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

Mathieu Sureau, Member IEEE, Russell Stevens, Member IEEE, Marco Leuenberger, Member IEEE, Nadia Rezzak, Member IEEE, Dorian Johnson, Kathy Zhang Member IEEE

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

I. INTRODUCTION

As technology is enabling humans to send more and more spacecrafts into deep space and explore new territory, 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 -55°C to 125°C, is classified under EAR 9a515.e.

The LX7730 shows its solid radiation response, TID tolerance rated greater than 100 krad (SIO2); ELDRS tolerance greater than 50 krad (SIO2), 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 300 krad (SIO2). 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](image)

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-
A 10-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 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.

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.

<table>
<thead>
<tr>
<th>Serial #</th>
<th>Tested TID dosage</th>
<th>+5V Pin Voltage</th>
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<tr>
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</tr>
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</tr>
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</tr>
<tr>
<td>SN634</td>
<td>300krad</td>
<td>5V</td>
</tr>
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<td>SN275</td>
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<td>SN281</td>
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<td>5.5V Applied</td>
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</table>

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.

100k TID Test Summary

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(SO₂).

200k TID Test Summary

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
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 6µs 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 200k rad(SiO2) 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 300k rad TID test was performed. Initial post-radiation test results show that the Analog Mux functionality stopped at room temperature after 250k rad TID exposure. However, overdriving the 5V pin to 5.5V restore the functionality. Therefore, a 300k rad TID test with 5.5V forced at 5V pin was ordered. The LX7730 performance after 300k rad(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 300k rad(SiO2) exposure is consistent with the 200k rad(SiO2) 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 (SiO2) TID RESULTS

The key parameters are shown here below in graphs. On the X axis, is the exposure dose, pre-rad, 100k, 200k and 300k rad, 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:

![Current Consumption Graph]

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

Standby Current:

![Standby Current Graph]

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

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

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

The ADC DNL is very stable at all doses up to 300k.
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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In this document, the Instrumental Amplifier gain setting of 10 is discussed. The IA gain when set for a gain of 10 is very stable at all doses up to 200k, no longer usable at 300k.

V. CONCLUSION

Extended Total Dose testing at 100krad, 200krad and 300krad(SiO2) have been performed. The results exhibit the hardening goals for the device which is rated 100krad(SiO2): The performance at 100krad(SiO2) 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(SiO2) TID exposure under proper biased conditions with some restrictions to be mitigated at system level.

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.
Table I. LX7730 TID Summary 100k

<table>
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<th>Parameters</th>
<th>Pre-Radiation Specification</th>
<th>SN 565</th>
<th>SN 566</th>
<th>Pre</th>
<th>Post 100k</th>
<th>Pre</th>
<th>Post 100k</th>
<th>Comment</th>
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<td><strong>Operating Current</strong></td>
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<td>73</td>
<td>84</td>
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<td>VCC UVLO</td>
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<td>10</td>
<td>10.5</td>
<td>V</td>
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<td>Analog MUX</td>
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Table II. LX7730 TID Summary 200k
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VI. REFERENCES