Single Event Transient Test Report

LM4040QAIM3-2.5/NOPB

Date Code: 1907M
2.5V Bandgap Voltage Reference
Texas Instruments

Prepared by	**Florian Krimmel**
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APPROVAL

Title Single Event Transient Test Report LM4040QAIM3-2.5/NOPB	
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CHANGE LOG

Reason for change	Issue Nr.	Revision Number	Date

CHANGE RECORD

Issue Number 0	**Revision Number 0**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

DISTRIBUTION

Name/Organisational Unit

Table of contents:

1 APPLICABLE/REFERENCE DOCUMENTS

1. ESCC25100 section 6: Single Event Effects Test Methods and Guidelines
2. Datasheet of LM4040-N/-Q:
   https://www.ti.com/lit/ds/symlink/lm4040-n-q1.pdf?ts=1646072144644

2 TEST OBJECTIVES AND REQUIREMENTS TO BE VERIFIED

2.1 Test Objectives

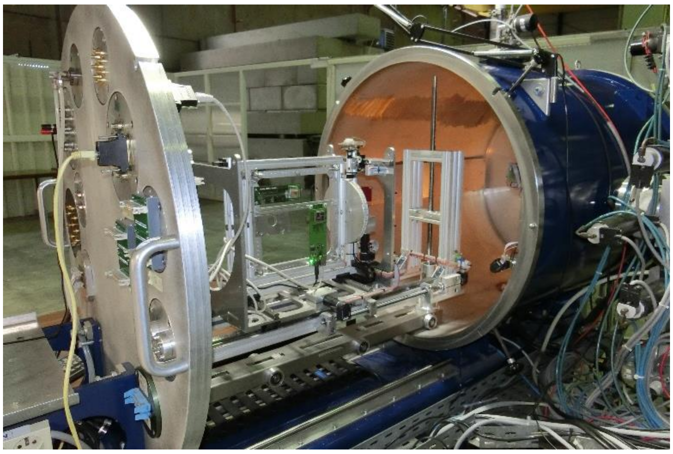
Test objective is to assess the heavy-ion SET sensitivity of this part.
This test report will be uploaded in the ESA Radiation Database (https://esarad.esa.int) and this data should also contribute to the development of safe design margins for COTS components.

The test campaign was performed on the 10th November at UCL.

2.2 Test facility

UCL Louvain Heavy Ion Facility

https://uclouvain.be/en/research-institutes/irmp/crc/heavy-ion-facility-hif.html



-Irradiation area: Ø25 mm
-Flux from a few ions/(s.cm2) up to 1,5E4 ions/(s.cm2)

Ion	Energy on device	Range on device	LET on device
	[MeV]	[µm]	[MeV/(mg/cm²)]
$^{13}C^{4+}$	131	269,3	1,3
$^{22}Ne^{7+}$	238	202	3,3
$^{27}Al^{8+}$	250	131,2	5,7
$^{36}Ar^{11+}$	353	114,0	9,9
$^{53}Cr^{16+}$	505	105,5	16,1
$^{58}Ni^{18+}$	582	100,5	20,4
$^{84}Kr^{25+}$	769	94,2	32,4
$^{103}Rh^{31+}$	957	87,3	46,1
$^{124}Xe^{35+}$	995	73,1	62,5

The ions used are highlighted.
Fluence was adapted in order to have enough statistical events.
All test were performed without tilting the components.

3 DUT & TEST CONFIGURATION/CONDITIONS

3.1 Description of the DUT

The LM4040-N is a precision micropower curvature-corrected bandgap shunt voltage reference. The LM4040-N has been designed for stable operation without the need of an external capacitor connected between the + pin and the − pin.

For the test, two samples of the same type have been used.

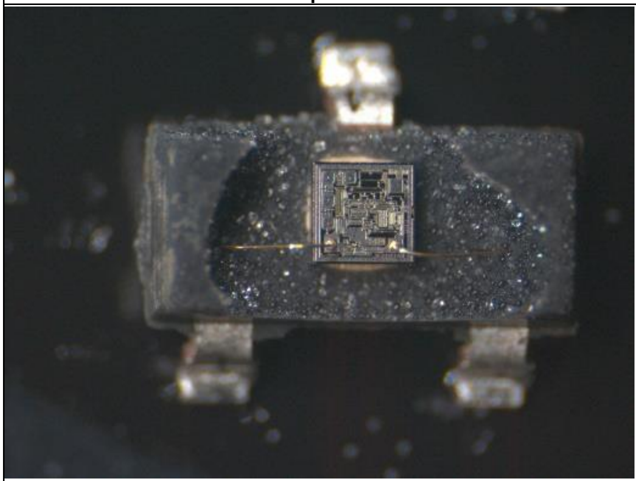
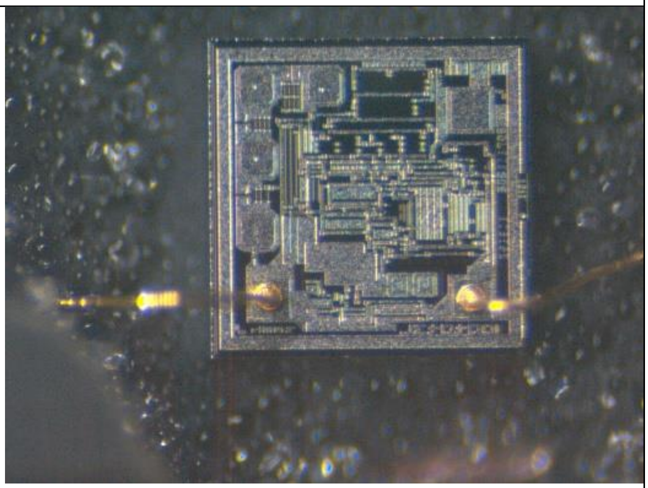
The table below shows the key parameters of the selected DUTs.

Component Family Name	Component Name	Manu-facturer	Automotive, AEC-Q100	Distributor	Component Laser Marking	Date-code YYWW	Lot-code from distributor
LM4040	LM4040QAIM3 -2.5/NOPB	TI	yes	Mouser	.R6A	1907M	9165023EM9

Vz	Initial Tolerance	IZ_min	IZ_typ	IZ_max	Long term stab.	Hysteresis (thermal) -40 to 125 degC	Package
2.5 V	0.1%	60µA	100µA	15mA	120ppm	0.08%	SOT-23-3

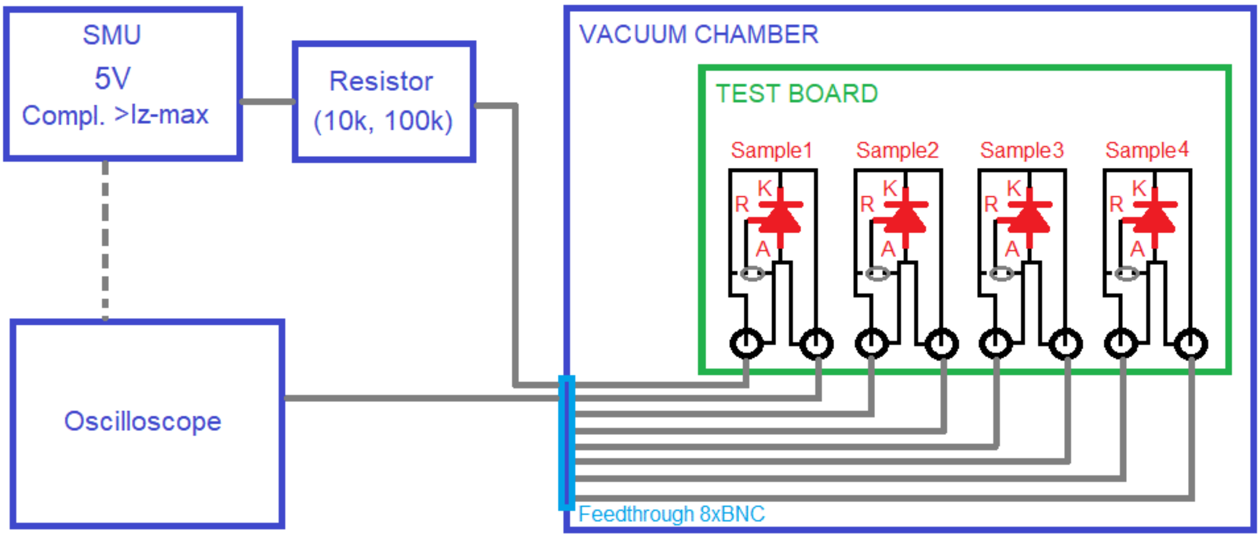
3.2 DUT Preparation

Two sets of the samples have been decapsulated by using Nitric Acid on the top side as shown in the pictures below:

Component	Die
	

3.3 Test set-up description and preparation

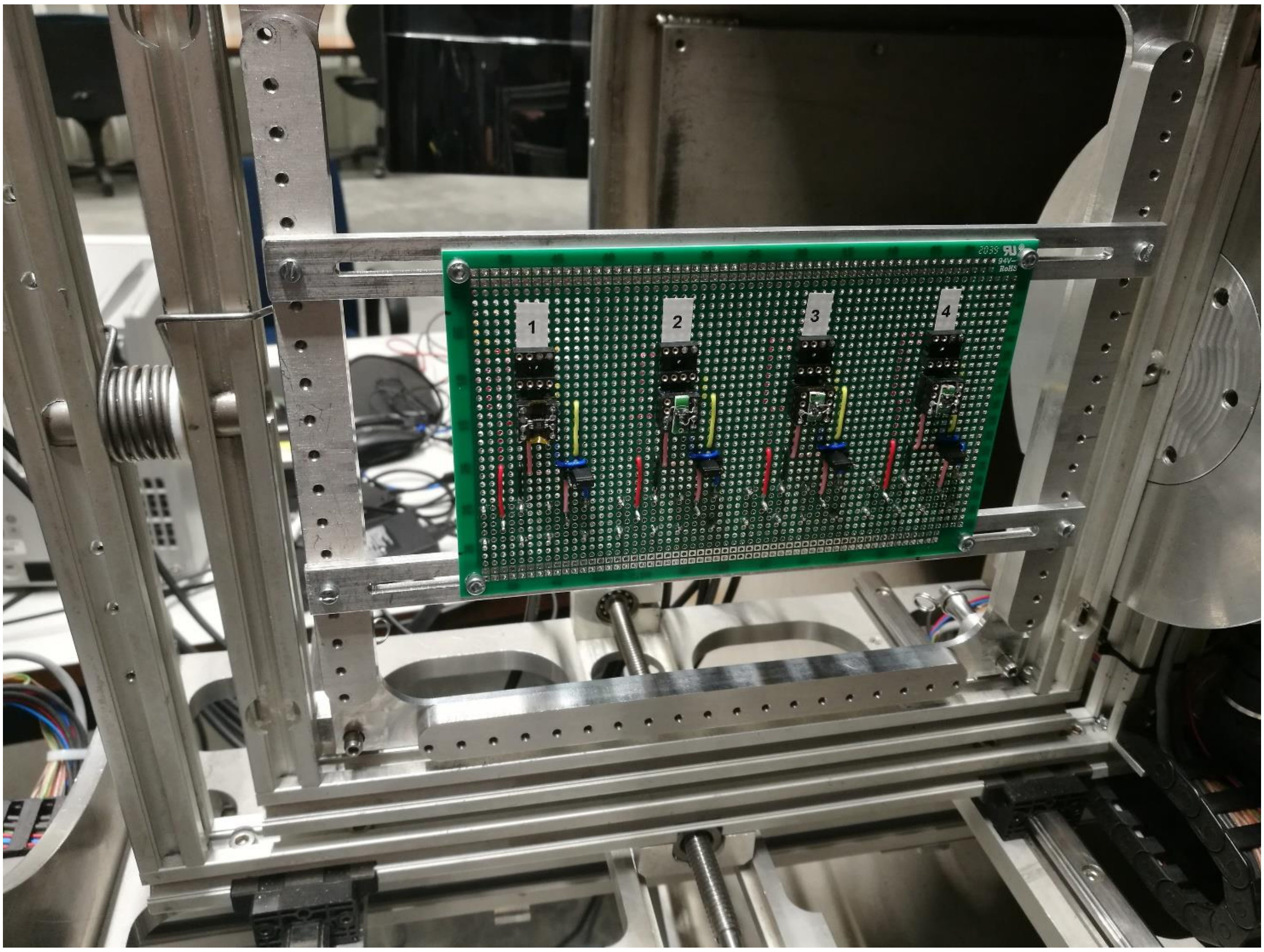
Schematic:



Measurement equipment:

Oscilloscope Agilent Technologies infiniium MSO9404A: 4Ghz	
SMU source measure unit KEITHLEY 2410	

Test Board mounted on the frame inside the vacuum chamber:



3.4 Test Parameters

Voltage Source:

- Provides a constant voltage of 5V
- Resistor adjusted accordingly to reach the min, typ and max Iz current (Value according to run log table)
- No capacitor on the input of the component

Load:

- Output of the references unloaded and without capacitor

Environmental condition:

- All test performed under vacuum
- All test performed at room temperature

Oscilloscope:

- Trigger Mode: Window trigger (min and max)
- Trigger level: as small as possible depending on the background noise (+- 150mV)

4 TEST RESULTS

4.1 Run Log

The Log table below shows runs related to the component LM4040:

PRE-RUN INPUTS

Run	DUT	Input Voltage (V)	Input resistor (Ohm)	Iz (MIN, TYP, MAX)	Title (°)	Vacuum (Y/N)?	Particle	Energy (MeV)	LET Normal in Si (90°) [For P see "SRIM"]	LET Effective (in Si)	Range (um)	Flux target (/cm²/s)	Fluence target (/cm²)	Duration Target (sec)	Beam Homogenity (%)	Scope - Trig_high (V)	Scope - Trig_low (V)	Scope - Hold off time (us)
17	LM4040_S1	5	39000	MIN	0	Yes	Xe	995	62.5	62.5	73.1	2.00E+03	1.00E+09	500000	10	2.65	2.35	10
18	LM4040_S1	5	39000	MIN	0	Yes	Xe	995	62.5	62.5	73.1	2.00E+03	1.00E+09	500000	10	2.65	2.35	130
19	LM4040_S1	5	24000	TYP	0	Yes	Xe	995	62.5	62.5	73.1	2.00E+03	1.00E+09	500000	10	2.65	2.35	130
20	LM4040_S1	5	180	MAX	0	Yes	Xe	995	62.5	62.5	73.1	2.00E+03	1.00E+09	500000	10	2.65	2.35	130
21	LM4040_S1	5	180	MAX	0	Yes	Xe	995	62.5	62.5	73.1	1.00E+03	1.00E+09	1000000	10	2.65	2.35	130
22	LM4040_S1	5	24000	TYP	0	Yes	Kr	769	32.4	32.4	94.2	1.00E+03	1.00E+09	1000000	10	2.65	2.35	130
29	LM4040_S1	5	24000	TYP	0	Yes	Cr	505	16.1	16.1	105.5	5.00E+03	1.00E+09	200000	10	2.65	2.35	130
32	LM4040_S2	5	24000	TYP	0	Yes	Cr	505	16.1	16.1	105.5	5.00E+03	1.00E+09	200000	10	2.65	2.35	130
33	LM4040_S2	5	24000	TYP	0	Yes	Cr	505	16.1	16.1	105.5	5.00E+03	1.00E+09	200000	10	2.65	2.35	130

POST-RUN INPUTS & RESULTS

Run	DUT	Start time	Duration actual (sec)	Fluence actual (/cm²)	Cumulative Fluence (/cm²)	Flux actual (/cm²/s)	Run dose (krad)	Total dose (krad)	Test OK/ NOK	Vout average (V)	Iz measured (mA)	# SET (scope triggers)	SET XS (cm²)	Vmax for this run (V)	Vmin for this run (V)	Observations
17	LM4040_S1	20:30	168	3.74E+05	3.74E+05	2226.19048	3.74E-01	3.74E-01	NOK		0.064					This run was a test run to help improve the scope setting
18	LM4040_S1	20:36	124	2.62E+05	6.36E+05	2112.90323	2.62E-01	6.36E-01	OK	2.40	0.064	321	1.23E-03	2.746	0.416	All good with this run. Scope settings seem good, flux is ok (on the upper side of OK).
19	LM4040_S1	20:42	135	2.84E+05	9.20E+05	2103.7037	2.84E-01	9.20E-01	OK	2.42	0.104	346	1.22E-03	2.855	0.473	All good with this run. Scope settings seem good, flux is ok (on the upper side of OK).
20	LM4040_S1	20:46	96	2.16E+05	1.14E+06	2250	2.16E-01	1.14E+00	OK - b	2.47	13.82	328	1.52E-03	4.383	0.906	All good but perhaps flux a bit high.
21	LM4040_S1	20:49	195	1.92E+05	1.33E+06	984.615385	1.92E-01	1.33E+00	OK	2.47	13.82	317	1.65E-03	4.696	0.841	Flux is halved for this run. XS same as above so above likely good too.
22	LM4040_S1	21:19	257	2.59E+05	1.59E+06	1007.7821	1.34E-01	1.46E+00	OK	2.43	0.104	257	9.92E-04	2.876	0.445	Settings are ok, run good.
29	LM4040_S1	22:30	92	4.46E+05	4.46E+05	4847.82609	1.15E-01	1.58E+00	OK	2.47	0.104	259	5.81E-04	2.842	1.058	We increase flux as for previous run it was not high enough (to gain time). Flux is a bit fast but seems OK (on the high end).
32	LM4040_S2	22:58	14	8.10E+04	8.10E+04	5785.71429	2.09E-02	2.09E-02	NOK		0.105					Time scale of scope is not updated. Discarded.
33	LM4040_S2	23:00	80	4.45E+05	5.26E+05	5562.5	1.15E-01	1.35E-01	OK	2.46	0.105	249	5.60E-04	2.871	0.816	Settings are ok, run good.

The component has been tested with three different ions (Xe, Kr, Cr). Under Xe, three tests runs at different Iz currents have been done in order to spot the worst case conditions.

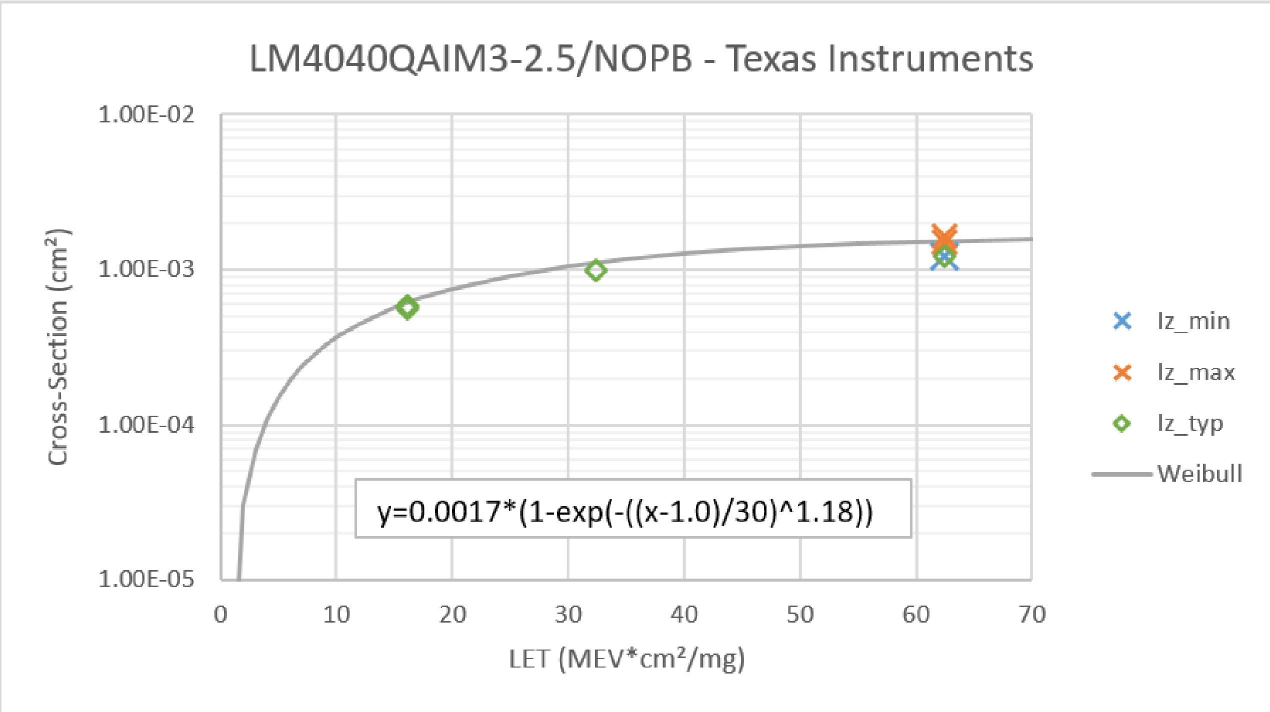
Only the typical Iz values was used to test under Kr and Cr.

The last run was done with nominal Iz condition but on a second to verify any possible part-to-part variations.

The two samples received a total cumulative TID of 1.58 krad and 0.14 krad.

4.2 Cross Section

The cross section of all runs was calculated and is shown in the plot for different LETs.



Weibull parameters	
W	30
S	1.18
Limit	0.0017
LET threshold	1.0

All different tested Iz condition show a similar behaviour in the same order of magnitude.

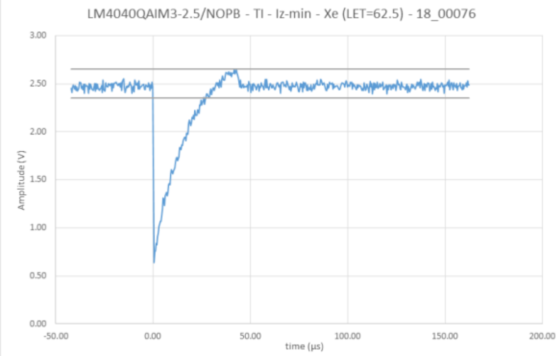
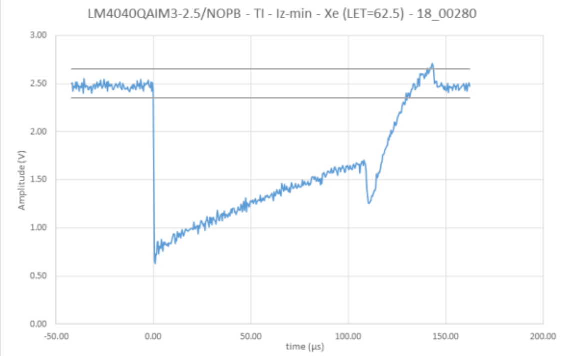
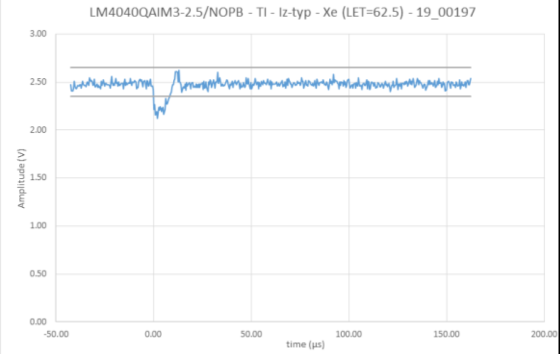
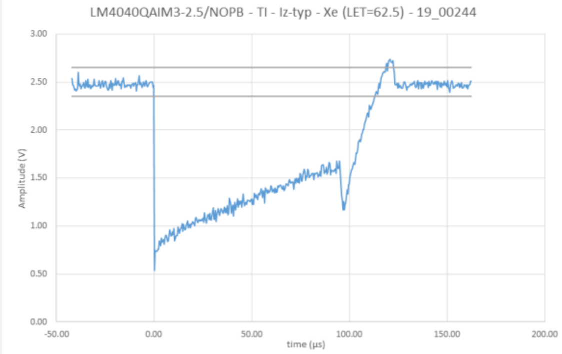
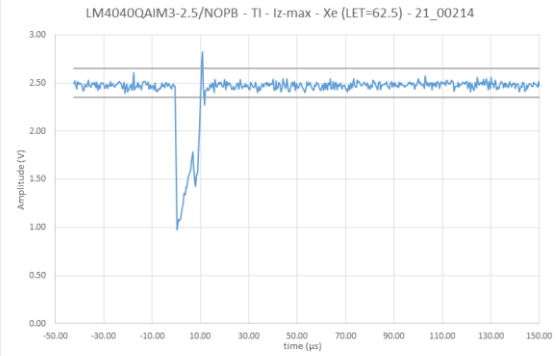
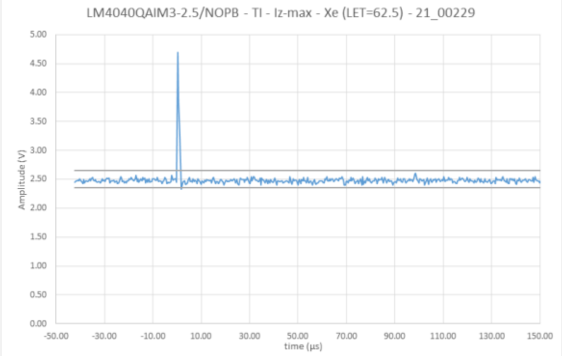
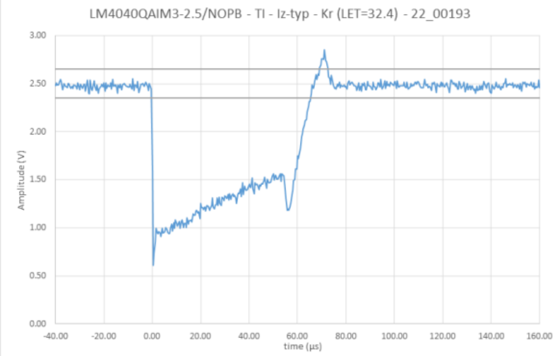
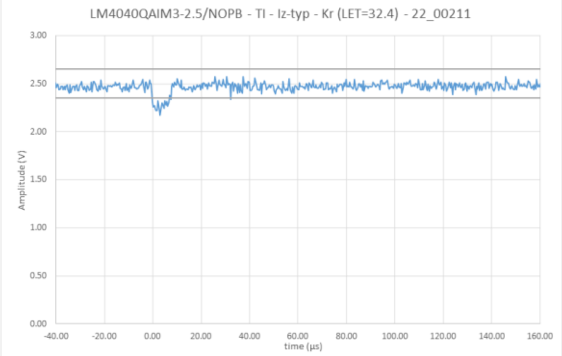
The part to part variation at a LET of 16.1 MeV*cm²/mg appears very low.

Due to the fact that around 300 events were measured, the very small error bars were not displayed.

The LET threshold is estimated only with 3 points interpolation with high inaccuracy. For a more accurate Weibull curve, more measurement points are required, including some close to the LET threshold

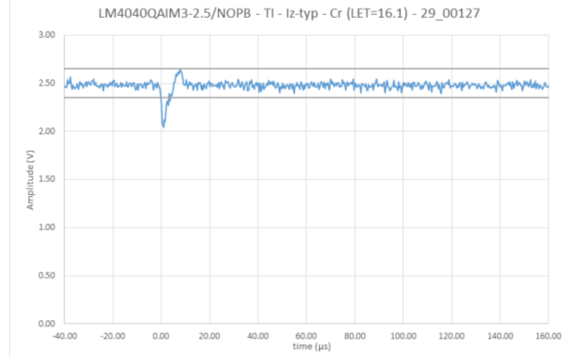
4.3 Transients

The following table shows examples of typical and worst case transients observed on the DUT. The trigger levels are shown by the grey lines.

Run No.	Transients	
18 Iz-min LET= 62.5		
19 Iz-typ LET= 62.5		
21 Iz-max LET= 62.5		
22 Iz-typ LET= 32.4		

<table>
<tr>
<td>29

Iz-typ

LET=
16.1</td>
<td>
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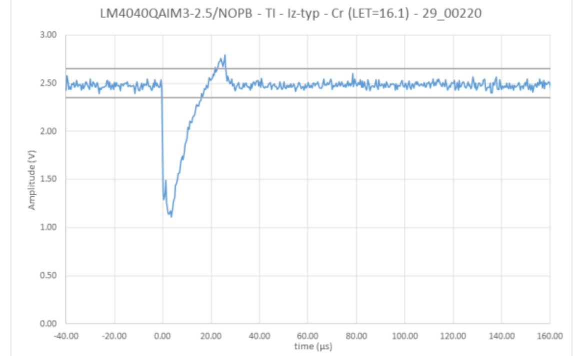
<td>
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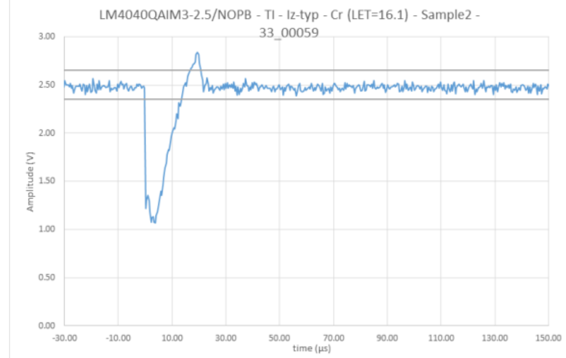
</tr>
<tr>
<td>33

Iz-typ

LET=
16.1

Sample 2</td>
<td>
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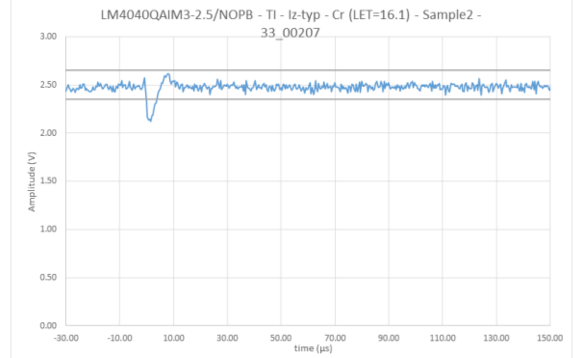
<td>
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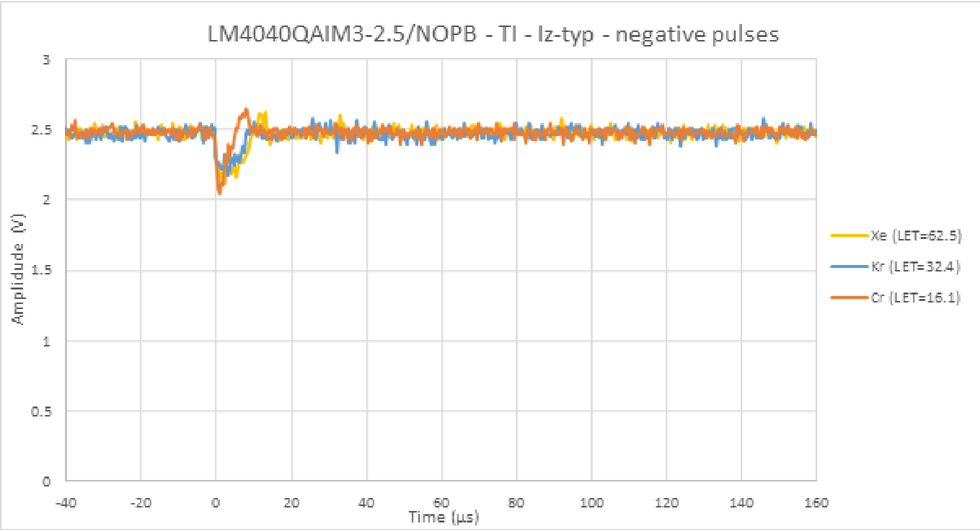
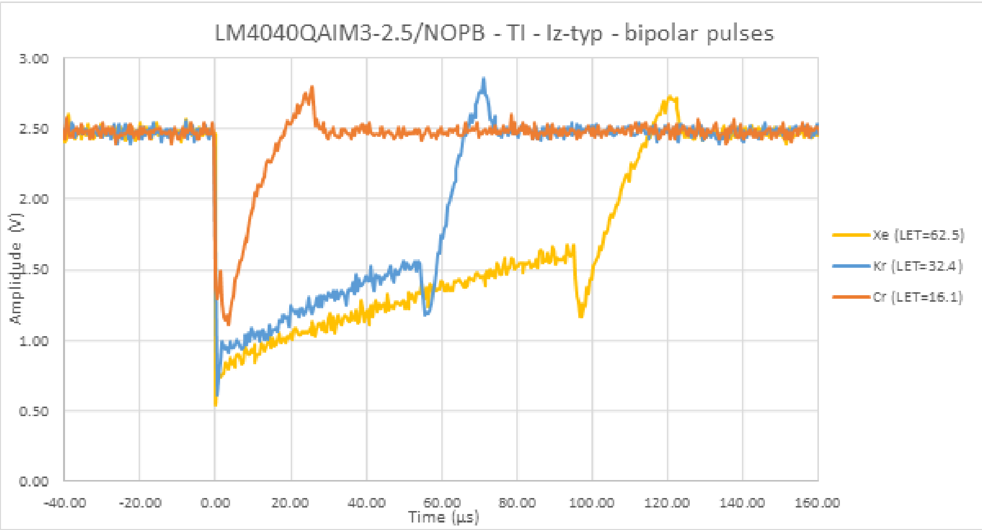
</table>

4.4 Transients Compared

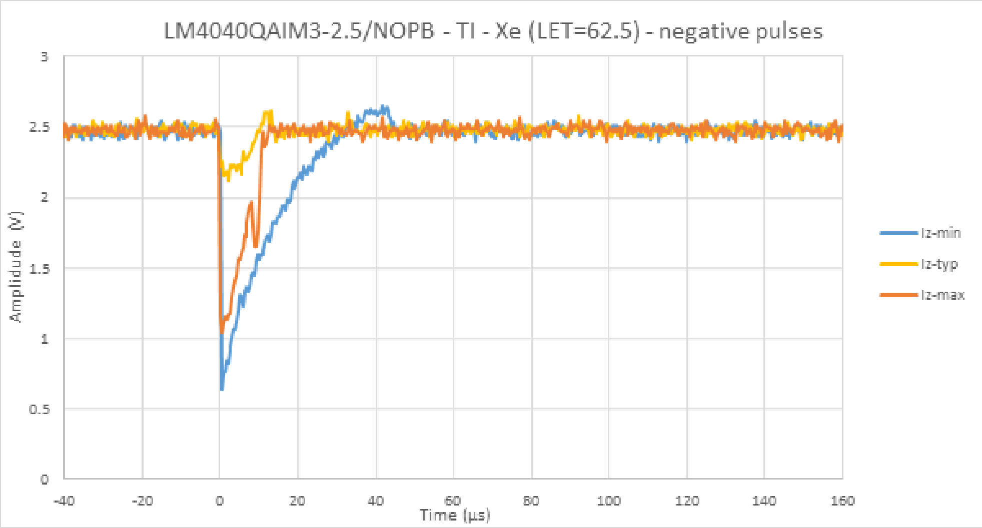
The following plots show the different shape of the worst case transients for both negative and bipolar pulses regarding the LET and different Iz values.

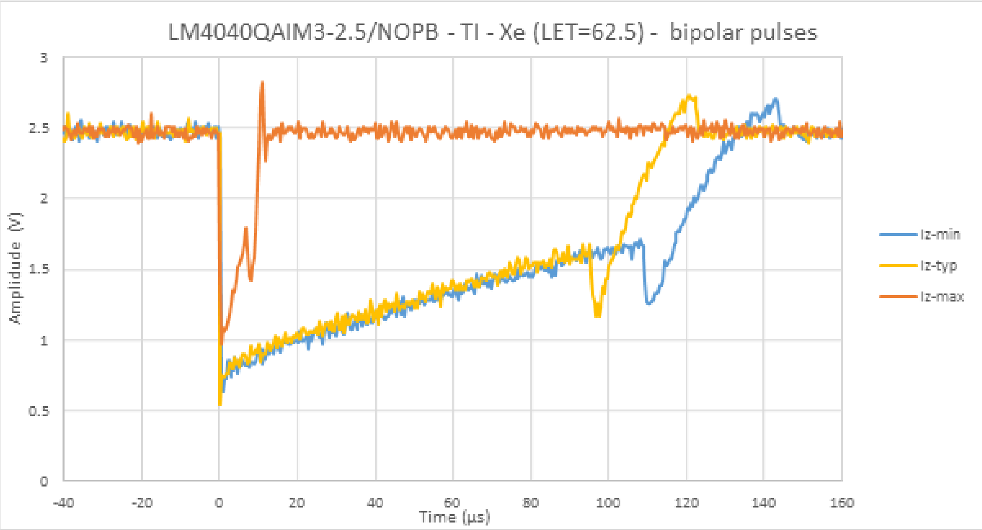
Negative pulses are those that have only exceeded the lower trigger level and the same for the positive pulses with the higher trigger level. Bipolar pulses are those events, which exceeded both the higher and the lower trigger level.





The worst case negative transients seem to be a bit depended of the LET in terms of their pulse width rater then there amplitude.
The bipolar pulses show the same behaviour with even more dependency of the LET.

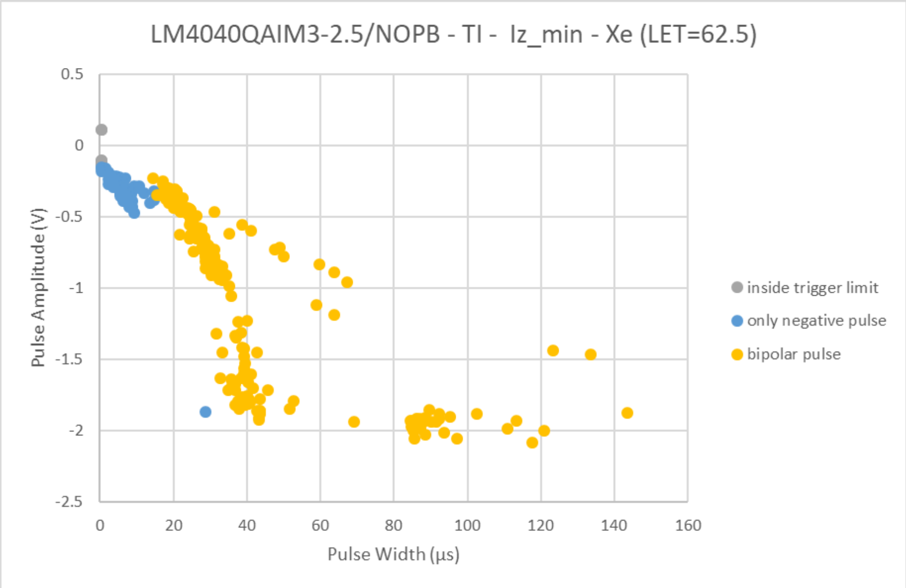


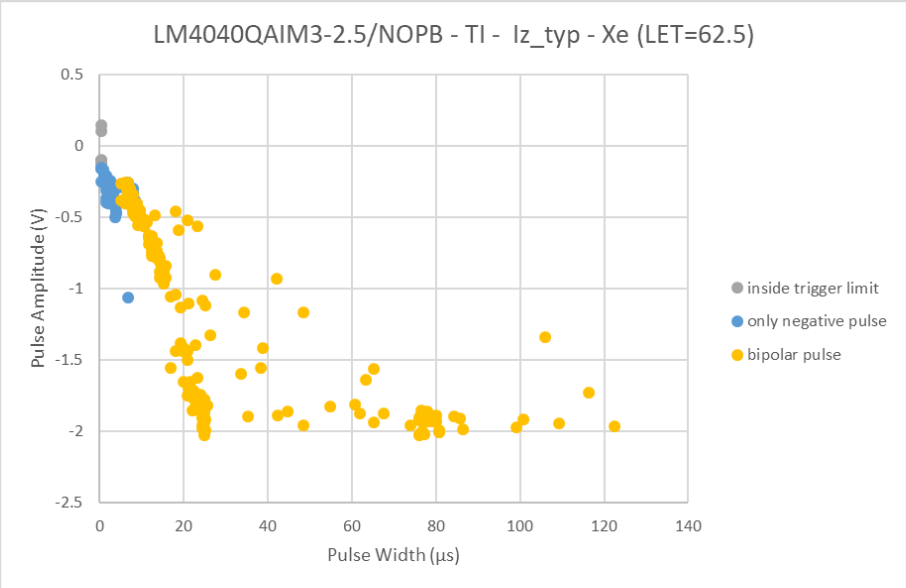


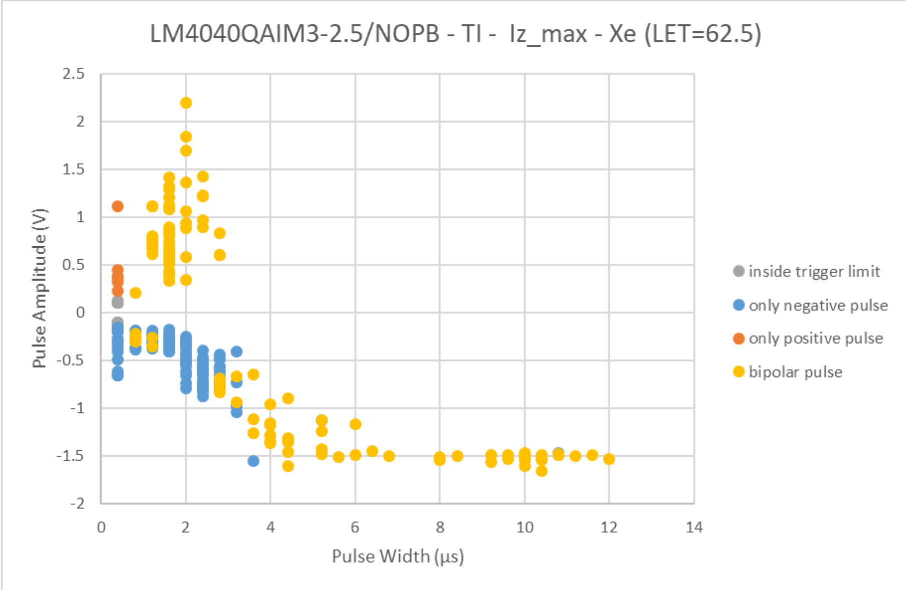
Seems like the Iz min condition is always the worst case and the shape of the pulse as well as its duration is even more dependent on the Iz condition than on the LET.

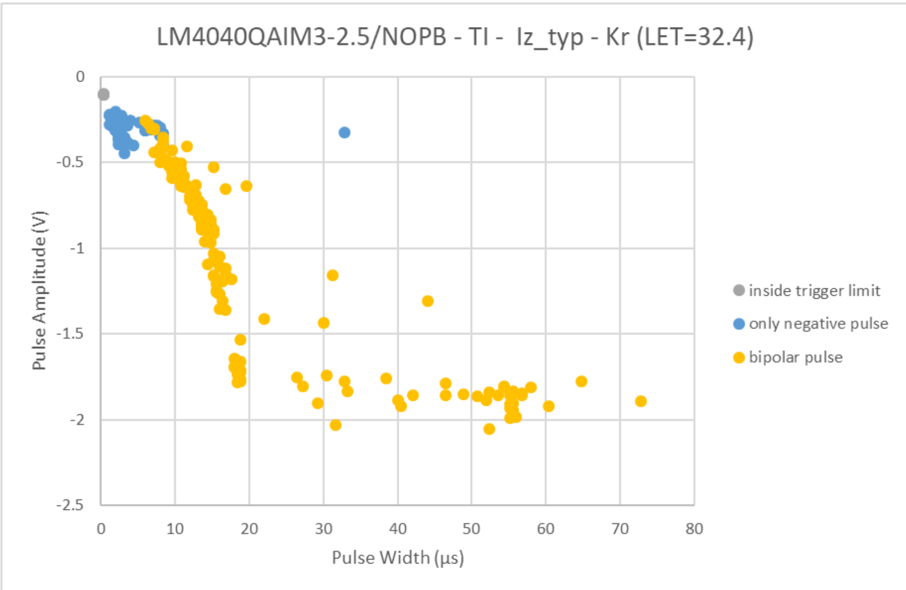
4.5 Pulse width and amplitude

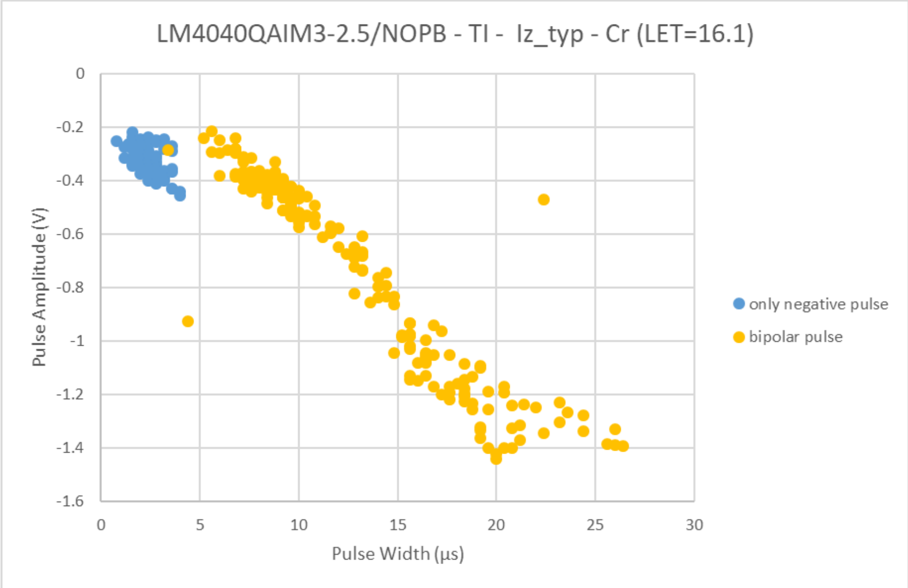
The following plots show all transients for each run on a plot regarding their maximum amplitude and the pulse width. The colour of the groups indicates if the pulse was only negative, positive or bipolar.
The pulses in grey are events, which triggered the scope but do not show any measurement pion outside the trigger levels due to the limited sampling rate.
The Amplitude level is plotted relative to the average output voltage without events.



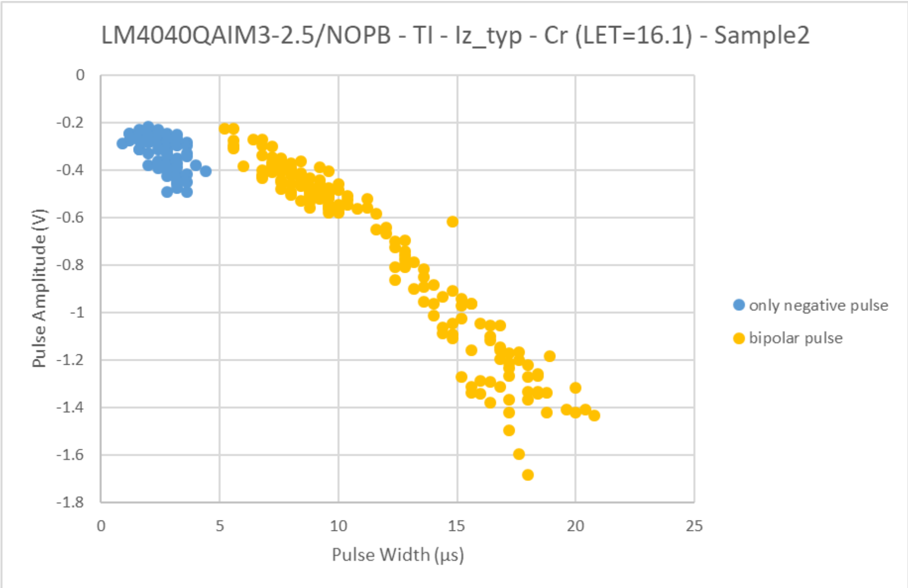



LM4040QAIM3-2.5/NOPB - TI - Iz_max - Xe (LET=62.5)
Pulse Amplitude (V)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
2
4
6
8
10
12
14
Pulse Width (µs)
inside trigger limit
only negative pulse
only positive pulse
bipolar pulse


LM4040QAIM3-2.5/NOPB - TI - Iz_typ - Kr (LET=32.4)
Pulse Amplitude (V)
0
-0.5
-1
-1.5
-2
-2.5
0
10
20
30
40
50
60
70
80
Pulse Width (µs)
inside trigger limit
only negative pulse
bipolar pulse

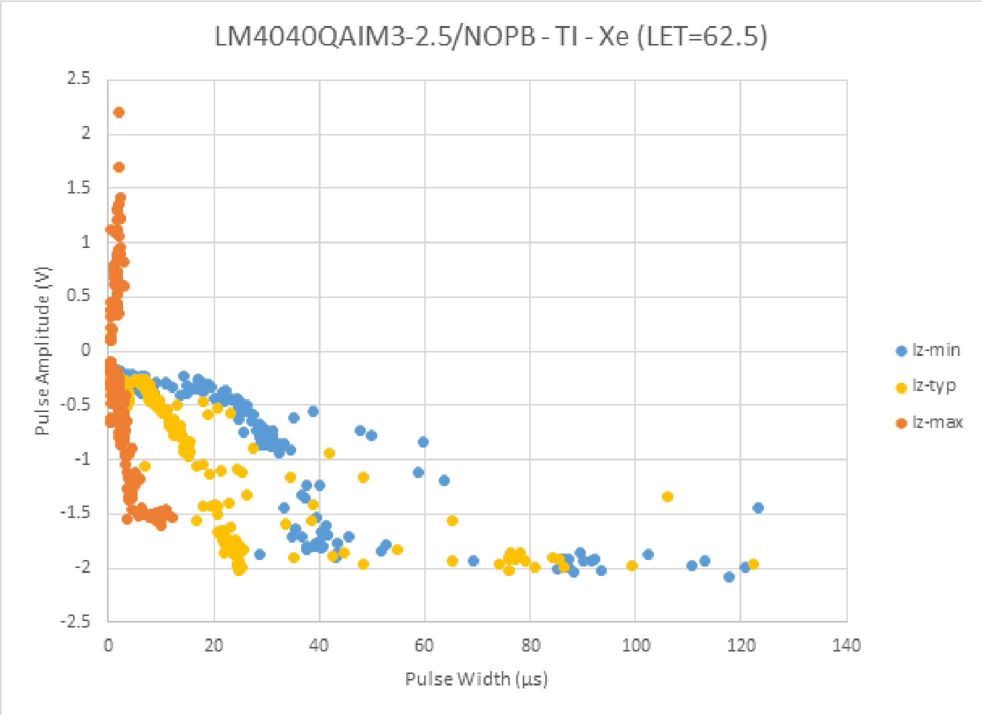


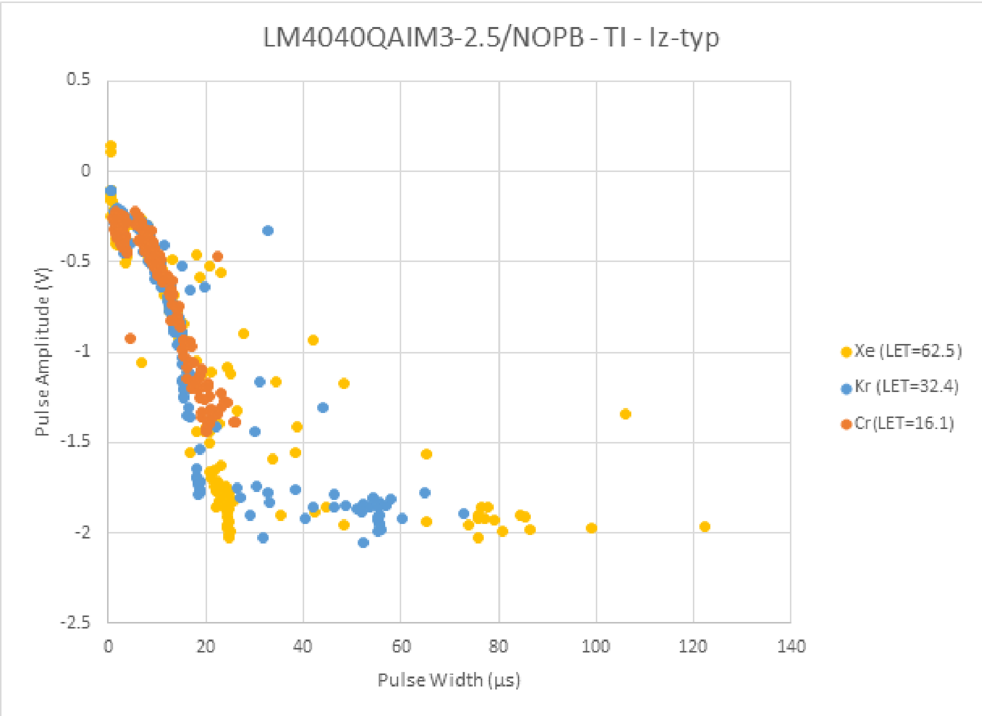
The last plot shows the second sample measured with the same condition at the lowest measured LET. It shows a very similar behaviour then the first sample.



4.6 Pulse width compared

The following plots show a comparison of pulse amplitude and pulse width vs. Iz current values and the LET.





5 CONCLUSION

No destructive events were observed up to an LET of 62.5 MeV*cm²/mg. All transients were analysed and their amplitudes were plotted against their width.

It seems that at these LET above 16, the Iz has more impact on the SET profile than the LET.

The lower the Iz, the longer the transient (up to 120 µs), the higher the Iz the shorter but the higher amplitude (up to 2.5V)

If SETs up to 150 µs pulse width and amplitudes of 2.5V can be filtered by using hardware filter devices next to the component, then there is no SET impact from this device.

Most of the pulses are bipolar or only negative. Especially for the max current measurement, a high positive voltage pulse could be observed. This could come from inductance loops in the test setup and could possibly be mitigated by using a capacitance on the input of the reference.
The cross section of the component could be calculated with the measurements to a bit more than 1.0E-03 cm² at a LET of 62.5 MeV*cm²/mg.

Finding the LET threshold for these SET events was not the scope of this campaign.