Abstract

The heavy ion SEL/SEE testing results of the Microsemi radiation hardened analog mixed-signal motor controller IC, the LX7720, are presented.

Heavy Ion Testing on Microsemi Integrated Motor Controller LX7720 Power Driver with Rotation and Current Sensing

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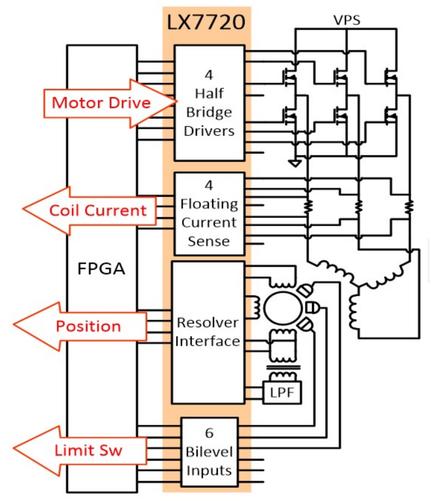
Conclusion

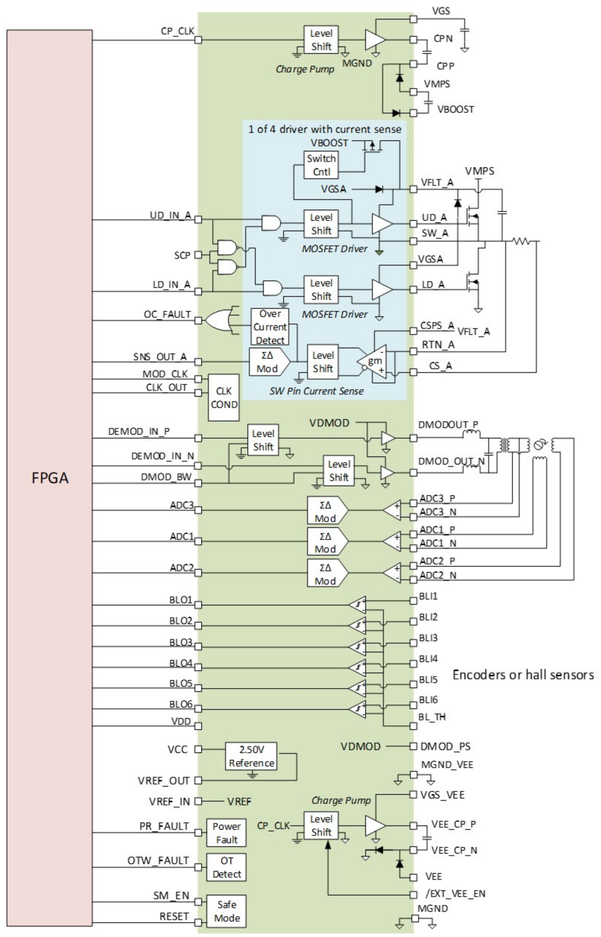
The first round of heavy ion beam testing to investigate the single-event effects of the LX7720 has been performed. The design is SEL immune up to 87 MeV.cm²/mg and 125°C (fluence of 1x10⁷ particles/cm²) for VMPS=36V. In addition, no SEFI was observed. Overall, the LX7720 shows strong performance under the beam for the evaluated blocks including the hardened flip-flops performance and the upper and lower high voltage drivers. Additional testing to be performed in October '18 to collect additional data on non evaluated blocks and at higher VMPS voltages.

I. INTRODUCTION

- The LX7720 is a power driver with rotation and position sensing.
- Features four half-bridge N-CH MOSFET drivers with four floating differential current sensors (option to be ground referenced or floating).
- Also available are: three differential ADC sense inputs, one pulse modulated resolver transformer driver and six bi-level logic inputs.
- Can be interfaced with an FPGA, microcontroller or other logic element.
- Manufactured as a dual die MCM solution in a custom 132-pin CQFP package, body 24mm*24mm.
- The LX7720 is designed to achieve the following radiation hardening goals:
  - Total dose objective: TID tolerance is greater than 100krad (S_iO_2) – results already available.
  - SEL/SEU objective: SEL immune at >80 MeV.cm²/mg and 125°C, Strong SEE performance – Testing July 2018 – presented here - follow-up October 2018
  - ELDRS sensitivity Objective: tolerance greater than 50krad (S_iO_2) – Testing scheduled for January 2019
- Temperature range: -55°C to 125°C. High temperature warning flag and thermal shutdown available.
- Qualification under MIL-PRF-38535 for QML-Q and QML-V.
- The LX7720 device is classified under EAR 9a515.e



II. LX7720 BLOCK DIAGRAM



Boost Circuitry

BOOTSTRAP circuitry
High-Side 50V N-CH driver
Low-Side N-CH driver
Floating differential current sensor with ΣΔ modulated processed outputs
4X

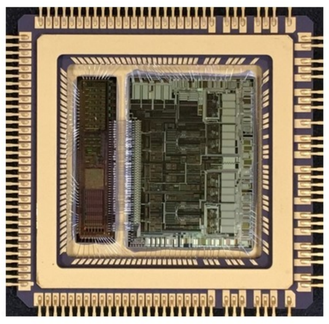
Pulse density modulated resolver exciter

Differential resolver sensor with ΣΔ modulated processed outputs
3X

Bilevel inputs – threshold configurable
6X

III. LX7720 – RADIATION HARD BY DESIGN

- The Microsemi hardening solution involves a series of test chips and careful device characterization prior to being used in analog designs. In addition, some primitive devices on a given process or inadequate biasing of devices can yield poor total dose results. Microsemi has developed a series of block design IP and a components library to overcome these issues.
- The LX7720 controller is designed using two technology processes:
  - BI-CMOS process for analog precision circuitry,
  - Dielectric Isolated technology process capable of high voltage operation up to 350V, which is well beyond the absolute max rated operating voltage of the LX7720 of 50V.
- The design is partitioned to take advantage of both processes in terms of accuracy requirements and high voltage device ratings and radiation performance.
- The device manufactured as a dual-die solution, co-packaged in a single package with interconnect bonds between the two dice is shown here.



LX7720 – dual-die solution

IV. LX7720 SEE TEST PLAN TEST RESULTS SUMMARY

- Single Event Effect initial tests were performed on the LX7720 at the Texas A&M University facility (TAMU) in College Station, TX using a 15MeV/n cocktail beam on July 26, 2018.
- Functions: The LX7720 is a complex device and the plan is exhaustive covering all mixed signal functions including/monitoring:
  - Supply current consumptions on all supplies VCC, VGS, VEE, VMPS.
  - Upper and lower MOSFET drivers.
  - Flip-flop performance.
  - ADC – not presented here.
  - Demodulator – not presented here.
  - Bilevel telemetry – not presented here.
- Conditions: Overall test conditions: VGS=15V, VEE=-15V External (+/-18 for SEL), DMOD_PS=15V, VDD=3.3V, MOD_CLK=24MHz, VMPS=50V nominal.
- Results summary: The SEE results obtained demonstrate the strong radiation performance of the device.
  - The LX7720 is SEL immune at VMPS=36V at 125° C when tested to a fluence of 1x107 particles/cm² and a LET = 87 MeV.cm²/mg.
  - Good SEU performance of the TMRed scan chain in line with the LX7730 performance.
  - No SEFI was observed.
  - Low rate of upsets for the high voltage FET drivers.
- Additional testing will be performed to complete the plan and determine the SEL LET threshold for higher voltage VMPS.

LX7720 and SEU board facing beam

- Availability of ions

Estimated Beam Change Times for 15 A MeV Beam

Final 15 A MeV Beam Configuration	He	N	Ne	Ar	Cu	Kr	Ag	Xe	Pr	Ho	Ta	Au	Initial LET (air)	
^{4}He		45	55	55	55	55	55	55	70	70	70		0.11	Helium
^{14}N	40		40	40	40	40	40	40	50	50	50		1.3	Nitrogen
^{20}Ne	50	40		25*	35	30	30	30	30	45	45	45	2.6	Neon
^{40}Ar	50	40	25*		35	30	30	30	30	45	45	45	8.0	Argon
^{63}Cu	50	40	35	35		35	35	35	35	45	45	45	18.7	Copper
^{84}Kr	50	40	30	30	35		25*	25	30	45	45	45	26.6	Kripton
^{109}Ag	50	40	30	30*	35	15		15	30	45	45	45	40.3	Silver
^{129}Xe	50	40	30	30	35	25	25*		30	45	45	45	49.3	Xenon
^{141}Pr	50	40	25	20*	35	25	25	25		45	45	45	56.0	Praseodymium
^{165}Ho	60	50	45	45	45	45	45	45	45		30	30	66.7	Holmium
^{181}Ta	60	50	45	45	45	45	45	45	45	30		20	74.8	Tantalum
^{197}Au	60	55	50	50	50	50	50	50	50	30	20		82.8	Gold
	He	N	Ne	Ar	Cu	Kr	Ag	Xe	Pr	Ho	Ta	Au		

Initial 15 A MeV Beam Configuration

V. LX7720 SEE TEST RESULTS

Single Event Latchup

- SEL tests were performed at a temperature of up to 125°C on 2 DUTs.

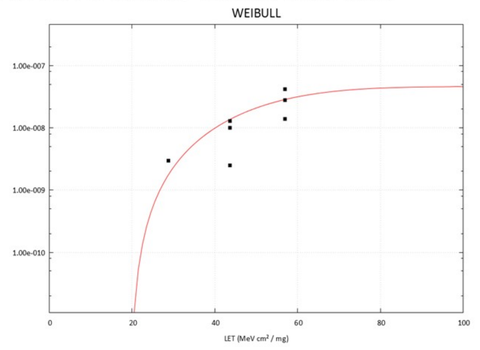
Run #	Part #	Ion	VMPS (V)	Temperature (°C)	Initial LET (MeV.cm2/mg)	Tilt Angle (Deg)	Flux (cm-2.s-1)	Effective Fluence (cm-2)	Effective LET (MeV.cm2/mg)	Supplies currents (mA)								Events Count	Comments
										VCC Pre	VCC Post	VGS Pre	VGS Post	VMPS Pre	VMPS Post	VEE Pre	VEE Post	SEL Events	
4	2_SEE	Au	36	125	87.10	0.00	7.12E+04	1.00E+06	87.10	137.2	137.2	38.3	38.3	0.0	0.0	5.9	5.9	0	
5	2_SEE	Au	36	125	87.10	0.00	7.09E+04	3.00E+06	87.10	137.2	137.3	38.3	38.5	0.0	0.0	5.9	6.0	0	
6	2_SEE	Au	36	125	87.10	0.00	7.15E+04	3.00E+06	87.10	137.3	137.1	38.5	38.5	0.0	0.0	6.0	6.0	0	
7	2_SEE	Au	36	125	87.10	0.00	7.55E+04	3.00E+06	87.10	137.1	137.1	38.5	38.5	0.0	0.0	6.0	6.0	0	
9	3_SEE	Au	50	125	89.00	0.00	6.64E+04	2.00E+06	89.00	141.0	141.6	41.0	41.5	0.0	0.0	6.3	6.4	0	
10	3_SEE	Au	50	125	87.10	0.00	8.00E+04	1.00E+07	87.10	141.6	141.8	41.5	41.7	0.0	0.0	6.4	6.5	1	LET threshold to be determined
11	3CC_SEE	Ag	50	25	43.60	0.00	7.95E+04	2.32E+06	43.60	134.3	23.7	41.7	23.7	0.0	0.0	6.5	6.9	0	
12	3CC_SEE	Ag	50	25	43.60	0.00	8.42E+04	2.40E+06	43.60	23.7	23.7	23.7	23.7	0.0	0.0	6.9	6.9	0	
13	3CC_SEE	Ag	50	25	43.60	0.00	8.38E+04	2.40E+06	43.60	23.7	23.7	23.7	23.7	0.0	0.0	6.9	6.9	0	
14	3CC_SEE	Ag	50	25	43.60	40.00	7.78E+04	1.72E+06	56.92	23.7	23.7	23.7	23.7	0.0	0.0	6.9	6.9	0	
15	3CC_SEE	Ag	50	25	43.60	40.00	7.85E+04	1.72E+06	56.92	23.7	23.7	23.7	23.7	0.0	0.0	6.9	6.9	0	
16	3CC_SEE	Ag	50	25	43.60	40.00	7.91E+04	1.72E+06	56.92	23.7	23.7	23.7	23.7	0.0	0.0	6.9	6.9	0	

- At 36V and 125°C, no SEL events were observed when tested to a fluence of 1x107 particles/cm² and a LET = 87 MeV.cm²/mg.
- At 50V and 125°C, no SEL events were observed when tested to a fluence of 2x106 particles/cm² and a LET = 89 MeV.cm²/mg, but some degradation was observed at a fluence of 1x107 particles/cm².
- At 50V and 25°C, no SEL events were observed when tested to a fluence of 5.2x106 particles/cm² and a LET = 57 MeV.cm²/mg particles/cm².
- At 50V and 25°C, no SEL events were observed when tested to a fluence of 3.3x107 particles/cm² and a LET = 43 MeV.cm²/mg particles/cm².
- Further tests will be required to determine SEL threshold at 125°C and 50V.

Scan Chain

- All 156 flip-flops in the registers and digital busses are included in the scan chain.
- A 1 MHz clock and 250kHz input pattern are used to test the flip-flop chain.
- The scan chain test shows good SEU performance from the TMR flip-flops similar to the LX7730 Telemetry Controller device which uses the same FF with the same LET threshold.
- Weibull curve shown below using OMERE software version 5.0.
- Resulting upset rate: 1.49x10^{-10}/FF/day for GEO environement.

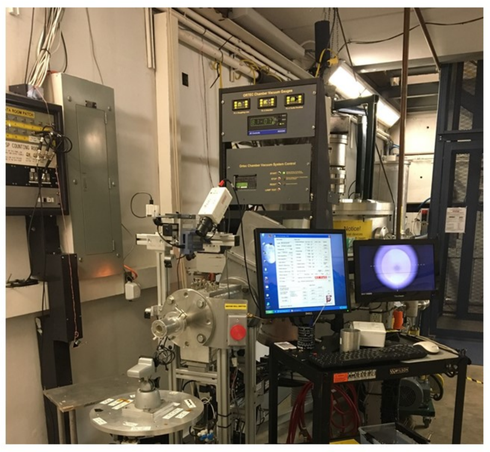
	Part #	Ion	Initial LET (MeV.cm2/mg)	Tilt Angle (Deg)	Flux (cm-2.s-1)	Effective Fluence (cm-2)	Effective LET (MeV.cm2/mg)	Events Count			Events X-section			Total Dose (krad)
								SEL Events	SET Events	Scan Chain SEU	SEL Events cm2/device	SET Events cm2/device	SEU #1 cm2/bit	
11	3CC_SEE	Ag	43.60	0.00	7.95E+04	2.32E+06	43.60			5	0.00E+00	0.00E+00	1.29E-08	1.62E+00
12	3CC_SEE	Ag	43.60	0.00	8.42E+04	2.40E+06	43.60			4	0.00E+00	0.00E+00	9.98E-09	1.67E+00
13	3CC_SEE	Ag	43.60	0.00	8.38E+04	2.40E+06	43.60			1	0.00E+00	0.00E+00	2.50E-09	1.67E+00
14	3CC_SEE	Ag	43.60	40.00	7.78E+04	1.72E+06	56.92			4	0.00E+00	0.00E+00	1.39E-08	1.57E+00
15	3CC_SEE	Ag	43.60	40.00	7.85E+04	1.72E+06	56.92			8	0.00E+00	0.00E+00	2.79E-08	1.57E+00
16	3CC_SEE	Ag	43.60	40.00	7.91E+04	1.72E+06	56.92			12	0.00E+00	0.00E+00	4.18E-08	1.57E+00
30	3CC_SEE	Kr	28.80	0.00	6.72E+04	2.00E+06	28.80			1	0.00E+00	0.00E+00	2.99E-09	9.40E-01
31	3CC_SEE	Kr	28.80	0.00	7.05E+04	2.00E+06	28.80			1	0.00E+00	0.00E+00	2.99E-09	9.40E-01



- The LX7720 is essentially an analog power solution, where the FFs have minimal functional use:
  - 90 of these FF are used for internal setting prior to zener programming -> no impact on the function of the device.
  - 35 are for fault filter setting -> minimal functional impact, fault signals may show a transient but will recover.
  - 27 FFs are for enable signals for the demodulator and the ADCs-> will only cause transients in enable for demodulator and ADC data. No Latched-behavior.
  - 4 FFs are used to set the charge pump clock-> an upset could create a temporary frequency change on the VBOOST and VEE signals with no or nominal functional impact.

UD and LD High-Voltage Drivers

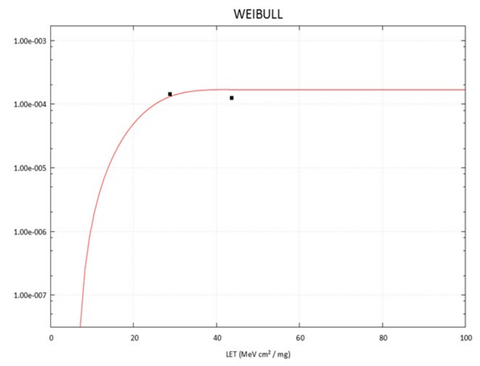
- The LX7720 can drive 4 half-bridges:
  - The high side external FET is driven by an internal upper driver referred as UD driver – 4 total UD drivers.
  - The low side external FET is driven by an internal upper driver referred as LD driver – 4 total LD drivers.
  - Both UD and LD drivers are identical, the UD driver being floating with the switch node.
  - No state upsets were recorded, only transients.
  - SETs are recorded for:
    - both UD and LD drivers when set high.
    - both UD and LD drivers when set low.
  - LET threshold estimated from data of other similar drivers previously tested. More testing to be performed to confirm threshold.



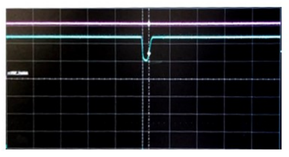
Beam front view

- Transients when drivers are set-high:

Run #	Part #	Ion	Initial LET (MeV.cm2/mg)	Tilt Angle (Deg)	Flux (cm-2.s-1)	Effective Fluence (cm-2)	Effective LET (MeV.cm2/mg)	Events Count			Events X-section			Total Dose (krad)
								SEL Events	SET Events	Scan Chain SEU	SEL Events cm2/device	SET Events cm2/device	SEU #1 cm2/bit	
24	3CC_SEE	Ag	43.60	0.00	7.53E+04	1.00E+06	43.60		84		0.00E+00	8.40E-05	0.00E+00	6.00E-01
25	3CC_SEE	Ag	43.60	0.00	7.67E+04	1.00E+06	43.60		89		0.00E+00	8.90E-05	0.00E+00	7.10E-01
28	3CC_SEE	Kr	28.80	0.00	6.97E+04	1.00E+06	28.80		112		0.00E+00	1.12E-04	0.00E+00	4.30E-01

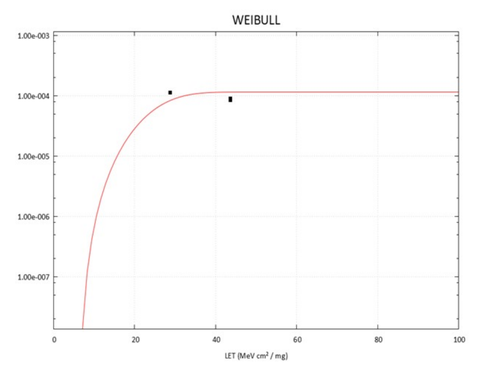


- Scale 10V/div and 1us/div. Typical transients observed <1us.
- Resulting transient rate: 1.9x10^{-4}/driver/day for GEO environment.



- Transients when drivers are set-low:

Run #	Part #	Ion	Initial LET (MeV.cm2/mg)	Tilt Angle (Deg)	Flux (cm-2.s-1)	Effective Fluence (cm-2)	Effective LET (MeV.cm2/mg)	Events Count			Events X-section			Total Dose (krad)
								SEL Events	SET Events	Scan Chain SEU	SEL Events cm2/device	SET Events cm2/device	SEU #1 cm2/bit	
24	3CC_SEE	Ag	43.60	0.00	7.80E+04	1.00E+06	43.60		84		0.00E+00	8.40E-05	0.00E+00	6.00E-01
25	3CC_SEE	Ag	43.60	0.00	6.96E+04	1.00E+06	43.60		89		0.00E+00	8.90E-05	0.00E+00	7.10E-01
28	3CC_SEE	Kr	28.80	0.00	6.67E+04	1.00E+06	28.80		112		0.00E+00	1.12E-04	0.00E+00	4.30E-01



- Scale 10V/div and 100us/div.
- Transient waveform on UD driver is shown, transient is also narrow <1us but decay <100us will vary with RC load on UD and SW nodes.
- The set-up here has no load which should be a worst case for the decay. Additional testing with different loading to be performed.
- Resulting transient rate: 1.17x10^{-4}/driver/day for GEO environment.