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Single Event Latchup Testing
Advanced Analog to Digital Converter
ADC14155W-MLS

Hi-Rel Operations

Radiation Engineering/RHA Programs
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Date: August 02, 2006

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1.0 Objective

To evaluate the SEL (Single Event Latchup) performance of ADC14155W-MLS, to measure the SEL cross section vs. the effective LET (Linear Energy Transfer) to the maximum cross section and effective LET possible at the experimental facility of use, or to verify that the part is immune to SEL for effective LET's up to 121 MeV/mg/cm^2.

2.0 Conclusion

The Space Level version of the ADC14155 is immune to SEL with LET's up to 121.89 MeV/mg/cm^2.

3.0 Summary

No latchup was observed on any of the 3 DUT's (Devices Under Test), at room and hot temperatures, with Bi^{209} at 0° incident angle, LET = 99.85 MeV/mg/cm^2 at the surface of the Silicon. The incident angle was increased to 35°, LET = 121.89 MeV/mg/cm^2 at the surface of the Silicon, and again no latchup was seen on the 3 DUT's at both room and hot temperatures.

4.0 Test Data

See Tables 1, 2 and 3 on pages 9 & 10 for SEL Data taken on the 3 DUT's.

5.0 Description of Product

The ADC14155W-MLS is a high-performance CMOS analog-to-digital converter capable of converting analog input signals into 14-bit digital words at rates up to 155 Mega Samples Per Second (MSPS). This converter uses a differential, pipelined architecture with digital error correction and an on-chip sample-and-hold circuit to minimize power consumption and the external component count, while providing excellent dynamic performance. A unique sample-and-hold stage yields a full-power bandwidth of 1.1 GHz. The ADC14155W-MLS operates from dual +3.3V and +1.8V power supplies and consumes typically 974 mW of power at 155 MSPS. The separate +1.8V supply for the digital output interface allows lower power operation with reduced noise. A power-down feature reduces the power consumption to 5 mW with the clock input disabled, while still allowing fast wake-up time to full operation.

The ADC14155W-MLS Space Level die was used for the DUT's. The die was placed in a decapsulated plastic package to facilitate SEL (Single Event Latchup) testing.

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6.0 Test Method

JESD57 (EIA/JEDEC Standard No. 57), "Test Procedures for the Measurement of Single Event Effects in Semiconductor Devices from Heavy Ion Irradiation" was strictly adhered to for test procedures and definitions (available at http://www.jedec.org/). ESCC 25100 was also used as a reference, and, as closely as possible, was adhered to (available at https://escies.org/public/radiation/esa/standards.html). JESD57 defines the requirements and procedures for Earth based SEE testing of integrated circuits. The test method is only valid when using a Van de Graaff or Cyclotron Accelerator. This method does not apply to SEE testing that uses neutrons, protons and other lighter particles. This test method assumes that the accelerator test facility has the ability to mount and position the DUT in a vacuum chamber, provide heavy ion dosimetry; etc. Inquiries and visits to the site have verified that this is indeed the case. All DUT's must be decapsulated.

7.0 Description of Test Setup

The test circuit for the ADC14155W-MLS consisted of the ADC14155 evaluation board connected to a WaveVision 4 data capture board, driven by WaveVision 4 software. The two boards were secured to the vacuum chamber fixture and powered up by two separate power supply sources.

The ADC evaluation board delivers conversion data along with a source-synchronous clock to the FPGA device on the WaveVision 4 board via a Future Bus connector.

A personal computer was connected to the WaveVision 4 board for communication, control, and data gathering. Data and events were uploaded to the personal computer after every run (exposure to accelerated ions) and after every power up sequence to make sure the DUT was still operating correctly.

For SEL testing the input was a slowly varying sine wave of approximately 1MHz, full scale and AC coupled through a balun and AC coupling capacitors, 4.7nF. The input signal was clocked in (sampled) at a frequency of 155 MHz and amplitude of 0 – 3Vp-p. A current probe was attached to an oscilloscope and was used to monitor the total current drawn by the evaluation board (which is primarily the sum of the V_A and V_{DR} currents drawn by the DUT).

A latchup event was defined as a sustained increase in DC current drawn by the evaluation board (which would coincide with an increase in current on either the V_A or V_{DR} power pins of the DUT) that persisted until the part was powered down. A temperature controller was connected to the thermistors and to the resistive heaters and

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provided both temperature measurement and heater control for the hot temperature testing.

8.0 Test Plan and Procedures

8.1 Ions, Angles, Temperatures, and Applied Voltages

The SEL test was started with the heaviest ion available at 0° incident angle (0° being the beam perpendicular to surface of die) to establish the saturated or largest cross-sectional area. The lower energy (lighter) ions were to be selected in descending order, as available, until latchup was no longer observed (below the threshold of SEL).

The SEL testing was performed at two different temperatures: ~35º C (ambient temp at "Room Temp" in the vacuum chamber), and 65º C (Hot Temp, as determined by thermistor attached to the evaluation board in the proximity of the DUT). V_A = 3.3V & V_{DR} = 1.8V was used for all temperatures. The 65°C, as determined by the thermistor near the DUT , was chosen because it is the maximum practical temperature that the part can be heated to on an evaluation board without the adhesive of the heaters melting and falling off the board. Since the LLP package containing the DUT for these experiments has a θja of 24°C/W and the power dissipation of the device is documented to be ~940mW, so the junction temperature was calculated to be 87.56°C (65°C + (24°C/W)*(0.94W) = 87.56°C). Therefore, at "Hot Temp", the DUT was running at a junction temperature of approximately 90°C.

Testing was also performed at 35° incident angle, measured from a perpendicular to the surface, when needed to achieve an effective LET of approximately 120MeV/mg/cm^2.

8.2 Power Up / Power Down and Testing Sequence

a) Set up test equipment/circuit, with DUT, and verify correct operation.
   Initial Power Up Sequence:
   1) Apply 5.0V to the evaluation board which then regulates and supply 3.3V to V_A and 1.8V to V_{DR} simultaneously
   2) Apply Clock – 155MHz sine wave 0-3.3Vp-p
   3) Apply Waveforms to be sampled (see section 7.0 for description)

   Subsequent Power Down Sequences:

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Power OFF the evaluation board, i.e., remove 3.3V from V_A and 1.8V from V_{DR} simultaneously (leave clock signal and inputs applied and running).

Subsequent Power Up Sequences:

1) Power ON the evaluation board, i.e., apply 3.3V to V_A and 1.8V to V_{DR} simultaneously (leave clock signal and inputs applied and running).

Final Power Down Sequence:

1) Power OFF the evaluation board, i.e., remove 3.3V from V_A and 1.8V from V_{DR} simultaneously
2) Remove Clock – 155MHz sine wave 0-3.3Vp-p
3) Remove Waveforms being sampled from input pins

b) Check with facility's personnel for correct ion beam characteristics, energy, and flux. Ensure detectors are working properly.
c) Power up Device-Under-Test (DUT), using the "Subsequent Power Up Sequences" step above. Ensure it is operating properly.
d) Expose the DUT to the ion beam.
e) Record all pertinent data after exposure including if DUT latched-up or not.
f) Power down DUT using the "Subsequent Power Down Sequences" step above.
g) Repeat steps "b" through "f" for different energies and ion species.
h) Repeat steps "b" through "g" for samples #2 and #3.
i) Repeat steps "b" through "h" at 65°C (case temperature).
j) Power Down as per "Final Power Down Sequence" above.
k) Upon completion, the data was analyzed and this final test report was generated.

8.3 Other Information Associated with Testing

a) Facility:
   Lawrence Berkeley National Laboratory
   1 Cyclotron Road
   Berkeley, CA 94720
b) Test Method: EIA/JESD 57 – "Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation", December, 1996
c) Sample Size: 3
d) Bias Voltage: V_A = 3.3V; V_{DR} = 1.8V.
e) Sampling Frequency: 155 MHz
f) Temperatures: ~35ºC (room temperature, no heat applied) and 65ºC (thermistor in close proximity to DUT).

g) Selected LET values, see figure 1 (page 8). The facility reserves the right to change this table. The actual "Cocktail" used was the 4.5MeV/nucleon "Cocktail" as per figure 1 with HeH^{+1}, B^{10}, Kr^{78}, Co^{59} not available, and Cu^{63} instead of Cu^{65}.

h) Ions used, see figure 1 (page 8) and the previous paragraph, (g).

i) Fluence: 1×10^2 to 5×10^7 ions/cm²

j) Flux: 1×10^2 to 1×10^6 ions/cm²·s

9.0 Test Facility, Dates, and Personnel

The test facility for the Single Event Effects testing was the 88" Cyclotron Facility at Lawrence Berkeley National Laboratory located in Berkeley, California. The 88" Cyclotron provides heavy ion beams to perform SEE testing in a controlled environment. The facility generates ion beams for about a dozen different ion species at three energies per nucleon, 4.5MeV, 10Mev, and 16MeV. The 88" Cyclotron is located in Building 88 at 1 Cyclotron Road in Berkeley, CA.

Test Facility Personnel:

a) Peggy McMahan
Operations Supervisor
(510) 486-5980

b) Michael Johnson
Technical Support
(510) 486-4389

The testing was performed 0800 to 2000 on June 14 and 15, 0800 to 1600 June 16, 2006.

10.0 Test Equipment

a) Triple Power Supply

b) Oscilloscope with current probes

c) 3 Function Generators – Two Rohde Schwarz SME 03 (5Khz to 3 GHz) and HP 8662A (1280Mhz) . Note both Rohde Schwarz generators were configured for an external reference from the HP generator.

d) Lakeshore Temperature Controller, Model 332

e) Laptop Computer – Executes WaveVision 4 Software

f) 5 DVM's for monitoring Supply Voltages and Currents

g) ADC14155 evaluation boards with decapsulated parts (DUT's) already mounted on them & WaveVision 4 boards for capturing data.

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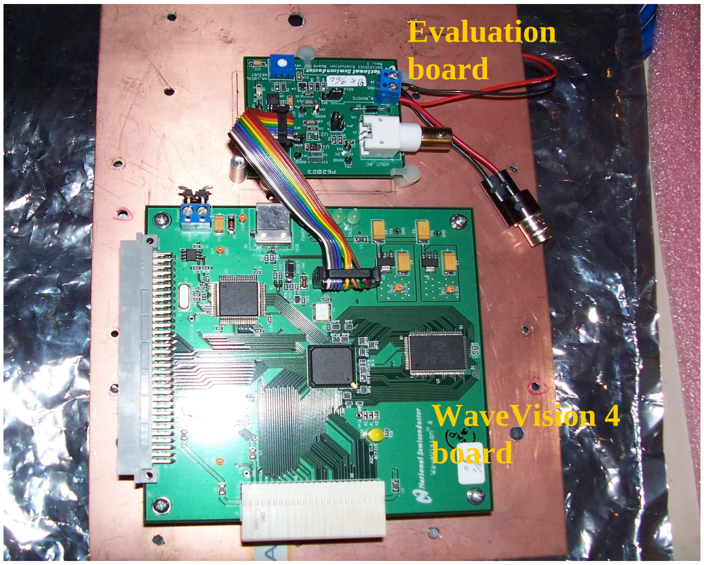
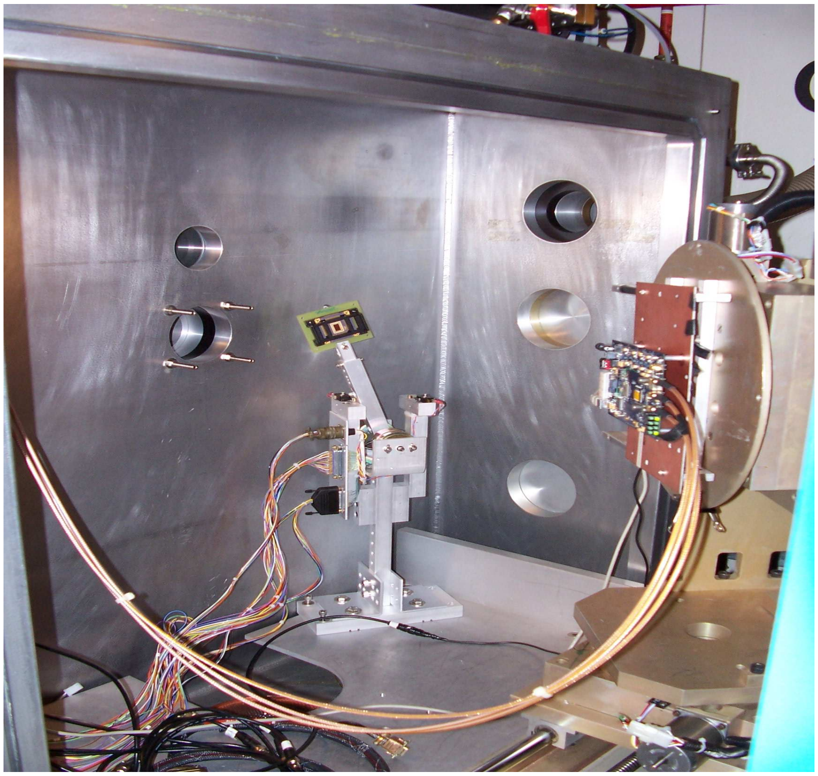
Evalulation and WaveVision 4 boards



Boards were mounted on the Cyclotron Accelerator chamber



Appendix A

Heavy-Ion Cocktail Bragg Curves

Fig. A1 is a Bragg curve plot from the Lawrence Berkeley National Laboratory [7] that shows the depth of penetration and energy for each ion used in the experiment. The ADC08D1000W-MLS had a thickness of 11 µm from the top of the passivation to the bottom of the epi layer. From Fig. A1, one can see that at 11 µm, none of the ions start to lose energy and some have a slight increase in energy. Thus, the LET value of the ion is almost constant as it passes through the sensitive charge collection region of the transistor. As a result, the need to correct LET magnitudes used in the report (for penetration depth) was eliminated.

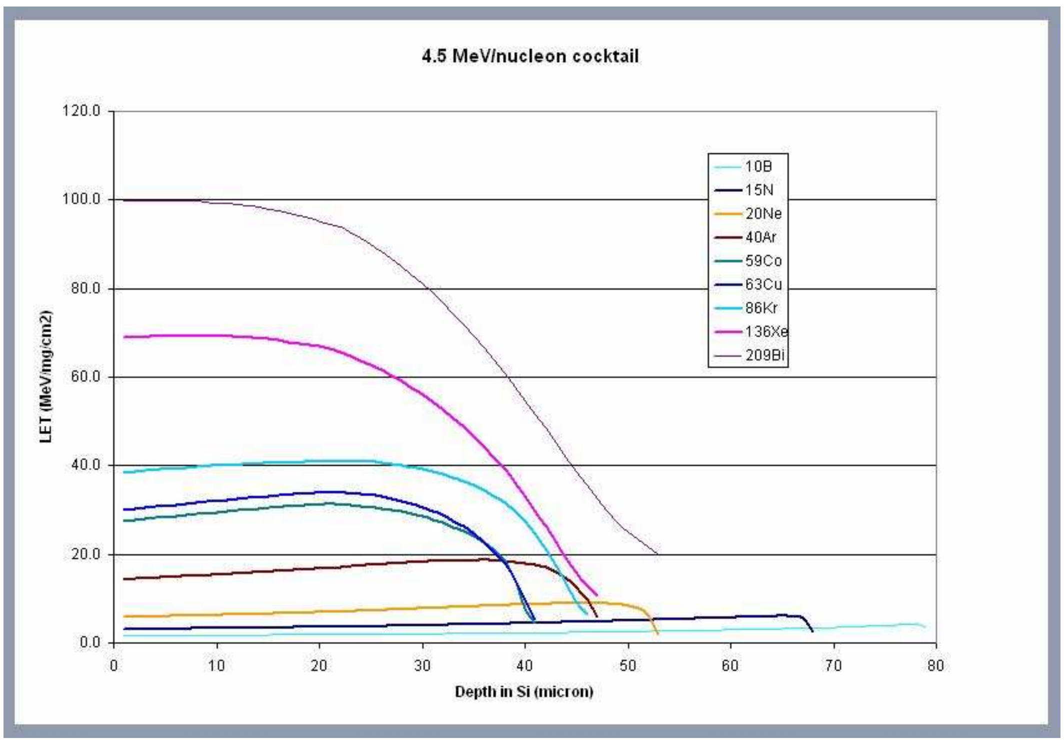


Fig. A1. LET vs. penetration profile for various ion species used in the heavy-ion experiments. After [7].

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Appendix B

4.5 MeV/nucleon cocktail (HeH^{+1} to Bi)

This cocktail, based on a tune-up of the ion source and Cyclotron using $^{40}Ar^{+8}$, has an A/q ratio of 5 and energy of 4.5 MeV/nucleon. To achieve lower LET, boron can be added by special request. For even lower LET, HeH^{+1} ions can be accelerated; this requires a special tune-up. For an LET of about 100 MeV/mg/cm^2, $^{209}Bi^{+41}$ can be run at this energy, but requires advance notice and the AECR-U ion source. All of the above information was obtained from LBNL.

Table B1. Heavy-ion cocktail used in the SEE experiments.

Ion	**Energy(MeV)**	**LET (MeV/mg/cm^2)** #	**Range in Si (µm)** #
HeH^{+1*}	18, 4.5	0.26,0.064	180,179
$^{10}B^{+2}$	45	1.64	79
$^{15}N^{+3}$	67	3.09	67
$^{20}Ne^{+4}$	90	5.77	53
$^{40}Ar^{+8}$	180	14.3	48
$^{59}Co^{+12}$	266	27.31	43
$^{65}Cu^{+13}$	293	29.89	44
$^{78}Kr^{+15}$	325	39.54	41
$^{86}Kr^{+17}$	378	39.24	47
$^{136}Xe^{+27}$	603	68.83	48
$^{209}Bi^{+41}$	940	99.64	54

#LETs and ranges calculated using SRIM2003
*After break up in target or a scattering foil.

Table 1 – Test Log

Date: 06/15/2006

Facility: Lawrence Berkeley National Laboratory

Product Type: ADC14155

DUT's: ADC14155 evaluation board with DUT #85D (Runs 47 – 60)

Run	Spec ies	Incident	LET	Flux	Effective Fluence	#events	Eval Bd Current	Flux Duration	Δ (diff) Latchup	Applied Voltage	Temp. ℃	Total Effective	Accumul-ated (note 1)
#		Angle	MeV/ Mg/cm2	#/cm2* sec	#/cm2	& type	(mA)	(sec)	Current mA	Va/Vdr (V)	@ therm.	Fluence $\#/cm^2$	Ionizing Dose(rads)
47	Bi^{209}	0°	99.85	3E4	7.07E6	0	455	246	NA	3.3/1.8	35	7.07E6	11.295E3
48	Bi^{209}	0°	99.85	3E4	1.01E7	0	457	298	NA	3.3/1.8	35	1.01E7	27.431E3
49	Bi^{209}	0°	99.85	3E4	1.01E7	0	457	357	NA	3.3/1.8	35	1.01E7	43.567E3
50	Bi^{209}	35°	121.89	5E4	1.01E7	0	457	471	NA	3.3/1.8	35	2.00E7	63.264E3
51	Bi^{209}	35°	121.89	6E4	1.01E7	0	458	520	NA	3.3/1.8	35	2.01E7	82.961E3
52	Bi^{209}	35°	121.89	5E4	1.03E7	0	459	552	NA	3.3/1.8	35	2.02E7	103.049E3
58	Bi^{209}	0°	99.85	4E4	1.00E7	0	478	236	NA	3.3/1.8	65	1.00E7	119.025E3
59	Bi^{209}	0°	99.85	4E4	1.00E7	0	478	233	NA	3.3/1.8	65	1.00E7	135.001E3
60	Bi^{209}	0°	99.85	4E4	1.01E7	0	478	233	NA	3.3/1.8	65	1.01E7	151.137E3

Table 2 – Test Log

Date: 06/16/2006

DUT's: ADC14155 evaluation board with DUT #84D (Runs 62 – 70)

Run	Spec ies	Incident	LET	Flux	Effective Fluence	#events	Eval Bd Current	Flux Duration	Δ (diff) Latchup	Applied Voltage	Temp. ℃	Total Effective	Accumul-ated (note 1)
#		Angle	MeV/ Mg/cm2	#/cm2* sec	#/cm2	& type	(mA)	(sec)	Current mA	Va/Vdr (V)	@ therm.	Fluence $\#/cm^2$	Ionizing Dose(rads)
62	Bi^{209}	0°	99.85	3E4	1.50E7	0	461	246	NA	3.3/1.8	35	1.50E7	23.964E3
63	Bi^{209}	0°	99.85	3E4	1.01E7	0	462	298	NA	3.3/1.8	35	1.01E7	40.100E3
64	Bi^{209}	0°	99.85	3E4	1.00E7	0	464	357	NA	3.3/1.8	35	1.00E7	56.076E3
65	Bi^{209}	35°	121.89	3E4	1.05E7	0	465	471	NA	3.3/1.8	35	1.27E7	76.553E3
66	Bi^{209}	35°	121.89	2.8E4	1.00E7	0	465	520	NA	3.3/1.8	35	1.22E7	96.056E3
67	Bi^{209}	35°	121.89	2.3E4	1.01E7	0	466	552	NA	3.3/1.8	35	1.23E7	115.753E3
68	Bi^{209}	35°	121.89	2.3E4	1.00E7	0	477	236	NA	3.3/1.8	65	1.20E7	135.256E3
69	Bi^{209}	35°	121.89	2.3E4	1.02E7	0	477	233	NA	3.3/1.8	65	1.25E7	155.148E3
70	Bi^{209}	35°	121.89	2.3E4	1.02E7	0	477	233	NA	3.3/1.8	65	1.24E7	175.040E3

Table 3 – Test Log

Date: 06/16/2006

DUT's: ADC14155 evaluation board with DUT #64C (Runs 71 – 76)

Run	Spec ies	Incident	LET	Flux	Effective Fluence	#events	Eval Bd Current	Flux Duration	Δ (diff) Latchup	Applied Voltage	Temp. ℃	Total Effective	Accumul-ated (note 1)
#		Angle	MeV/ Mg/cm2	#/cm2* sec	#/cm2	& type	(mA)	(sec)	Current mA	Va/Vdr (V)	@ therm.	Fluence #/cm^2	Ionizing Dose(rads)
71	Bi^{209}	35°	121.89	3.0E5	1.20E7	0	462	55	NA	3.3/1.8	35	1.50E7	23.403E3
72	Bi^{209}	35°	121.89	3.0E5	1.01E7	0	464	44	NA	3.3/1.8	35	1.20E7	43.100E3
72	Bi^{209}	35°	121.89	2.7E5	1.05E7	0	464	46	NA	3.3/1.8	35	1.30E7	63.578E3
74	Bi^{209}	35°	121.89	2.5E5	1.03E7	0	477	44	NA	3.3/1.8	65	1.26E7	83.665E3
75	Bi^{209}	35°	121.89	3.0E5	1.04E7	0	477	45	NA	3.3/1.8	65	1.26E7	103.948E3
76	Bi^{209}	35°	121.89	3.0E5	1.02E7	0	477	44	NA	3.3/1.8	65	1.25E7	123.840E3

Note 1: Accumulated Ionizing Dose is an estimate of the worst case bound according to annex B of EIA/JESD57. The large Z (number of protons) species used in this testing lose their energy and stop rather quickly in Si (although the depth vs. LET curve of all the species used showed that the rapid drop off of LET and the penetration depth was well below the epitaxial layer and into the substrate, that is well below the active circuitry and associated parasitics). The formula given in annex B of EIA/JESD57, 1.6E-5*LET*Fluence, with LET in MeV/mg/cm^2, and Fluence in ions/cm^2, assumes that the LET of the species does not decrease and the ion flux continues on through the Si undiminished. Thus, the accumulated ionizing dose presented in the last two tables is certainly an over estimate, and the over estimate gets worse with as Z gets larger. Certainly for Bi209, these figures are greatly over estimated. Through out the testing the performance of the DUT's with checked with WaveVision4 software (developed by National Semiconductor Corp.) and no degradation of performance was observed on any of the DUT's.