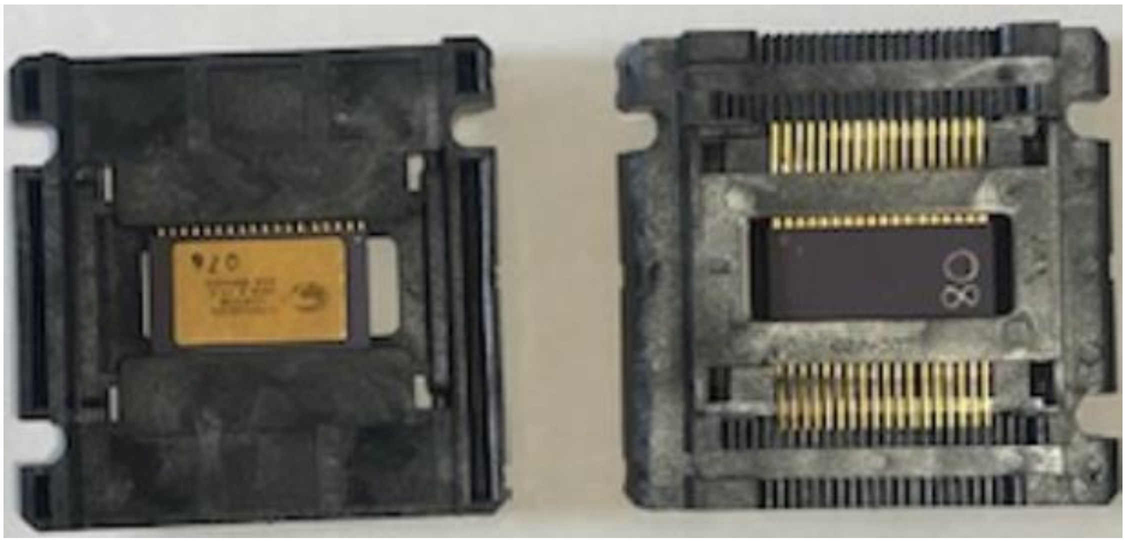

Figure 2. 32 Pin Ceramic Flat-Packs in Plastic Carriers

During irradiations parts were installed into bias boards shown in figure 3.

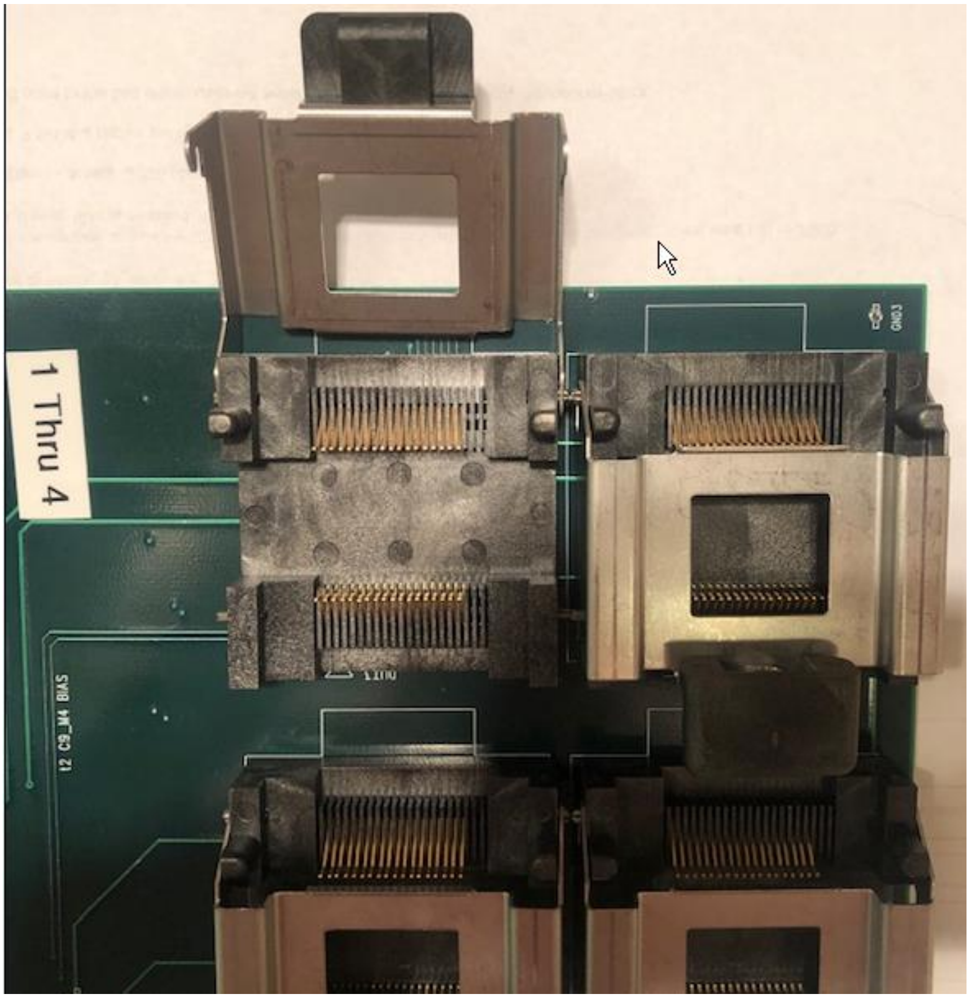

Figure 3. Four position Bias Board

2.1 Parts Identification

Parts were provided with serial numbers printed on their metal lid. The serial numbers were also hand written on the under side of the ceramic package. Serial numbers were entered in the test run log for traceability and reporting.

2.2 Parts Handling and Storage

All parts are considered sensitive to electrostatic discharge (ESD) and were handled accordingly.

2.3 Test Facility

The ^{60}CO source at AFRL is a room irradiator. All bias boards were installed in a lead-aluminum box during irradiation to minimize dose enhancement effects caused by low-energy, scattered radiation. This box has a minimum of 1.5 mm Pb, surrounding an inner shield of at least 0.7 mm Al as required by Mil Std 883, Method 1019.

Figure 4 shows the lead-aluminum box in front of the source shroud at AFRL.

Figure 4. Room Irradiation Facility at AFRL

Dosimetry was performed using a calibrated/certified ion chamber manufactured by Radcal Corporation, Monrovia, CA. Irradiations were performed on 1 DUT at a time so requirements to maintain dose variations within a range of +/-5% across the DUT was definitely achieved.

All irradiations using the DC test board were done with a dose rate of 54.1 rad(Si)/sec.

2.4 Specific Test Requirements

2.4.1 Test Sequence

A total of 12 DUTs were tested during this campaign. Eight of the parts were irradiated in a biased condition and 4 in an unbiased condition. Further, some parts were packed on dry ice and shipped back to Cypress Semiconductor for more complete characterization immediately after being irradiated to some level and tested on-site. Figure 5 shows the complete sequence of how these parts were irradiated/tested.

Biased Parts		Unbiased Parts	
DUTs 9, 17, 21, 35	DUTs 76, 80, 84, 99	DUTs 39, 50	DUTs 58, 73
10K Rad		Irradiate at Same Time	
Char (10K)			
10K Rad		Irradiate at Same Time	
Char (20K)		Char (20K)	
Pack			
		30K Rad	
		(50K)	
		Pack	
			75K Rad
			Char (125K)
			25K Rad
			Char (150K)
	10K Rad		
	Char (10K)		
	10K Rad		
	Char (20K)		
	10K Rad		
	Char (30K)		

Figure 5. Radiation/Test Sequence

This figure shows that DUTs 9, 17, 21 and 35 were irradiated twice in steps of 10K rad(Si) to a TID level of 20K rad(Si), being characterized after each irradiation. They were then packed on dry ice for shipment and returned to Micross Components – STS for post radiation testing.

While these parts were being irradiated, 4 other DUTs (39, 50, 58 and 73) were being irradiated in an unbiased condition. All 4 of these parts were characterized at the 20K rad(Si) level and then further irradiated to 50K rad(Si). At that point all 4 parts were characterized and DUTs 39 and 50 were packed on dry ice and also returned to Micross Components – STS for post radiation.

The incoming temperature measurement of the samples shipped on dry ice Oct 29 from Albuquerque, NM to Milpitas, CA confirmed a DUT temperature of -69C which is conformal with the dry ice shipping procedure in MIL-STD-883 TM 1019.

DUTs 58 and 73 were then further irradiated to TID levels of 125K rad(Si) and 150K rad(Si), being characterized at each level.

DUTs 76, 80, 84 and 99 were irradiated under bias in 3 increments of 10K rad(Si) and characterized after each radiation step.

Thus, 8 DUTs were irradiated in a biased condition and step-stress characterized to a total dose level of 20K rad(Si). Full characterization testing was performed on all 8 of these DUTs to this level which consisted of functional testing of READ, ERASE and WRITE operations and Vt profiling. Four of these devices were then further irradiated to 30K rad(Si) where they were only tested for READ operations and profiling of Vt distributions.

Similarly, 4 DUTs were irradiated in an unbiased condition and step stress tested for full functionality and Vt profiled to a total dose level of 50K rad(Si). Two of the DUTs were then further irradiated to 125K rad(Si) and 150K rad(Si) at which points they were only tested for READ functionality and were Vt profiled.

2.4.4 Data Collection

These parts have 5 modes of operation: Deep Power Down (DPD), Standby (SBY), READ, ERASE and]WRITE. At every radiation level currents were measured for parts in Deep Power Down, Standby and while performing READ operations. At all but the highest dose levels currents were also measured during ERASE and WRITE operations.

At every radiation level Vt profiling measurements were made on every DUT.

DUTs that were shipped back to Cypress Semiconductor were measured for input and output leakage currents (Ili and Ilo) and also for power supply currents during high speed operation. Power supply currents were measured with the parts operating in SPI mode (onsite and offsite) and also in QPI mode (offsite).

3.0 Test Results

3.1 Idd Measurements

Figures 6 to 11 show Idd measurements for all DUTs while in their 5 operating modes.

3.1.1 Idd During Normal Standby

Figure 6 shows Idd measurements for all DUTs while in normal standby (SPI mode). Note that measurements were made at all radiation points specified in figure 5 above.

	Idd StandBy											
	SN009	SN017	SN021	SN035	SN076	SN080	SN084	SN099	SN039	SN050	SN058	SN073
Pre-Rad	1.43E-05	1.42E-05	1.39E-05	1.39E-05	1.40E-05	1.41E-05	1.40E-05	1.41E-05	1.43E-05	1.42E-05	1.42E-05	1.42E-05
10K rad(Si)	1.44E-05	1.42E-05	1.38E-05	1.39E-05	1.44E-05	1.43E-05	1.41E-05	1.42E-05	--------	--------	--------	--------
20K rad(Si)	1.51E-05	1.46E-05	1.43E-05	1.41E-05	1.47E-05	1.45E-05	1.44E-05	1.44E-05	1.42E-05	1.42E-05	1.41E-05	1.41E-05
30K rad(Si)	--------	--------	--------	--------	2.53E-05	1.77E-05	2.84E-05	1.91E-05	--------	--------	--------	--------
50K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	2.76E-05	2.29E-05	2.38E-05	1.91E-05
125K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	1.37E-04	9.78E-05
150K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	1.91E-04	1.37E-04

Figure 6. Idd While In Standby - I_{sb} (SPI mode)

In this figure DUTs that were irradiated while unbiased are shown with a light blue background. Measurements that were significantly different from pre-rad levels are shown in red.

This figure shows a slight but noticeable increase in I_{sb} for biased parts irradiated to 30K rad(Si) and a significant increase for unbiased parts irradiated to 125K and 150K rad(Si).

These parts were tested in SPI mode. The limit for I_{sb} in this condition is 200uA. SN058 and SN073 both pass the datasheet limit at 150K rad(Si).

3.1.2 Idd During Deep Power Down

Figure 7 shows Idd measurements for all DUTs while in Deep Power Down.

	Idd Deep Power Down											
	SN009	SN017	SN021	SN035	SN076	SN080	SN084	SN099	SN039	SN050	SN058	SN073
Pre-Rad	2.10E-06	2.10E-06	1.99E-06	2.00E-06	1.99E-06	1.98E-06	1.98E-06	2.06E-06	1.99E-06	2.02E-06	2.00E-06	2.02E-06
10K rad(Si)	2.32E-06	2.14E-06	2.14E-06	2.11E-06	2.08E-06	2.08E-06	2.09E-06	2.18E-06	--------	--------	--------	--------
20K rad(Si)	3.18E-06	2.69E-06	2.75E-06	2.41E-06	2.50E-06	2.42E-06	2.49E-06	2.52E-06	2.51E-06	2.46E-06	2.57E-06	2.32E-06
30K rad(Si)	--------	--------	--------	--------	1.32E-05	5.78E-06	1.67E-05	7.44E-06	--------	--------	--------	--------
50K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	1.59E-05	1.14E-05	1.24E-05	7.54E-06
125K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	1.25E-04	8.70E-05
150K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	1.79E-04	1.26E-04

Figure 7. Idd While In Deep Power Down - I_{dpd}

Idds during Deep Power Down are the lowest condition for these parts and, consequently, show the greatest proportional increase with dose. The limit for this parameter is 200uA. All biased parts passed this limit even when irradiated to 30K rad(Si) biased and 150K rad(Si) unbiased.

Unsurprisingly, I_{dpd} in SN058 and SN073 increased to almost the same levels as they had for I_{sb} at radiation levels of 125K rad(Si) and 150K rad(Si). This probably indicates turn-on of edge leakage currents within the DUTs as dominant leakage source.

Figure 8 shows a comparison of standby and deep power down currents for all DUTs. The legend shows each DUT listed twice with entries for deep power down having a “d” suffix added to the name.

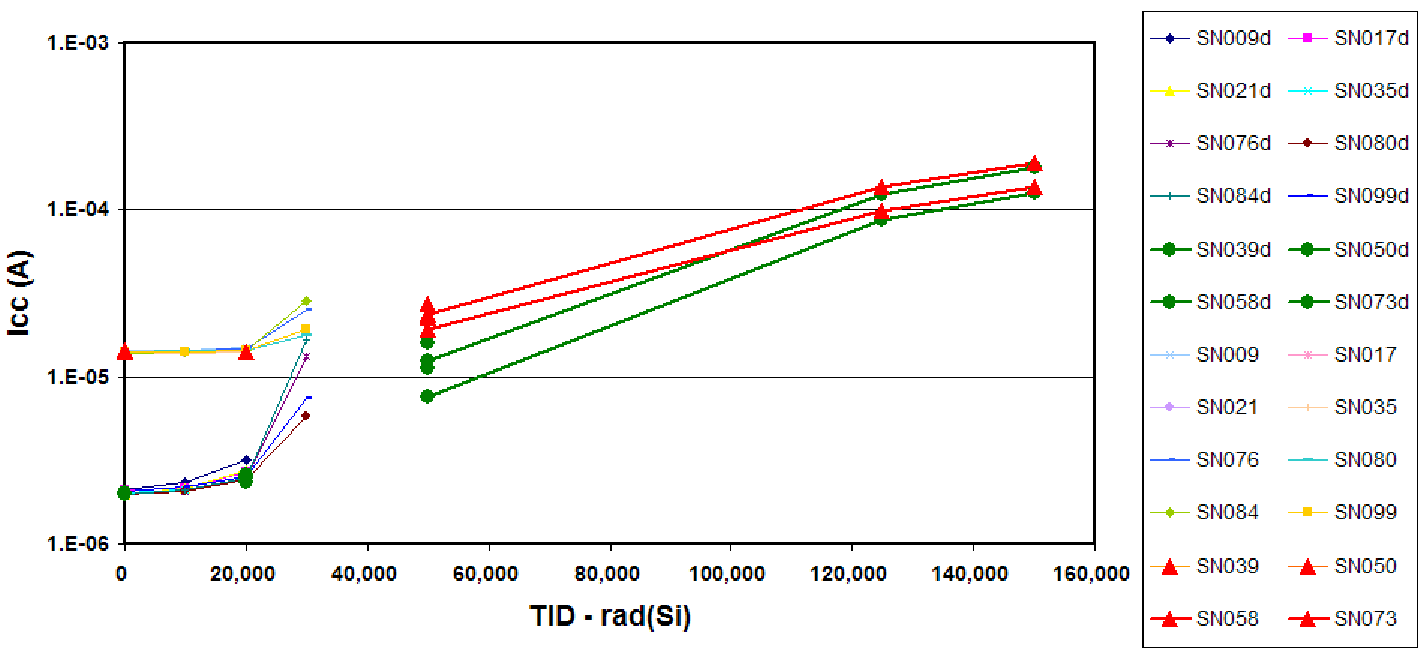

Figure 8. Comparison of I_{dpd} and I_{sb}, All Parts

At the left edge of figure8 there are 2 groups of measurements showing that, pre-radiation, all parts had very similar values of I_{dpd} the and I_{sb}. All parts were measured at 20K rad(Si) where there was a slight rise in I_{dpd}.

Biased parts only were measured at 30K rad(Si). The plot shows that biased parts were exhibiting a definite increase in both I_{dpd} and I_{sb} at this point, but were still below specified limits.

Four unbiased parts were measured at 50K rad(Si) with 2 of the parts being continued to 125K and 150K rad(Si). For clarity I_{dpd} measurements on all unbiased parts were plotted as bold green lines with round symbols. I_{sb} measurements were plotted using bold red lines and triangle symbols. In the plot is is clear that there was a marked increase in both currents at 50K rad(Si) with I_{dpd} values approaching I_{sb} values. At 50K rad(Si) all currents were still below specified levels. By 125K rad(Si) the values of I_{dpd} the and I_{sb} were practically the same in both parts and all currents pass specified limits.

3.1.3 I_{sb} 10% Power-On

One application for these parts would be as boot ROMs where the parts would normally be unbiased and bias would only be applied during boot operations. Increases in I_{sb} with radiation while parts were unbiased or always biased were shown in figure 8. The question naturally arises how power-on duty cycle affects this increase.

To answer this question a commercial version of this part was tested where bias was applied 10% of the time. This was an S25FL256S which uses the same die as the CYRS16B256 but has plastic packaging and uses slightly different ERASE/WRITE parameters. For this test power was applied for 10 seconds and then turned off for 90 seconds during each radiation exposure. Figure 9 plots I_{sb} measurements for this DUT using green circles. Data from figure 8 for CYRS16B256 DUTs SN058 and SN073 is repeated here using red symbols for comparison. Only I_{sb} data was recorded since the power supply was constantly being cycled off-on with little time to put the DUT into a deep power down mode.

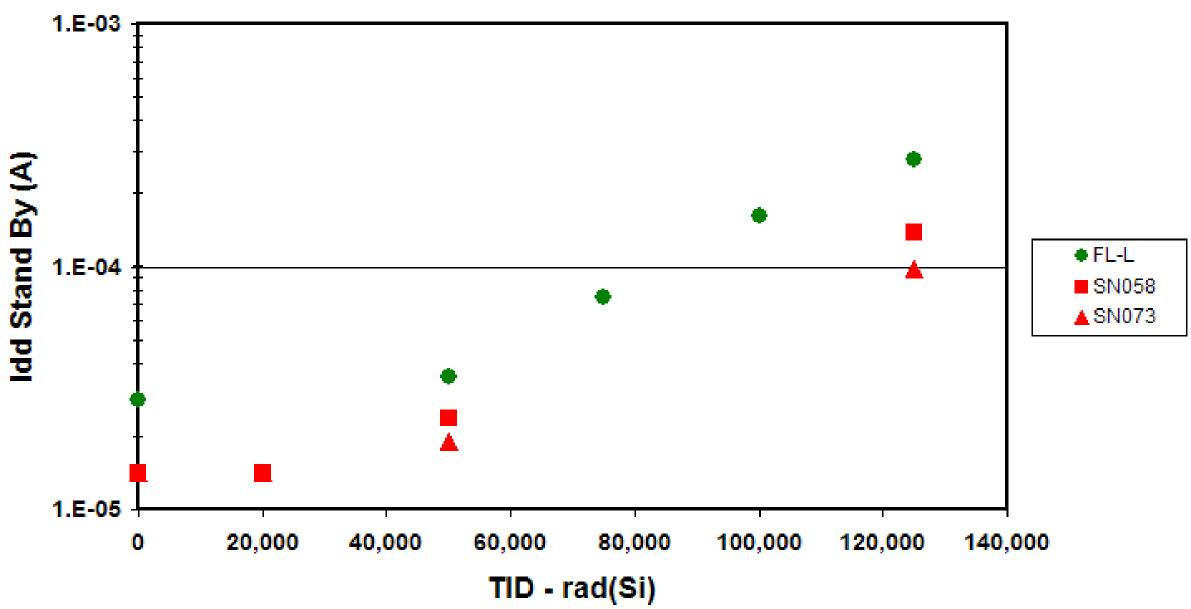

Figure 9. Comparison of I_{sb} UnBiased and 10% Power-On

In this figure the commercial part began with a slightly higher I_{sb} than the rad-tolerant parts and showed an increase with radiation that was very similar to the rad-tolerant parts.

The conclusion from this test is that i_{sb} increases with radiation faster when power is applied 10% of the time, but not drastically so.

3.1.4 Idd During READ

Figure 10 shows Idd measurements for all DUTs while performing READ operations
.

	Idd READ											
	SN009	SN017	SN021	SN035	SN076	SN080	SN084	SN099	SN039	SN050	SN058	SN073
Pre-Rad	7.70E-03	7.70E-03	7.60E-03	7.70E-03	7.50E-03	7.60E-03	7.56E-03	7.54E-03	7.70E-03	7.68E-03	7.63E-03	7.62E-03
10K rad(Si)	7.73E-03	7.63E-03	7.39E-03	7.69E-03	7.73E-03	7.62E-03	7.53E-03	7.53E-03	-------	-------	-------	-------
20K rad(Si)	7.99E-03	7.76E-03	7.49E-03	7.71E-03	7.87E-03	7.63E-03	7.65E-03	7.53E-03	7.22E-03	7.36E-03	7.26E-03	7.28E-03
30K rad(Si)	-------	-------	-------	-------	1.19E-02	9.56E-03	1.19E-02	9.63E-03	-------	-------	-------	-------
50K rad(Si)	-------	-------	-------	-------	-------	-------	-------	-------	7.22E-03	7.29E-03	7.22E-03	7.19E-03
125K rad(Si)	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	7.46E-03	7.27E-03
150K rad(Si)	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	7.55E-03	7.32E-03

Figure 10. Idd While READing

READ operations require much higher currents than either standby mode. Figure 8 shows that the only increase in I_{cc1} (Serial SDR) was for biased DUTs after they had been irradiated to 30K rad(Si). All parts stayed well within the specified limit of 30mA.

3.1.5 Idd During ERASE

Figure 11 shows Idd measurements for all DUTs while performing ERASE operations
.

	Idd ERASE											
	SN009	SN017	SN021	SN035	SN076	SN080	SN084	SN099	SN039	SN050	SN058	SN073
Pre-Rad	2.20E-02	2.20E-02	2.18E-02	2.20E-02	2.19E-02	2.19E-02	2.20E-02	2.19E-02	2.19E-02	2.16E-02	2.20E-02	2.19E-02
10K rad(Si)	2.20E-02	2.20E-02	2.16E-02	2.20E-02	2.20E-02	2.00E-02	2.20E-02	2.20E-02	-------	-------	-------	-------
20K rad(Si)	2.30E-02	2.29E-02	2.27E-02	2.23E-02	2.30E-02	2.10E-02	2.23E-02	2.22E-02	2.20E-02	2.19E-02	2.20E-02	2.21E-02
30K rad(Si)	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
50K rad(Si)	-------	-------	-------	-------	-------	-------	-------	-------	2.23E-02	2.26E-02	2.24E-02	2.22E-02

Figure 11. Idd While ERASEing

Note that these currents were only measured up to 20K rad(Si) for biased parts and 50K rad(Si) for unbiased parts. There was no noticeable change in these currents over these ranges and all measurements were well within the specified limit of 70mA.

3.1.6 Idd During WRITE

Figure 12 shows Idd measurements for all DUTs while performing WRITE operations
.

	Idd WRITE											
	SN009	SN017	SN021	SN035	SN076	SN080	SN084	SN099	SN039	SN050	SN058	SN073
Pre-Rad	3.20E-03	3.20E-03	3.19E-03	3.12E-03	3.12E-03	3.19E-03	3.17E-03	3.16E-03	3.20E-03	3.20E-03	3.18E-03	3.20E-03
10K rad(Si)	3.20E-03	3.13E-03	3.10E-03	3.15E-03	3.20E-03	3.18E-03	3.13E-03	3.14E-03	--------	--------	--------	--------
20K rad(Si)	3.24E-03	3.21E-03	3.19E-03	3.19E-03	3.28E-03	3.19E-03	3.19E-03	3.19E-03	3.10E-03	3.13E-03	3.13E-03	3.12E-03
30K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
50K rad(Si)	--------	--------	--------	--------	--------	--------	--------	--------	3.14E-03	3.16E-03	3.12E-03	3.10E-03

Figure 12. Idd While WRITEing

Again there was no noticeable increase in these currents for any device over these ranges and all measurements were well within the specified limit of 70mA.

3.2 Vt Changes

The population distributions of Vt's for programmed and erased bits change when exposed to ionizing radiation. The following sections show changes induced in biased and unbiased parts during radiation.

3.2.1 Vt Changes in Biased Parts

Figure 13 shows Vt profiles for the 4 parts that were step-stress irradiated to a maximum of 20K rad(Si) while being biased normally. In these plots the pre-radiation distributions are plotted using black lines, the 10K rad(Si) distributions are plotted using red lines and the 20K rad(Si) distributions are plotted using blue lines. From these plots it is easy to see that the populations remained well separated after 20K rad(Si) of TID radiation.

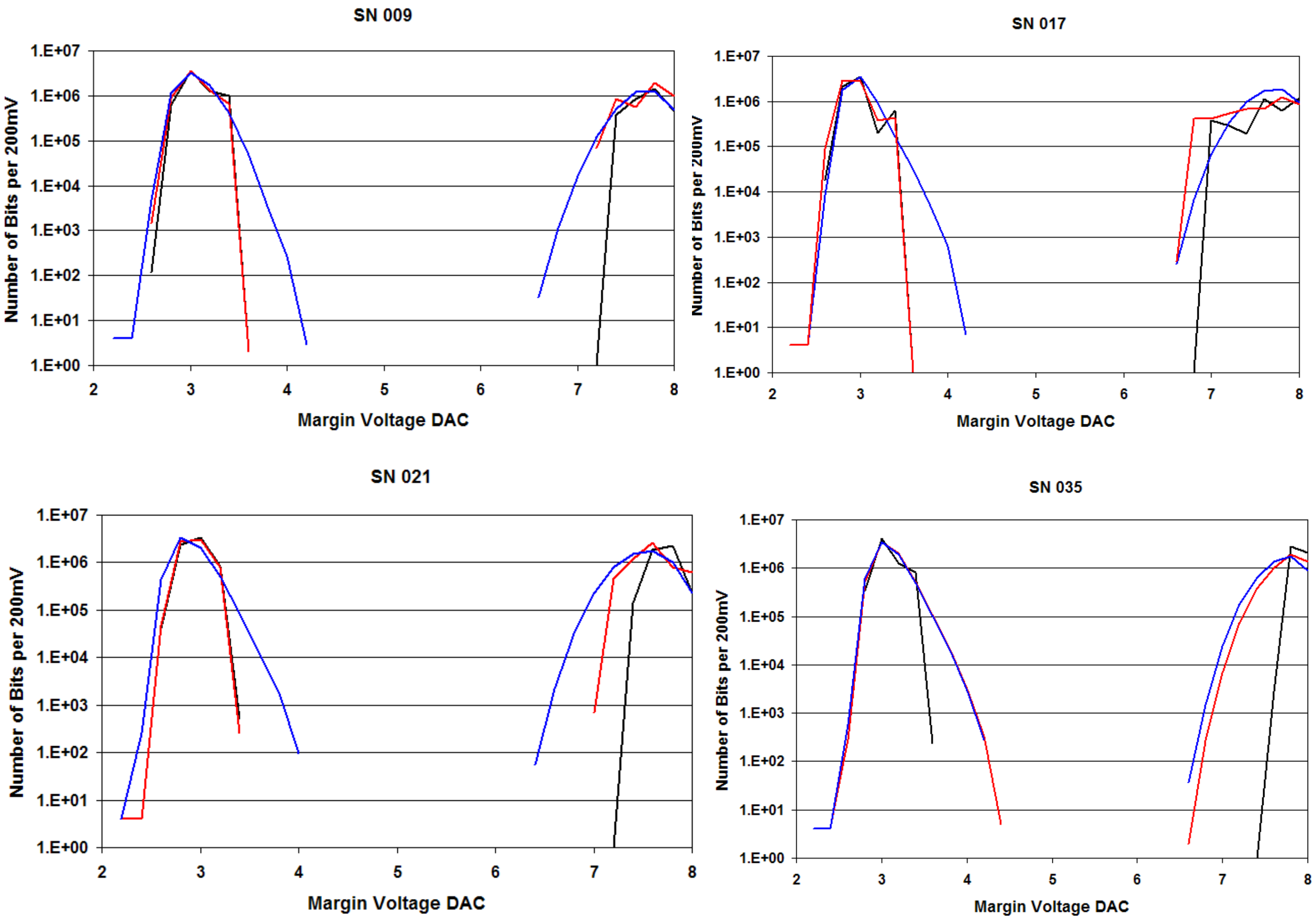

Figure 13. Vt Distributions for Biased DUTs Irradiated to 10K and 20K rad(Si)

Figure 14 shows similar plots for the 4 parts that were irradiated under bias to 10K, 20K and 30K rad(Si). These graphs show what additional changes would happen to Vt distributions in parts used only for READs above 20K rad(Si) (e.g. boot ROMs) since ERASE/WRITE operations are not guaranteed above 20K rad(Si).

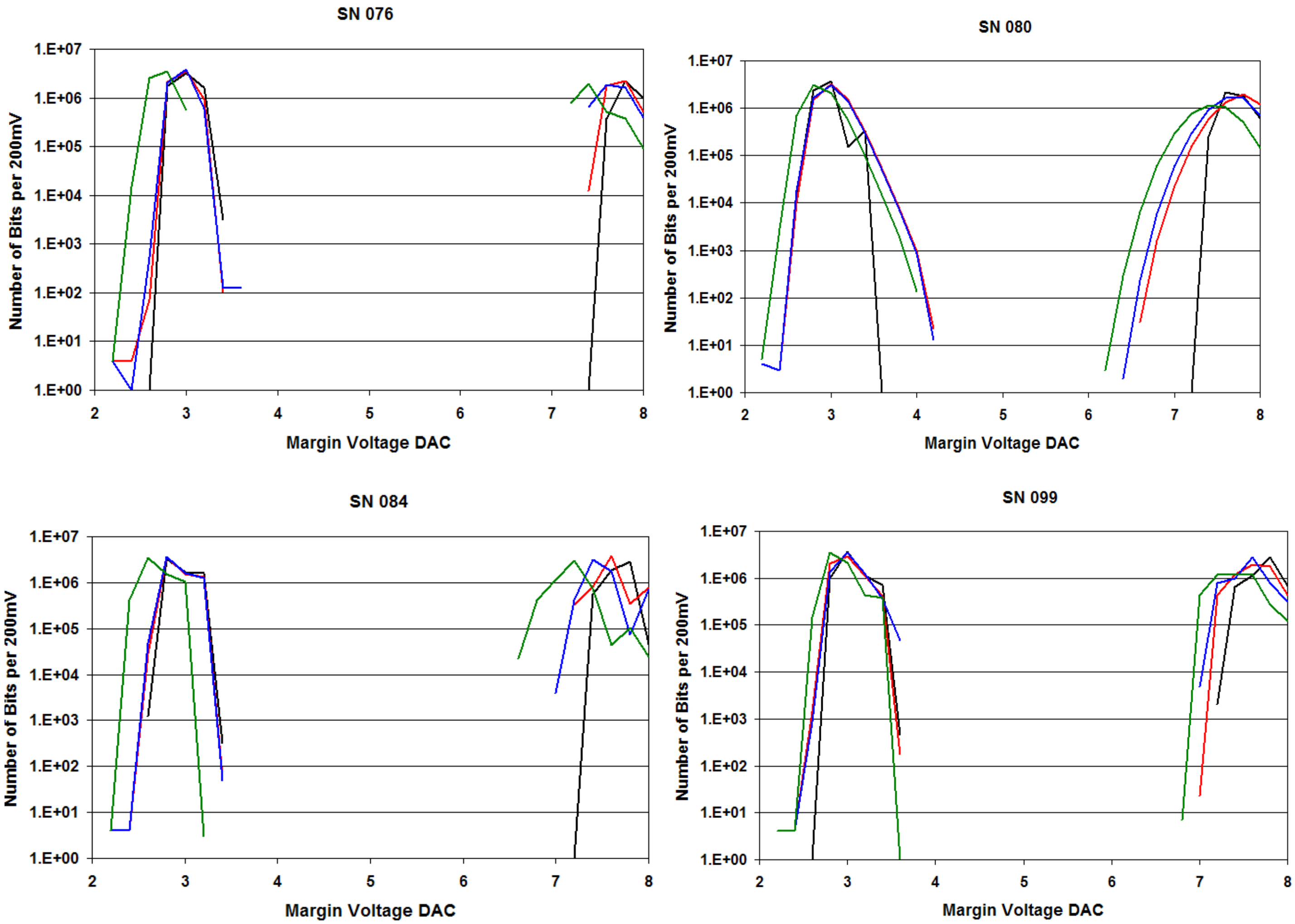

Figure 14. Vt Distributions for Biased DUTs Irradiated to 10K, 20K and 30K rad(Si)

In these plots the 30K rad(Si) data is plotted using a green line. These plots show that the Vt distributions still have plenty of separation even after the parts were irradiated to 30K rad(Si).

3.2.2 Vt Changes in UnBiased Parts

Figure 15 shows Vt profiles for the 2 unbiased parts that were step-stress irradiated to a maximum of 50K rad(Si). For these plots pre-radiation data is again plotted using black lines. Data for 20K radiations are plotted using blue lines and data for 50K radiations are plotted using red lines. A lot of separation remains between the erased and programmed populations at the end of the 50K rad(Si) irradiation.

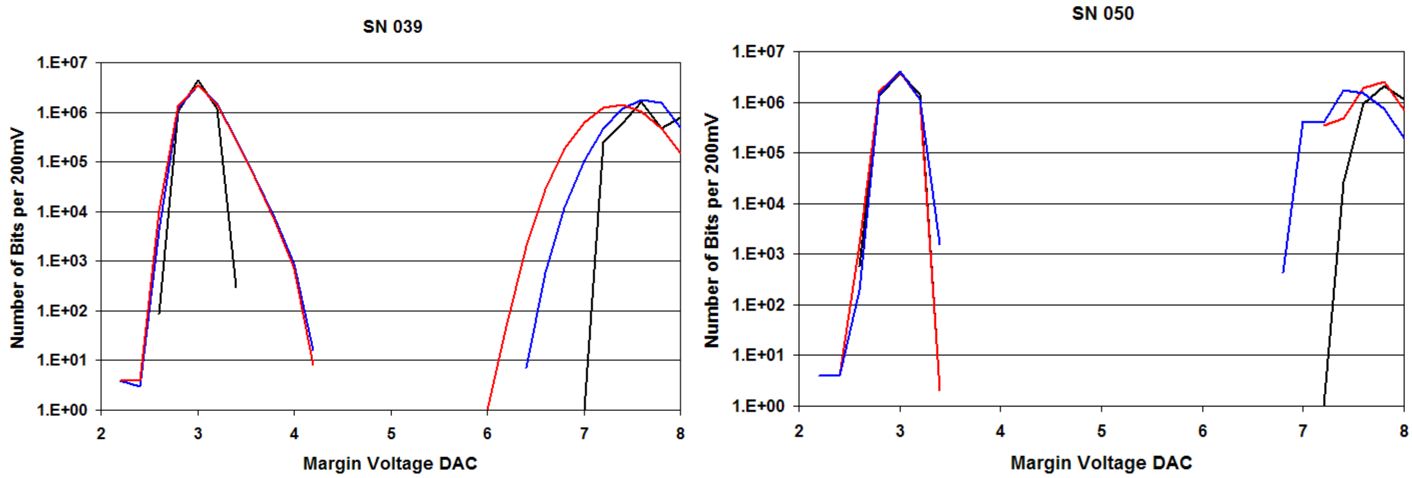

Figure 15. Vt Distributions for UnBiased DUTs Irradiated to 20K and 50K rad(Si)

Figure 16 shows Vt profiles for the 2 unbiased parts that were step-stress irradiated all the way to 150K rad(Si). In these plots a green trace has been added to show data from the 125K rad(Si) exposures and a dashed red line shows results after being irradiated to 150k rad(Si). The plot for SN 073 does not have a plot for 150K rad(Si) data as it became non-functional at that radiation level.

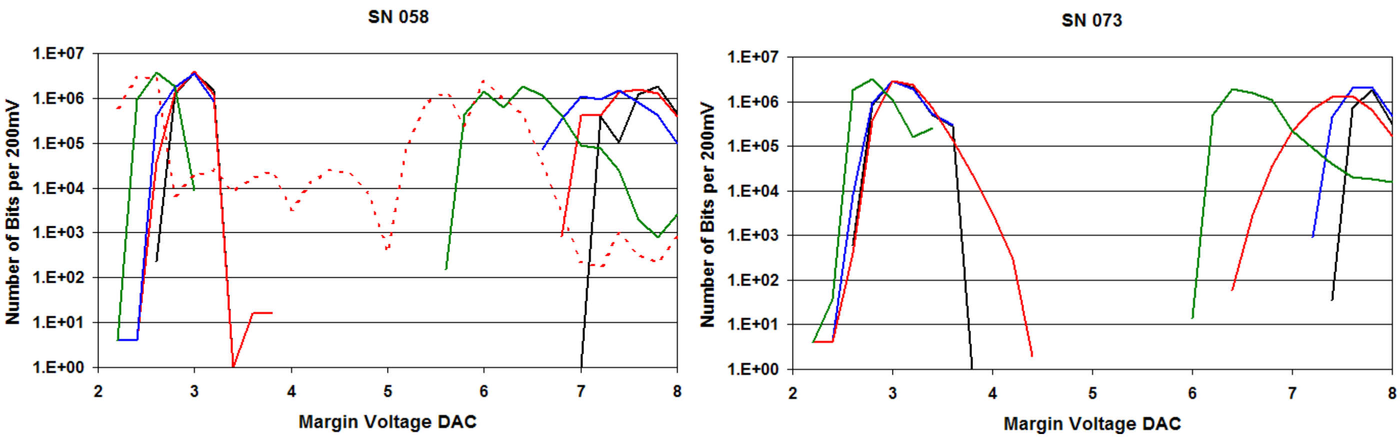

Figure 16. Vt Distributions for UnBiased DUTs Irradiated to 20K and 50K rad(Si)

The large change in shape of the distribution curve for SN058 at 150K rad(Si) is interpreted as being due to failure in some portion of the READ circuitry.

Figure 15 shows that the Vt distribution of these parts retained significant separation between erased and programmed bits even when irradiated to 125K rad(Si).

3.3 Post-Radiation Production Tests

Figure 17 shows post-radiation test results for devices that were packed in dry ice and shipped back to Micross Components - STS for production measurement on their production tester.

	Post Radiation Production Tests						
	SN009	SN017	SN021	SN035	SN039	SN050	LIMIT
Ili (Lo) (nA)	356.0	357.0	364.0	362.0	363.0	356.0	+/-4000 nA
Ili (Hi) (nA)	78.0	47.0	31.0	13.0	37.0	56.0	+/-4000 nA
Ilo (Lo) (nA)	353.0	356.0	362.0	358.0	359.0	353.0	+/-4000 nA
Ilo (Hi) (nA)	76.0	45.0	32.0	11.0	37.0	57.0	+/-4000 nA
Isb (SPI) (uA)	18.0	17.8	17.6	17.4	26.1	24.0	200uA
Isb (QPI) (uA)	120.2	120.1	120.2	120.2	49.2	46.5	200uA

Figure 17. Post Radiation Production Measurements

In this figure devices with white background were irradiated under bias to a level of 20K rad(Si). Devices with a blue background were irradiated with no bias to a level of 50K rad(Si).

This figure clearly shows that all devices remained within specified limits to these levels of radiation.

4.0 Conclusions

These parts behaved as expected with radiation. When under bias they were fully functional up to a dose of 20K rad(Si) and could be read correctly at 30K rad(Si). When irradiated in an unbiased condition they remained fully functional to 50K rad(Si) and could be read correctly at 125K rad(Si).

Units exposed with power being applied with a 10% duty cycle passed READ functionality testing at 125K rad(Si).

Distribution of threshold voltages (Vt's) of programmed and erased bits remained well separated over all radiation levels of interest. When irradiated to 150K rad(Si) one part became non-functional and the measurement of the Vt distribution for a second DUT became erratic which was also interpreted as a device failure and not the true distribution.

The tested units pass all specified datasheet limits after radiation exposure as well as during post-rad production testing