Extended TID, ELDRS and SEE Hardening and Testing on Mixed Signal Telemetry LX7730 Controller

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***Abstract*—Extended TID test results up to 300krad TID for the first radiation hardened analog mixed-signal telemetry controller IC, the LX7730, are presented.**

I. INTRODUCTION

FAST growing technology is enabling humans to send more and more spacecrafts into deep space and explore new territory. In the harsh radioactive environment of space, radiation tolerance of the components used in these missions is critical. The LX7730 is a radiation-hardened spacecraft telemetry manager [1] which successfully completed MIL-PRF-38535 qualification for QML-Q and QML-V in 2017. The LX7730 is a highly integrated solution, embedding the necessary functions for telemetry acquisition, amongst others analog MUXes, instrumentation amplifier, ADC converter, programmable conditioning current sources, DACs, Bi-Level comparators. The LX7730 solution is able to meet challenging space exploration applications requirements that demand a smaller footprint, less weight, powerful performance and flexibility. This device temperature range is -55C to 125C, is classified under EAR 9a515.e.

The LX7730 shows its solid radiation response, TID tolerance rated greater than 100 krad (S_iO_2); ELDRS tolerance greater than 50 krad (S_iO_2), and SEL immunity as well as strong SET performance. To further explore the possibility of using the LX7730 in deep space exploration, the device got tested up to 300krad (S_iO_2). The data for 100kRad exposure as well as 200k and 300krad are presented in this paper and demonstrates that LX7730 is functional after 300k TID exposure under proper biased conditions with some restrictions. Some parameter shifts are observed and can be mitigated with system design.

II DEVICE DESCRIPTION

1 Device Technology

The LX7730 controller is designed using two technology processes, a BI-CMOS process for analog precision circuitry and a dielectrically isolated process capable of high-voltage operation up to 350V, well beyond the 20V absolute max rated operating voltage of the device. The LX7730 embeds many diverse functions [2, 3] and the design is partitioned to take advantage of both processes in terms of accuracy requirements and high voltage device rating requirements.

The device is manufactured as a dual-die solution with interconnect bonds between the two dies, co-packaged in a 132-CQFP package as shown in Fig 1.

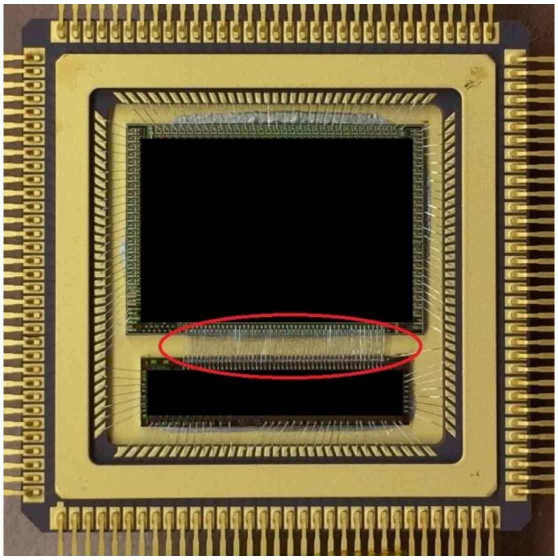

Fig. 1. LX7730 – a dual-die solution

2. Device Function

The LX7730 is a spacecraft telemetry manager that functions as a companion to an FPGA. The LX7730, as shown in the top-level block diagram in Fig. 2 contains a 64-universal input multiplexer to be configured as a mix of differential and single ended sensor inputs. For input conditioning, a programmable current source can be directed to any of the 64 universal inputs. The universal inputs can be sampled with a 12-

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bit analog-to-digital converter. Internal Gain for conversion is settable to accommodate for a wide range of input voltages. The universal inputs can also be set as variable bi-level inputs with a threshold set by an internal 8-bit digital-to-analog converter. There is an additional 10 bit digital-to-analog current DAC with complementary outputs. There also are eight fixed threshold bi-level inputs.

The telemetry manager is register-programmable with 17 addressable 8-bit registers. Two options are available for communication with the host FPGA. There is an 8-bit parallel bus with 5 address bits and a read/write bit that can communicate at a speed of up to 25MHz. The second option is a pair of 12.5MBPS SPI interfaces that can support redundant communication to two different hosts. The LX7730 is powered out of a single supply VCC nominally at 15V in addition to the VDD supply used by the FPGA.

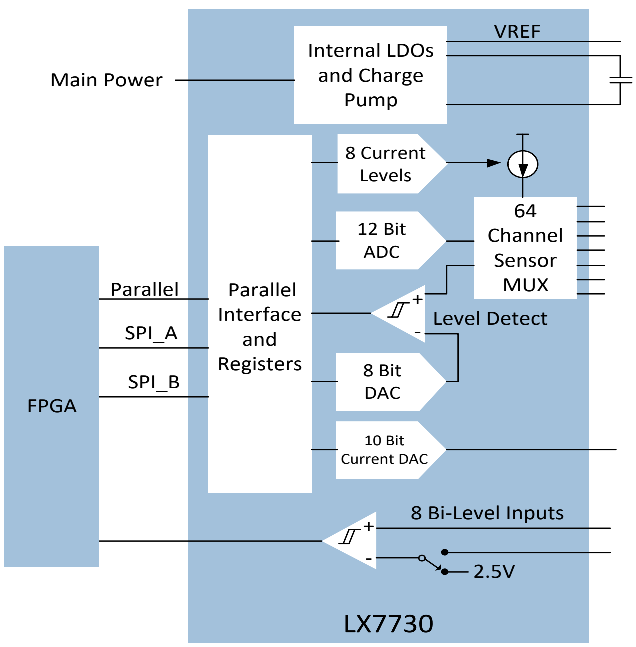

Fig. 2. LX7730 Top-Level Block Diagram

III LX7730 TID RESULTS

The TID test results shown in this paper were performed on the first production lot. The testing was completed at the Defense Microelectronics Activity (DMEA) Test Facility in McClellan, California. The devices were characterized pre-radiation and post radiation. The TID Testing followed test method MIL-STD-883J, 1019.9, Condition A with a dose rate of 50rad/s. A total of 12 units were tested under different TID dosage. The summary of TID testing dosage is presented on Fig. 3.

Serial #	Tested TID dosage	+5V Pin Voltage
SN565	100krad	5V
SN566	100krad	5V
SN567	100krad	5V
SN568	100krad	5V
SN234	200krad	5V
SN268	200krad	5V
SN624	300krad	5V
SN630	300krad	5V
SN633	300krad	5V
SN634	300krad	5V
SN275	300krad	5.5V Applied
SN281	300krad	5.5V Applied

Fig. 3. LX7730 TID Testing summary

The greyed-out rows for SN624, SN630, SN633, SN634 highlight were the tests was not successful, parts being non-functional post radiation. All other test in light green show where it was successful.

<u>100k TID Test Summary</u>

The 100krad TID test shows very good results on all key blocks of the design, the performance of the device being comparable to the pre-radiation performance, see summary Table 1. In particular, the results show very stable reading on supply current consumptions, under-voltage detection thresholds, as well as internally regulated voltages. Also negligible added leakage on channel MUX inputs was observed which remain well within the specification of 200nA on all channel inputs over the full voltage range. The instrumental amplifier gain remain stable for all gain settings, and so does the ADC performance. As for noted discrepancies, some delay increase in Analog Mux settling time was observed, post-radiation results of 4us still remaining within the 10us specification. Results also exhibit a decrease in programmable current source full-scale by about 3% from pre-radiation values, as well as some offsets shift of the instrumental amplifier. These variations can be mitigated at the system level by using a reference channel for calibration on one of the channels.

Thus, we conclude that the performance of the LX7730 is TID tolerant up to 100krad(S_iO_2).

<u>200k TID Test Summary</u>

Similarly to 100k exposure, results show very stable supply current consumptions, UVLOs, regulated voltages, AMUX leakage currents, stable IA gain for all settings, essentially no

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added leakage on analog mux pins and stable ADC performance. Also similarly to the 100k exposure, results exhibit some offsets shift of the instrumental amplifier, to be mitigated at the system level by using a reference channel for calibration. For a 200krad mission, the programmable current sources function for channel conditioning no longer operates adequately and should not be used by the user. Input conditioning can be applied externally if required, also for two edge corners of the voltage supplies and common mode specifications, the instrumental amplifier was no longer functional, these are VCC=11.4V for a gain of 10 and -5V common mode for a gain of 2. For reference the IA is specified for a CM of +/-5V for supply voltage of 11.4-16. As for additional noted discrepancies, some further delay increase in Analog Mux settling time was observed at 200k, post-radiation results of 6u still remaining within the 10us specification.

In conclusion with the exception of loss of condition current function to be applied externally if required, the LX7730 performance after 200krad(S_iO_2) exposure is consistent with pre-radiation results, see summary results on Table II.

250k and 300k TID Test Summary

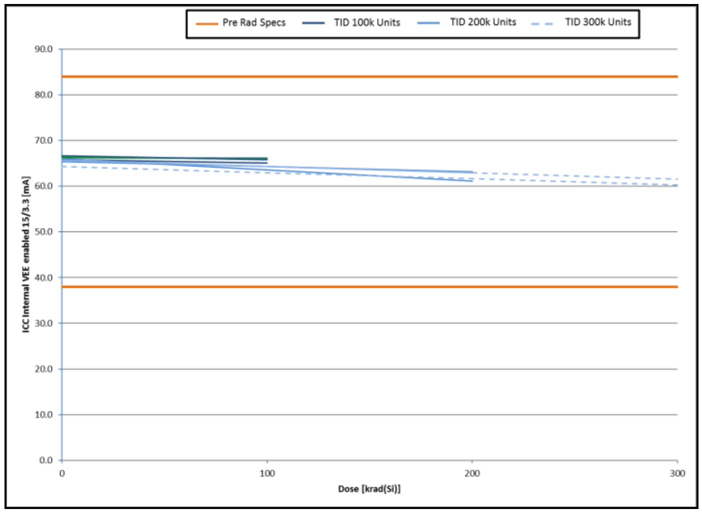
To further evaluate the LX7730's radiation tolerance, a 300krad TID test was performed. Initial post radiation test results show that the Analog Mux functionality stopped at room temperature after 250krad TID exposure. However, overdriving the 5V pin to 5.5V restore the functionality. Therefore, a 300krad TID test with 5.5V forced at 5V pin was ordered. The LX7730 performance after 300krad(Si) exposure is overall stable and comparable to pre-radiation if the +5V regulator is powered at 5.5V except for the programmable current source block which remained not functional, which is similar to the 200k exposure findings. Additionally to the 200k findings, the Instrumental Amplifier under the gain of 10 setting no longer functions. However the telemetry path accuracy is maintained with gain=2 and 0.4, by using proper calibration similarly to the 200k exposure. Further increase in delay mux is observed pushing the post-exposure reading out of the 10us specification, observed values are in the order of 20us. Telemetry acquisition being slow, this is not anticipated to be an issue at system level.

All other functions and parameters are observed as being very stable just like the 100k and 200k results such as supply current readings, voltage detection threshold, voltage regulation values, analog mux leakage values and ADC performance. In summary, the LX7730 performance after 300krad(S_iO_2) exposure is consistent with the 200krad(S_iO_2) performance - see summary results on Table III - with the limitations below: +5V regulator to be forced to 5.5V and Instrumental amplifier gain setting limited to gain of 0.4 and gain of 2.

IV. EXTENDED TID TESTING RESULTS: 100K, 200K AND 300K (S_iO_2) TID RESULTS

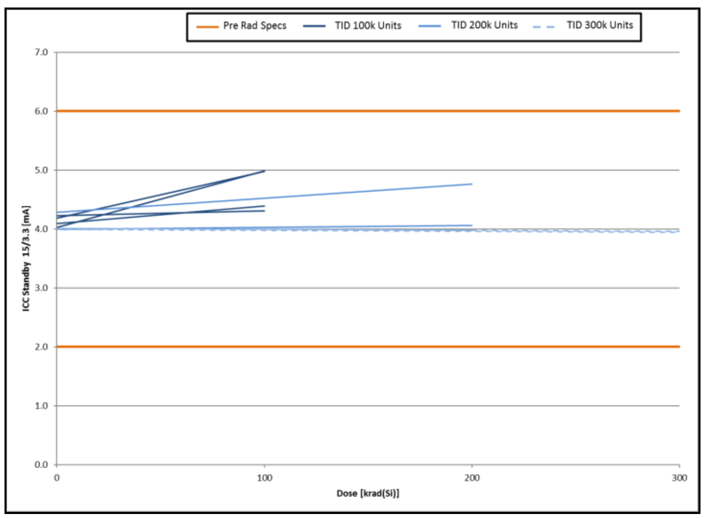
The key parameters are shown here below in graphs. On the X axis, is the exposure dose, pre-rad, 100k, 200k and 300krad, the Y axis is the actual reading for the measured parameters. The dark blue lines show the performance of the parts tested from 100k TID exposure, the light blue ones show the performance of the parts test for 200k TID exposure and the light blue dotted line are for the 300k parts. The red lines show the specification parameters as listed in the datasheet.

Current Consumption:



The current consumption is very stable at all doses up to 300k.

Standby Current:



The standby current is very stable at all doses up to 300k.

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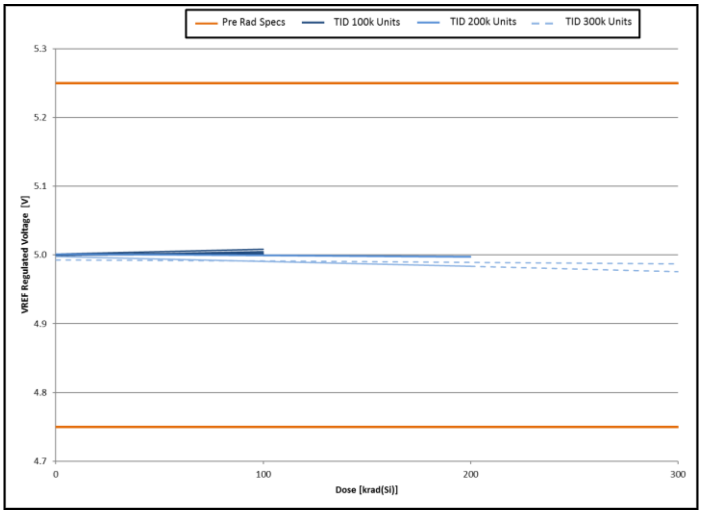
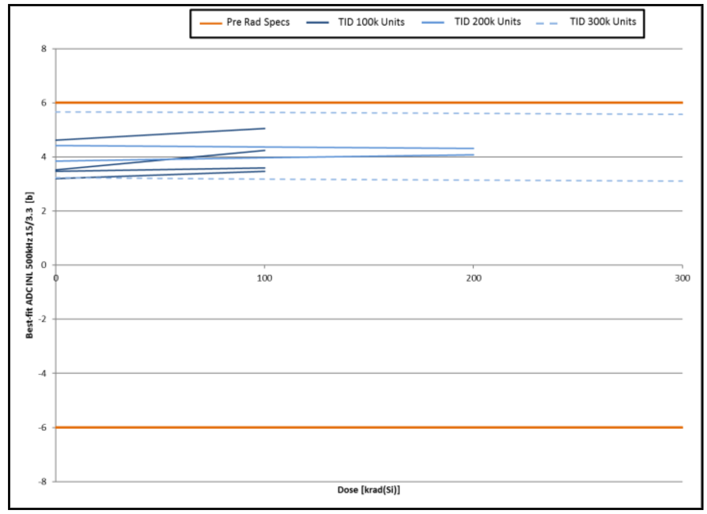
Regulator:



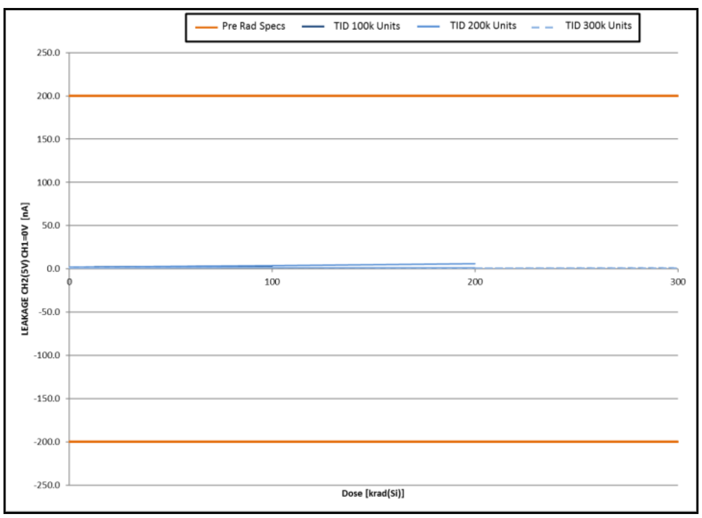
The internally regulated voltages are very stable at all doses up to 300k.

ADC INL:



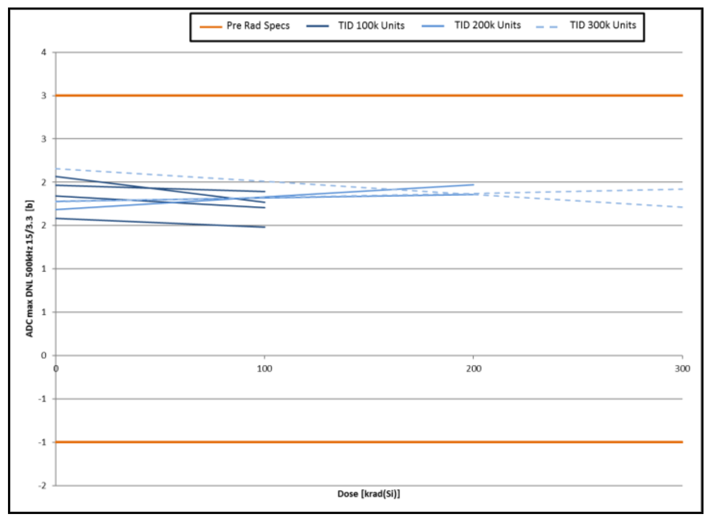
The ADC INL is very stable at all doses up to 300k

High-Voltage Analog Mux Leakage:



The high voltage Analog inputs leakage are very stable at all doses up to 300k.

ADC DNL:



The ADC DNL is very stable at all doses up to 300k.

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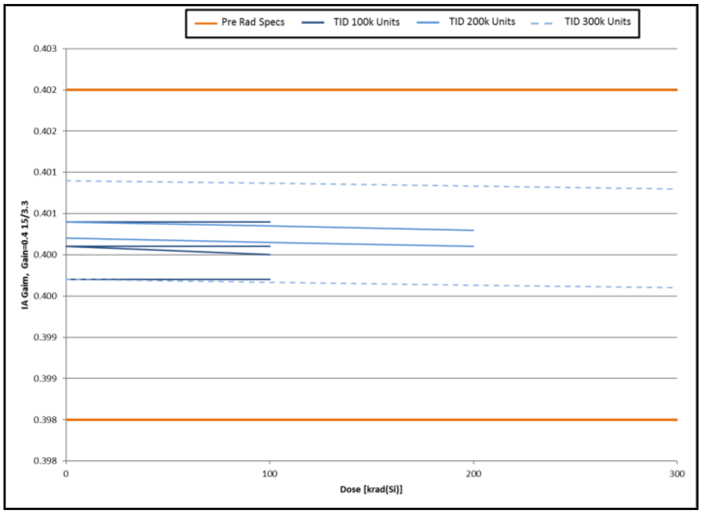
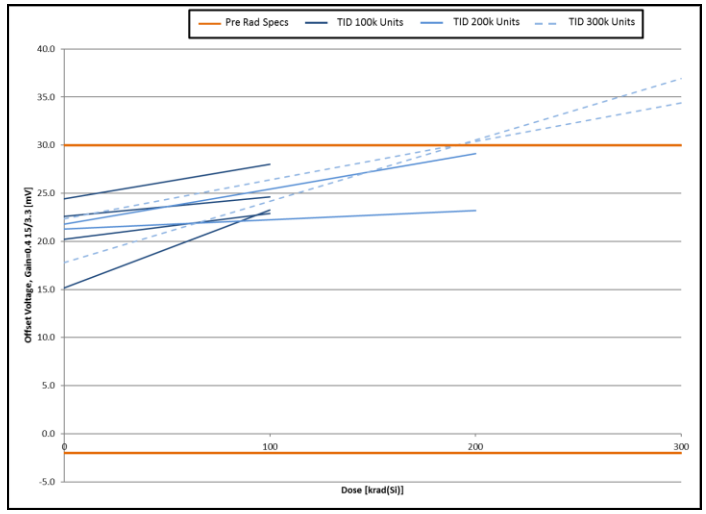
Instrumental Amplifier gain setting of 0.4:

IA Gain 0.4



The IA gain when set for a gain of 0.4 is very stable at all doses up to 300k.

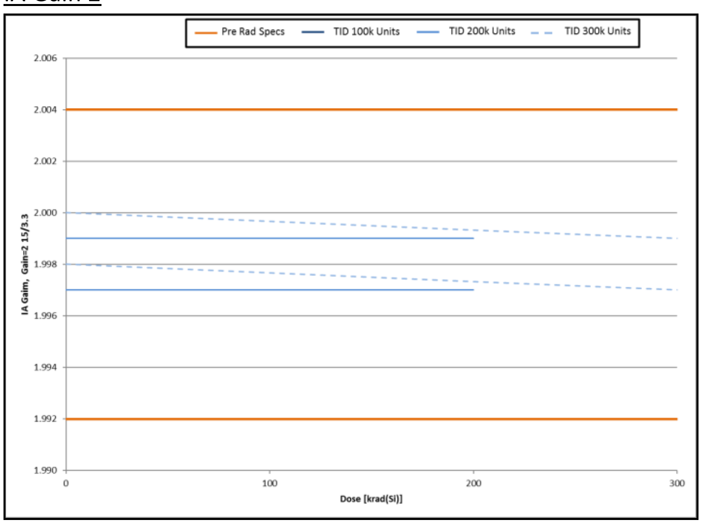
IA Offset 0.4



Some offset drifts is observed on the IA with gain of 0.4, within specification at 200k, usable at 300k, these inaccuracies to be calibrated out at system level.

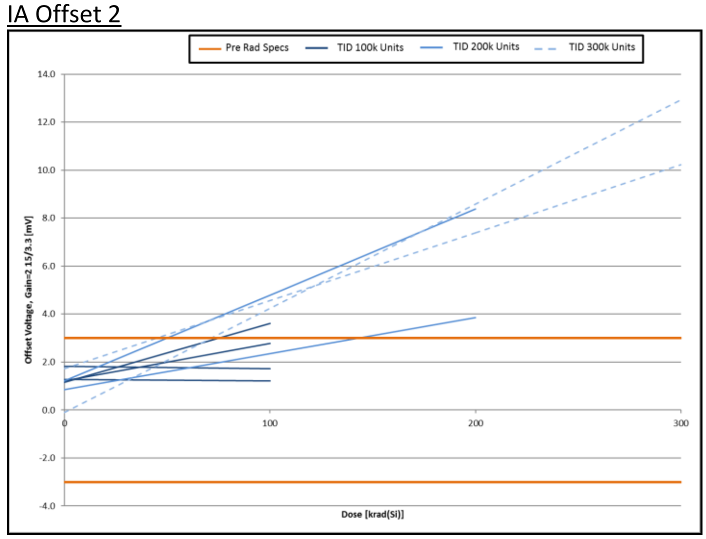
Instrumental Amplifier gain setting of 2:

IA Gain 2



The IA gain when set for a gain of 2 is very stable at all doses up to 300k.

IA Offset 2



Some drifts is observed on IA offset when set for a gain of 2, pushing this parameter outside of pre-radiation specification after exposure, these inaccuracies to be calibrated out at system level.

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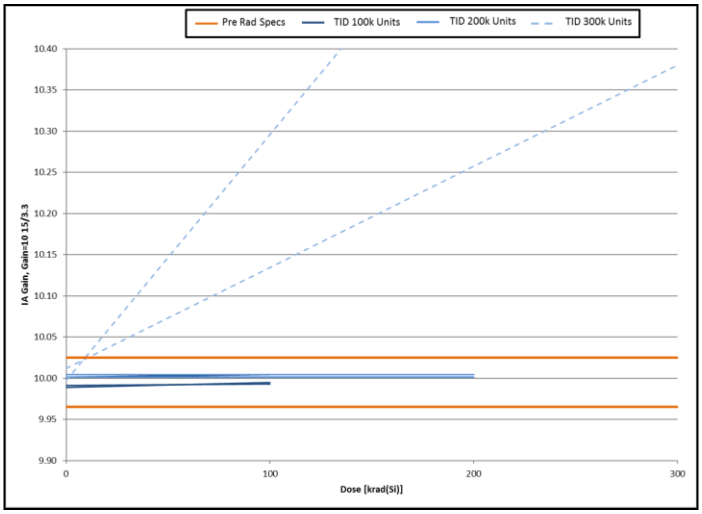
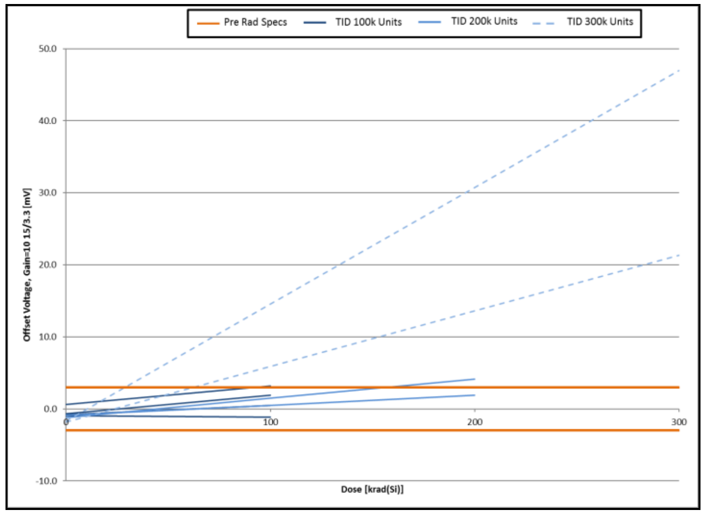
Instrumental Amplifier gain setting of 10:

IA Gain 10



The IA gain when set for a gain of 10 is very stable at all doses up to 200k, no longer usable at 300k.

IA Offset 10



Some drifts is observed on IA offset when set for a gain of 10, pushing this parameter slightly outside of pre-radiation specification after 200k exposure, no longer usable at 300k under this setting.

V. CONCLUSION

Extended Total Dose testing at 100krad, 200krad and 300krad(S_iO_2) have been performed. The results exhibit the hardening goals for the device which is rated 100krad(S_iO_2):
The performance at 100krad(S_iO_2) total dose of the different blocks of this highly integrated device is consistent with the pre-radiation results.
The LX7730 is functional even after 300krad(S_iO_2) TID exposure under proper biased conditions with some restrictions to be mitigated at system level.

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Table. I. LX7730 TID Summary 100k

	Pre-Radiation Specification				SN 565		SN 566		
Parameters	**Min**	**Typ**	**Max**	**Units**	**Pre**	**Post 100k**	**Pre**	**Post 100k**	**Comment**
Operating Current									
VCC Normal Current	38	73	84	mA	67.926	65.915	67.369	65.094	Slight decrease
VCC Standby Current	2.0	4.0	7.0	mA	4.465	4.352	4.447	4.447	Slight increase
VEE Current	-6.0	-5.0	-2.5	mA	-5.308	-4.588	-5.039	-4.347	Slight decrease
Under Voltage Detection									
VCC UVLO	9.5	10	10.5	V	9.945	9.985	9.94	9.925	Very stable
VEE UVLO	-7.5	-8.00	-8.20	V	-8.05	-8.105	-8.07	-8.13	Very stable
+5V UVLO	3.9	4.15	4.40	V	4.125	4.125	4.115	4.105	Very stable
+5V UVLO Hyst	0	200	400	mV	0.195	0.200	0.200	0.200	Very stable
Internally Regulated Voltages and Currents									
VCC to VEE voltage drop	1.5	2.5	3.0	V	2.784	2.617	2.722	2.496	Slight decrease
+5V voltage	4.75	5.00	5.25	V	4.988	4.994	5.014	5.02	Very stable
VREF voltage	4.95	5.00	5.05	V	5.002	5.004	5.003	4.995	Very stable
IREF pin voltage	1.568	1.60	1.632	V	1.608	1.608	1.589	1.586	Very stable
Analog MUX									
Voltage Clamp power applied	15	16	17	V	16.013	15.951	16.013	16.013	Very stable
	-23	-17	-15	V	-20.880	-21.048	-20.888	-21.050	Very stable
Voltage Clamp (VCC=VEE=0)	15	20	23	V	20.829	20.846	20.671	20.856	Very stable
	-23	-20	-15	V	-20.788	-20.944	-20.792	-20.965	Very stable
Settling Time			10	us	2.68	4.03	3.03	4.32	50% increase
Leakage Current	-200	0	200	nA	0.614	1.85	-1.40	3.21	Very stable
Instrumentation Amplifier									
Offset Voltage, Gain = 0.4	-2		25	mV	15.95	21.41	6.91	9.53	Up to 6mV increase
Offset Voltage, Gain = 2	-3		3	mV	0.55	1.04	-0.38	-0.79	Up to 3mV change
Offset Voltage, Gain = 10	-3		3	mV	-1.08	-1.20	-0.73	-1.78	Up to 3.5mV change
Gain Accuracy, Gain = 0.4	0.398	0.400	0.402	-	0.4000	0.3999	0.3997	0.3997	Very stable
Gain Accuracy, Gain = 2	1.992	2.000	2.004	-	1.997	1.997	1.997	1.997	Very stable
Gain Accuracy, Gain = 10	9.965	9.995	10.025	-	9.991	9.991	9.987	9.988	Very stable
Analog-to-Digital Converter (input at ADC_IN)									
Linear Range	0		2.0	V	Pass	Pass	Pass	Pass	
Full scale error	-2.5	0	2.5	%	-0.38	-0.29	-0.54	-0.42	Very stable
Offset Error	-10		10	mV	-3.99	-3.81	-6.36	-5.08	Very stable
Integral nonlinearity	-6		6	LSB	4.366	3.724	4.618	3.252	Very stable
Differential nonlinearity	-1		3	LSB	2.104	1.789	2.007	1.890	Very stable

Table. II. LX7730 TID Summary 200k

	Pre-Radiation Specification				SN 234		SN 268		
Parameters	**Min**	**Typ**	**Max**	**Units**	**Pre**	**Post 200k**	**Pre**	**Post 200k**	**Comment**
Operating Current									
VCC Normal Current	38	73	84	mA	65.972	61.072	65.387	63.177	Slight decrease
VCC Standby Current	2.0	4.0	7.0	mA	3.993	4.060	4.286	4.760	Stable
VEE Current	-6.0	-5.0	-2.5	mA	-5.024	-3.556	-4.611	-3.110	Slight decrease
Under Voltage Detection									
VCC UVLO	9.5	10	10.5	V	9.960	9.970	9.955	9.960	Very stable
VEE UVLO	-7.5	-8.00	-8.20	V	-8.000	-8.040	-8.015	-8.060	Very stable
+5V UVLO	3.9	4.15	4.40	V	4.150	4.150	4.155	4.160	Very stable
+5V UVLO Hyst	0	200	400	mV	200	195	205	205	Very stable
Internally Regulated Voltages and Currents									
VCC to VEE voltage drop	1.5	2.5	3.0	V	2.192	2.143	2.133	2.033	Slight decrease
+5V voltage	4.75	5.00	5.25	V	5.007	4.994	4.997	4.996	Very stable
VREF voltage	4.95	5.00	5.05	V	5.001	4.998	5.001	4.997	Very stable
IREF pin voltage	1.568	1.60	1.632	V	1.606	1.605	1.590	1.588	Very stable
Analog MUX									
Voltage Clamp power applied	15	16	17	V	16.008	16.034	16.002	16.026	Very stable
	-23	-17	-15	V	-20.735	-20.839	-20.797	-20.918	Very stable
Voltage Clamp (VCC=VEE=0)	15	20	23	V	20.681	20.647	20.530	20.647	Very stable
	-23	-20	-15	V	-20.624	-20.750	-20.701	-20.814	Very stable
Settling Time			10	Us	2.230	5.880	2.420	6.510	2.5x increase
Leakage Current	-200	0	200	nA	-1.775	1.265	-2.077	5.882	Very stable
Instrumentation Amplifier									
Offset Voltage, Gain = 0.4	-2		25	mV	21.771	29.126	21.300	23.201	Up to 8mV increase
Offset Voltage, Gain = 2	-3		3	mV	1.207	8.381	0.858	3.851	Up to 7mV change
Offset Voltage, Gain = 10	-3		3	mV	-1.179	4.162	-0.907	1.900	Up to 5mV change
Gain Accuracy, Gain = 0.4	0.398	0.400	0.402	-	0.4002	0.4001	0.4004	0.4003	Very stable
Gain Accuracy, Gain = 2	1.992	2.000	2.004	-	1.997	1.996	1.999	1.998	Very stable
Gain Accuracy, Gain = 10	9.965	9.995	10.025	-	10.001	10.011	10.004	10.017	Very stable
Analog-to-Digital Converter (input at ADC_IN)									
Linear Range	0		2.0	V	Pass	Pass	Pass	Pass	
Full scale error	-2.5	0	2.5	%	-0.167	-0.020	-0.282	-0.093	Very stable
Offset Error	-10		10	mV	-1.075	1.011	-3.593	-1.142	Very stable
Integral nonlinearity	-6		6	LSB	3.841	4.085	4.419	4.315	Very stable
Differential nonlinearity	-1		3	LSB	1.686	1.972	1.778	1.856	Very stable

Table. III. LX7730 TID Summary 300k

	Pre-Radiation Specification				SN 275		SN 281		
Parameters	**Min**	**Typ**	**Max**	**Units**	**Pre**	**Post 300k**	**Pre**	**Post 300k**	**Comment**
Operating Current									
VCC Normal Current	38	73	84	mA	35.686	31.532	34.336	30.276	Slight decrease
VCC Standby Current	2.0	4.0	7.0	mA	1.010	0.963	0.991	0.944	Stable
VEE Current	-6.0	-5.0	-2.5	mA	-5.242	-3.688	-4.776	-3.247	Slight decrease
Under Voltage Detection									
VCC UVLO	9.5	10	10.5	V	9.94	9.905	9.965	9.97	Very stable
VEE UVLO	-7.5	-8.00	-8.20	V	-8.02	-8.115	-8.03	-8.075	Very stable
+5V UVLO	3.9	4.15	4.40	V	4.165	4.15	4.16	4.165	Very stable
+5V UVLO Hyst	0	200	400	mV	205	195	200	200	Very stable
Internally Regulated Voltages and Currents									
VCC to VEE voltage drop	1.5	2.5	3.0	V	2.666	2.397	2.62	2.31	Slight decrease
+5V voltage	4.75	5.00	5.25	V	Forced to 5.5V				
VREF voltage	4.95	5.00	5.05	V	4.998	4.976	4.993	4.987	Slight decrease
IREF pin voltage	1.568	1.60	1.632	V	1.596	1.589	1.6	1.598	Very stable
Analog MUX									
Voltage Clamp power applied	15	16	17	V	16.015	16.049	16.019	16.058	Very stable
	-23	-17	-15	V	-20.63	-20.748	-20.641	-20.769	Very stable
Voltage Clamp (VCC=VEE=0)	15	20	23	V	20.451	20.6	20.596	20.756	Very stable
	-23	-20	-15	V	-20.523	-20.649	-20.571	-20.694	Very stable
Settling Time			10	us	1.83	21.56	2.1	26.3	10x increase
Leakage Current	-200	0	200	nA	1.397	1.52	1.369	1.057	Very stable
Instrumentation Amplifier									
Offset Voltage, Gain = 0.4	-2		25	mV	22.363	34.374	17.804	36.939	Up to 20mV increase
Offset Voltage, Gain = 2	-3		3	mV	1.719	10.227	-0.109	12.937	Up to 13mV change
Offset Voltage, Gain = 10	-3		3	mV	-1.794	21.353	-1.684	46.96	Up to 50mV change
Gain Accuracy, Gain = 0.4	0.398	0.400	0.402	-	0.3997	0.3996	0.4009	0.4008	Very stable
Gain Accuracy, Gain = 2	1.992	2.000	2.004	-	1.998	1.997	2	1.999	Very stable
Gain Accuracy, Gain = 10	9.965	9.995	10.025	-	9.997	10.893	10.012	10.38	Up to 8% increase
Analog-to-Digital Converter (input at ADC_IN)									
Linear Range	0		2.0	V	Pass	Pass	Pass	Pass	
Full scale error	-2.5	0	2.5	%	-0.31	-0.49	-0.02	-0.06	Very stable
Offset Error	-10		10	mV	-3.09	-3.48	2.31	0.00	Very stable
Integral nonlinearity	-6		6	LSB	3.227	3.11	5.672	5.574	Very stable
Differential nonlinearity	-1		3	LSB	2.159	1.712	1.777	1.919	Very stable

VI. References

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