Single Event Transient Test Report

LM4041CFTA

Date Code: 2023
1.225V Bandgap Voltage Reference
Diodes Inc.

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APPROVAL

Title Single Event Transient Test Report LM4041CFTA	
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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 LM4041CFTA:
   https://www.diodes.com/assets/Datasheets/LM4041.pdf

2 TEST OBJECTIVES AND REQUIREMENTS TO BE VERIFIED

2.1 Test Objectives

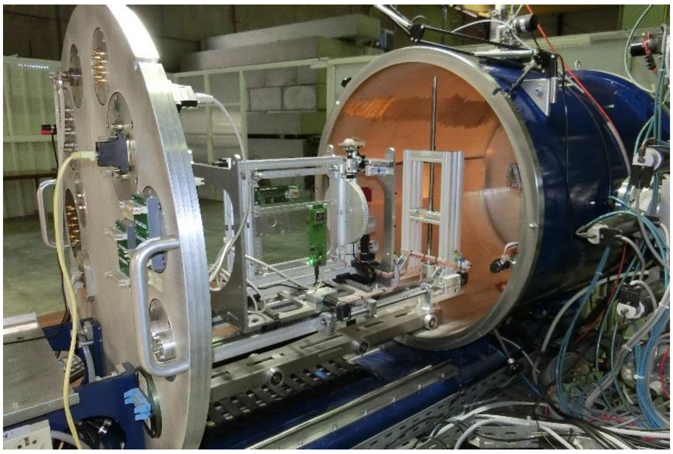
Test objective is to assess the heavy-ion SET sensitivity of this part.
This test report will be uploaded in the ESA Radiation Database (https://esarad.esa.int) and this data should also contribute to the development of safe design margins for COTS components.

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 LM4041 is a bandgap circuit designed to achieve a precision micro-power volta ge reference of 1.225 V. The device has been designed to be highly tolerant of capacitive loads so maintaining excellent stability.

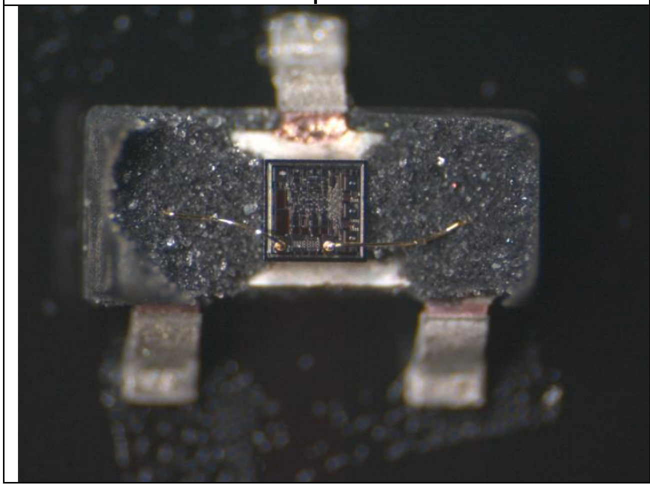
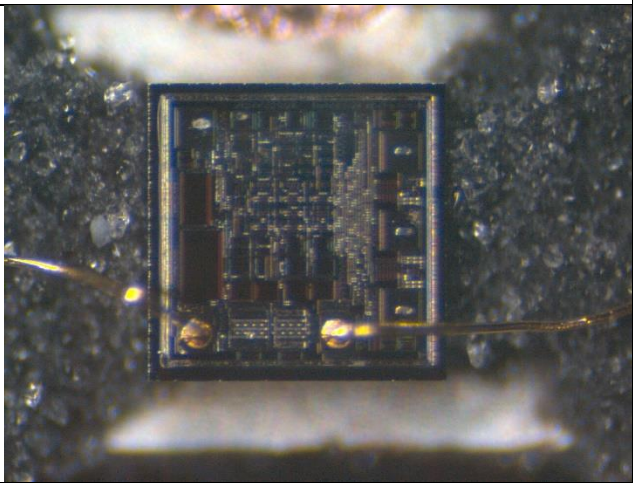
For the test, two samples of the same type have been used.
The table below shows the key parameters of the selected DUTs.

Component Family Name	Component Name	Manu-facturer	Automotive, AEC-Q100	Distributor	Componen t Laser Marking	Date-code YYWW	Lot-code from distributor
LM4041	LM4041CFTA	Diodes	no	Farnell	R1C	2023	A643574.H1

Vz	Initial Tolerance	IZ_min	IZ_typ	IZ_max	Long term stab.	Hysteresis (thermal) -40 to 125 degC	Package
1.225 V	0.5%	60µA	100µA	12mA	120ppm	-	SOT-23-3

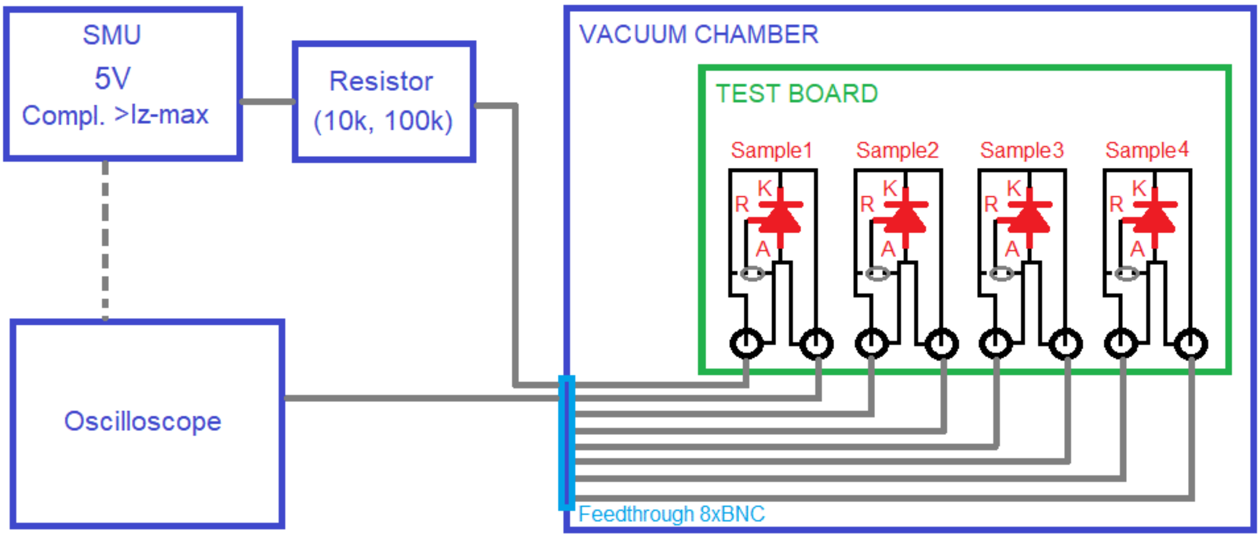
3.2 DUT Preparation

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

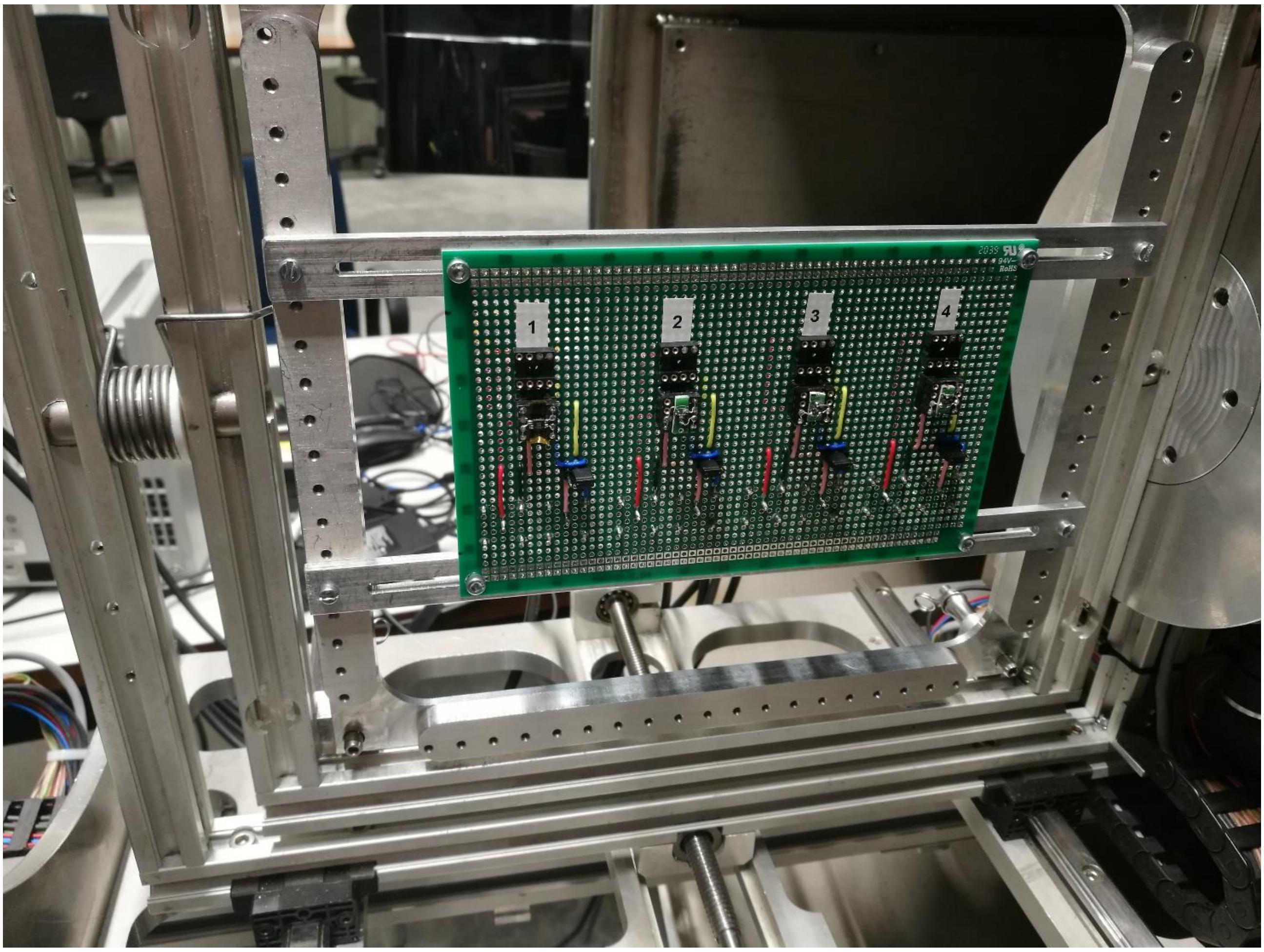
Schematic:



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 all runs related to the component LM4041:

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)
13	LM4041_S1	5	62000	MIN	0	Yes	Xe	995	62.5	62.5	73.1	2.00E+02	1.00E+09	5000000	10	1.36	1.06	10
14	LM4041_S1	5	62000	MIN	0	Yes	Xe	995	62.5	62.5	73.1	6.00E+02	1.00E+09	1666667	10	1.36	1.06	10?
15	LM4041_S1	5	36000	TYP	0	Yes	Xe	995	62.5	62.5	73.1	6.00E+02	1.00E+09	1666667	10	1.36	1.06	10?
16	LM4041_S1	5	330	MAX	0	Yes	Xe	995	62.5	62.5	73.1	2.00E+03	1.00E+09	500000	10	1.36	1.06	10?
23	LM4041_S1	5	36000	TYP	0	Yes	Kr	769	32.4	32.4	94.2	1.00E+03	1.00E+09	1000000	10	1.36	1.06	30
28	LM4041_S1	5	36000	TYP	0	Yes	Cr	505	16.1	16.1	105.5	2.50E+03	1.00E+09	400000	10	1.36	1.06	30
34	LM4041_S2	5	36000	TYP	0	Yes	Cr	505	16.1	16.1	105.5	5.00E+03	1.00E+09	200000	10	1.36	1.06	30

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
13	LM4041_S1	19:33	407	9.34E+04	9.34E+04	229.484029	9.34E-02	9.34E-02	NOK							This run was a test run that helped to improve the setting for the transients.
14	LM4041_S1	19:43	900	5.44E+05	6.37E+05	604.444444	5.44E-01	6.37E-01	OK	1.18	0.061	212	3.90E-04	1.565	0.414	All SET are similar, mainly length is changing, amplitude seems more or less between 0.5V and 1.5V, going from neg. to positive in a linear way (between 10 and 30 us).
15	LM4041_S1	20:00	868	5.10E+05	1.15E+06	587.557604	5.10E-01	1.15E+00	OK	1.20	0.105	204	4.00E-04	1.686	0.397	Same comments.
16	LM4041_S1	20:16	308	6.49E+05	1.80E+06	2107.14286	6.49E-01	1.80E+00	OK	1.23	11.45	255	3.93E-04	2.327	0.501	SET shape is different with higher Iz (duration much short, higher amplitudes) but the XS is the same as the previous run.
23	LM4041_S1	21:29	621	6.00E+05	6.00E+05	966.183575	3.11E-01	2.11E+00	OK	1.20	0.097	219	3.65E-04	1.623	0.413	Settings are ok, run good.
28	LM4041_S1	22:23	221	5.44E+05	5.44E+05	2461.53846	1.40E-01	2.25E+00	OK	1.20	0.097	108	1.99E-04	1.626	0.503	Flux seems a bit low but OK.
34	LM4041_S2	23:05	181	9.66E+05	9.66E+05	5337.01657	2.49E-01	2.49E-01	OK	1.20	0.097	207	2.14E-04	1.608	0.499	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.

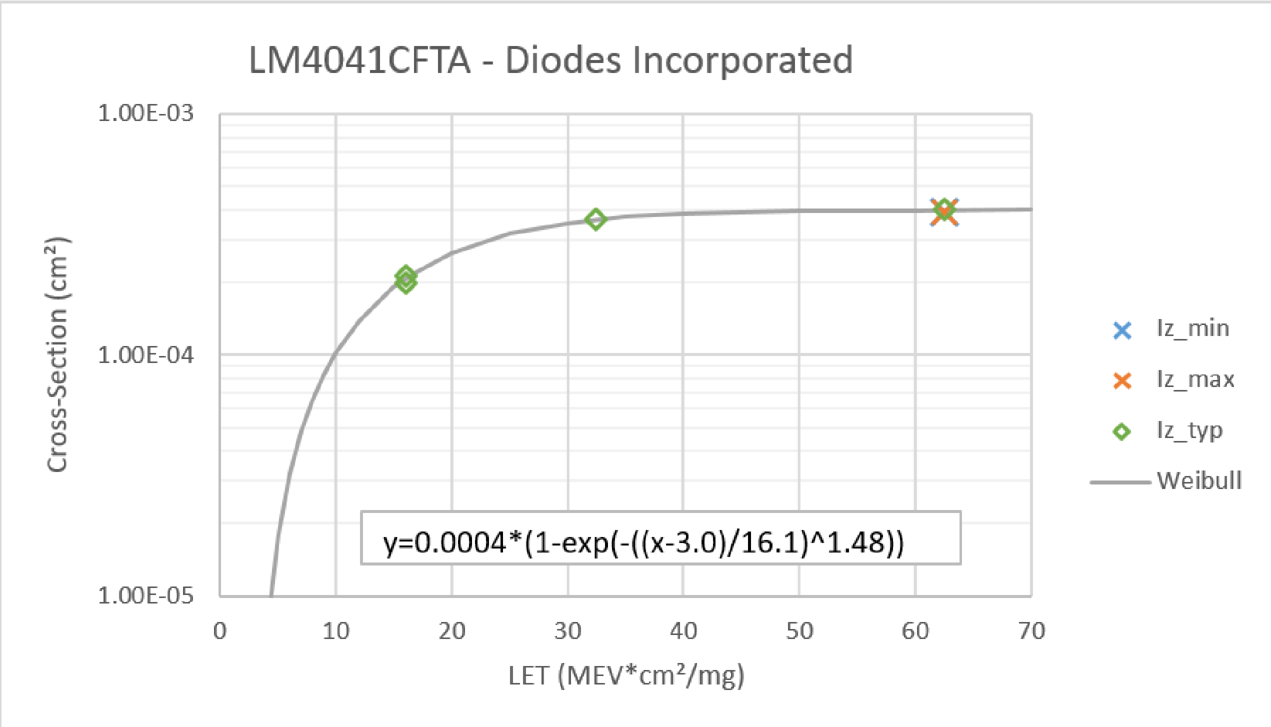
Only the typical Iz values was used to test under Kr and Cr.

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 2.25 krad and 0.25 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	16.1
S	1.48
Limit	0.0004
LET threshold	3.0

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

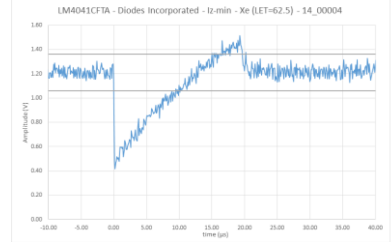
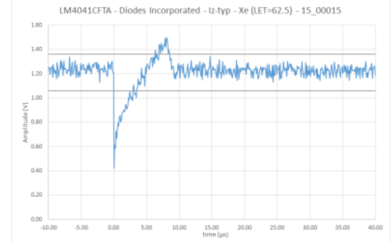
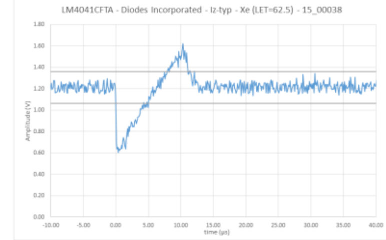
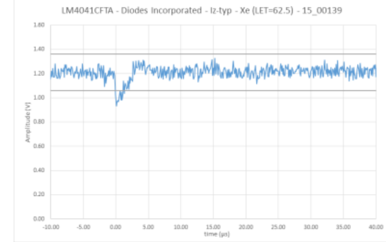
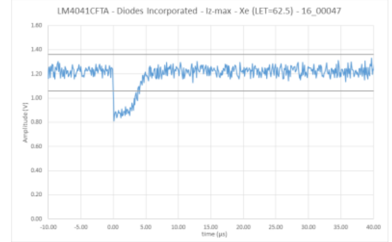
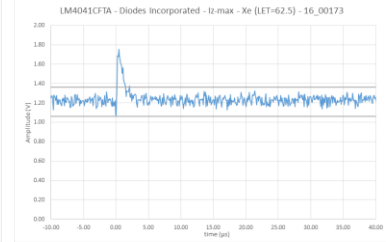
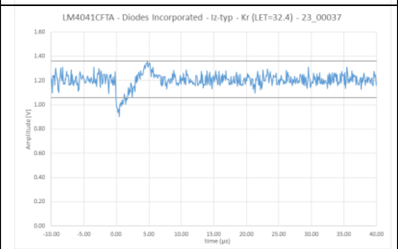
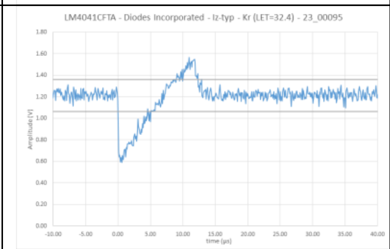
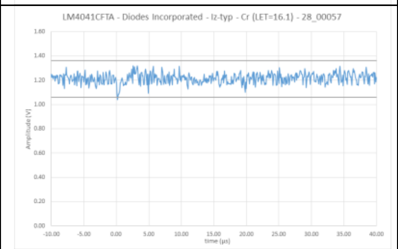
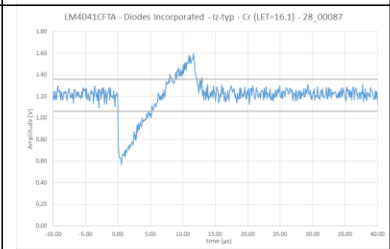
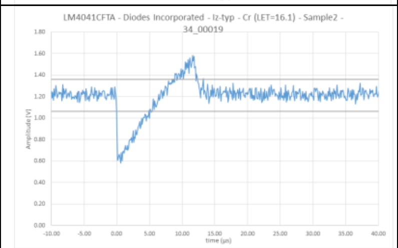
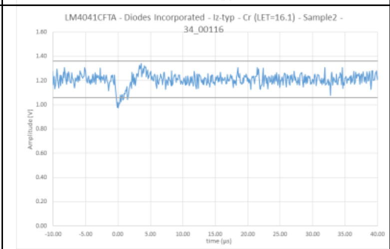
The part to part variation at a LET of 16.1 MeV*cm²/mg appears very low.

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

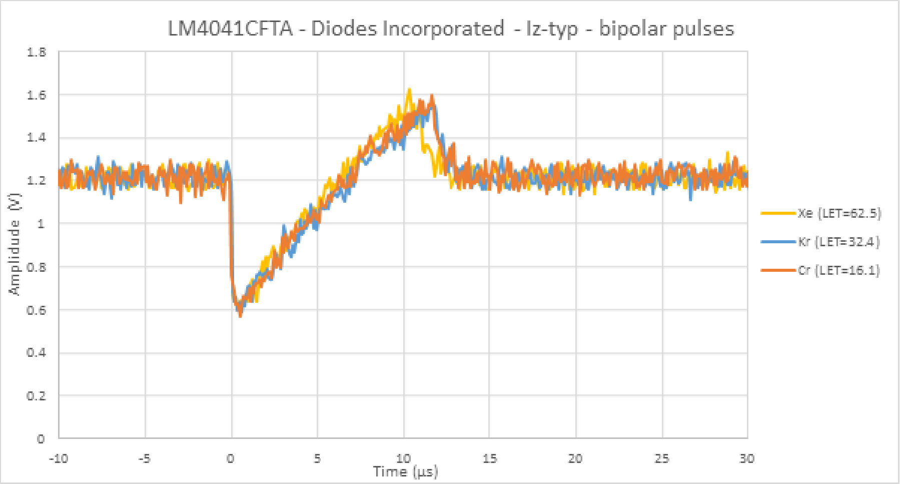
The following table shows examples of typical and worst case transients observed on the DUT. The trigger levels are shown by the grey lines.

Run No.	Transients		
14 Iz-min LET= 62.5			
15 Iz-typ LET= 62.5			
16 Iz-max LET= 62.5			
23 Iz-typ LET= 32.4			
28 Iz-typ LET= 16.1			
34 Iz-typ LET= 16.1 Sample2			

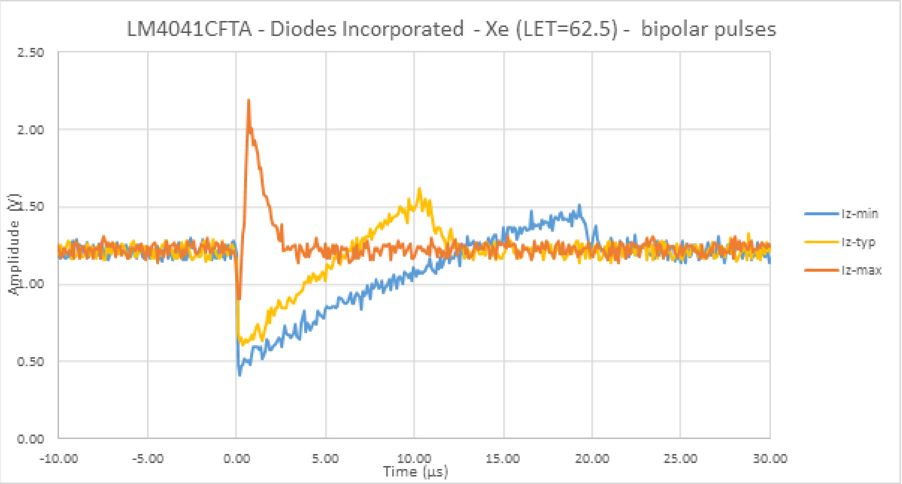
4.4 Transients Compared

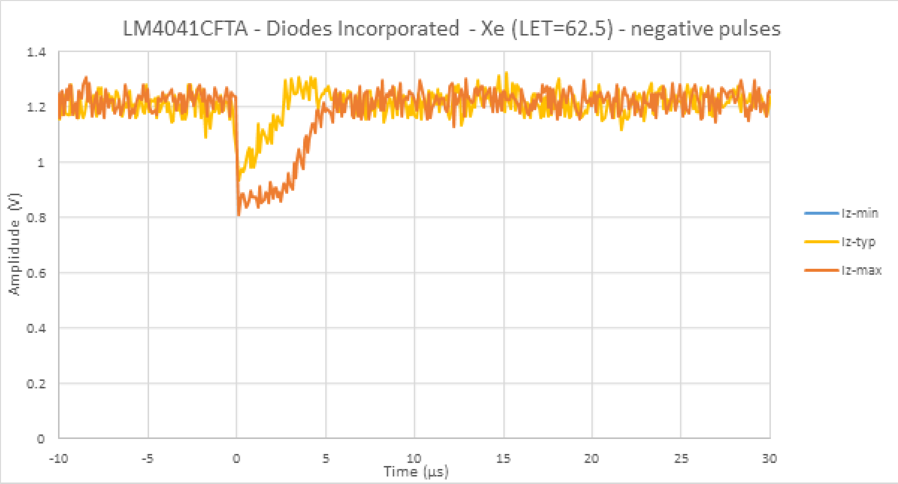
The following plots show the different shape of the worst case transients for both negative and bipolar pulses regarding the LET and different Iz values.

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 bipolar transients seem not to be depended of the LET in terms of their pulse width or there amplitude.

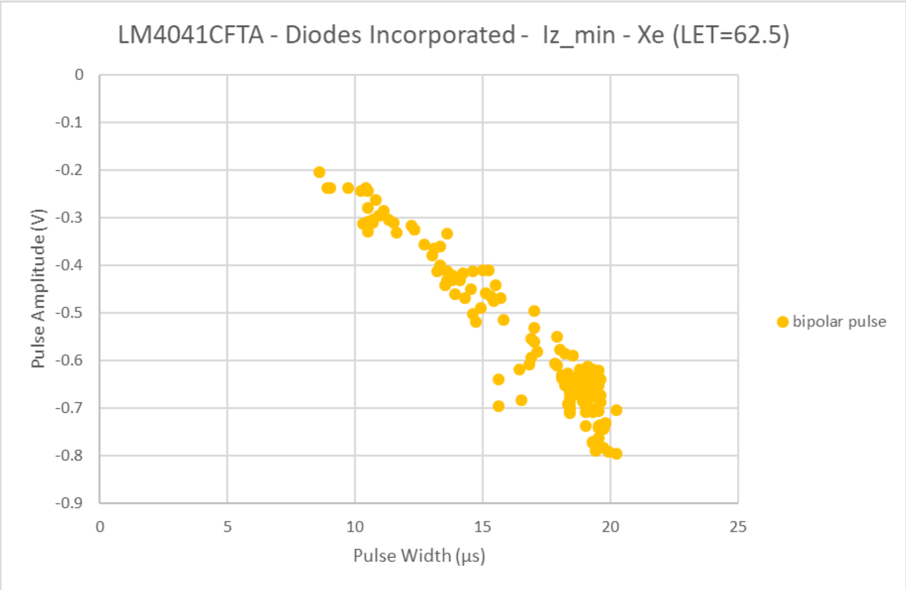


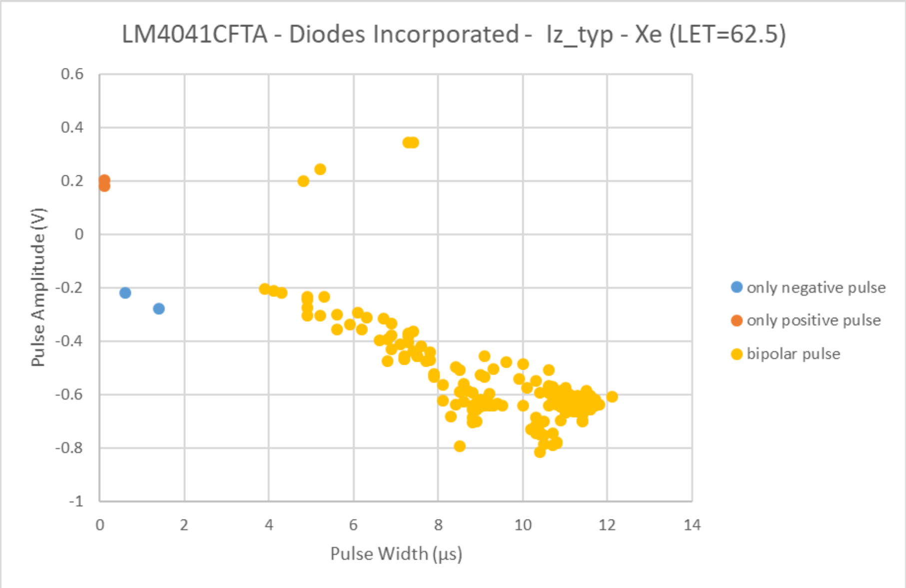


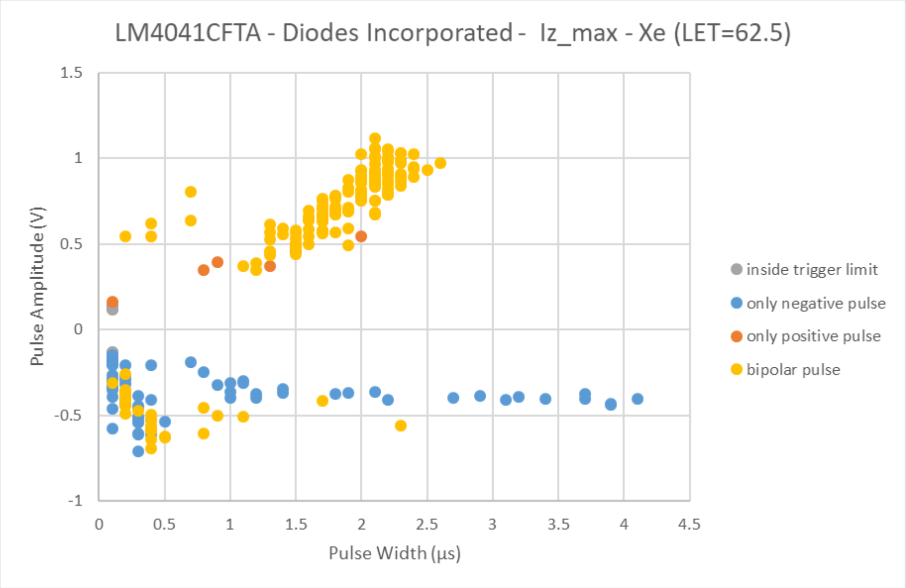
Seems like the shape of the pulse as well as its duration is more dependent on the Iz condition than on the LET.

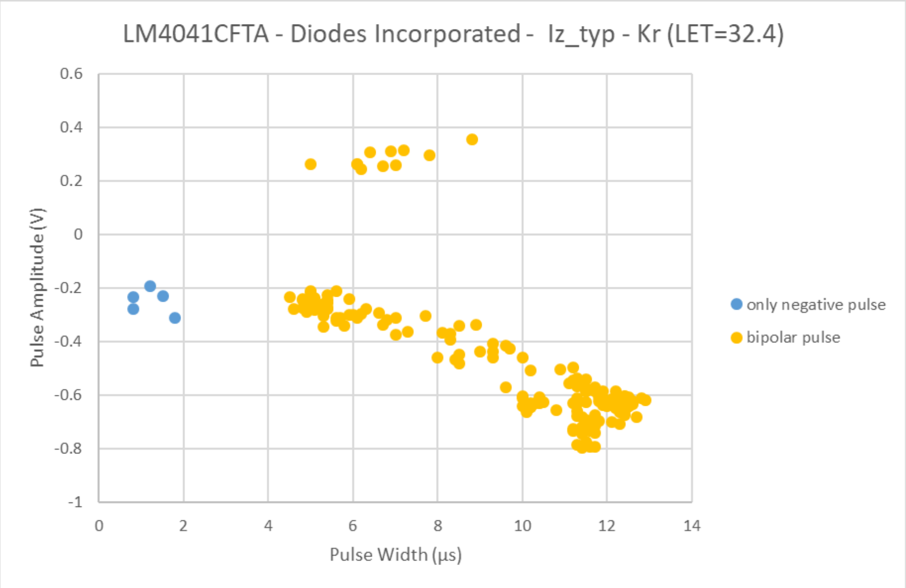
4.5 Pulse width and amplitude

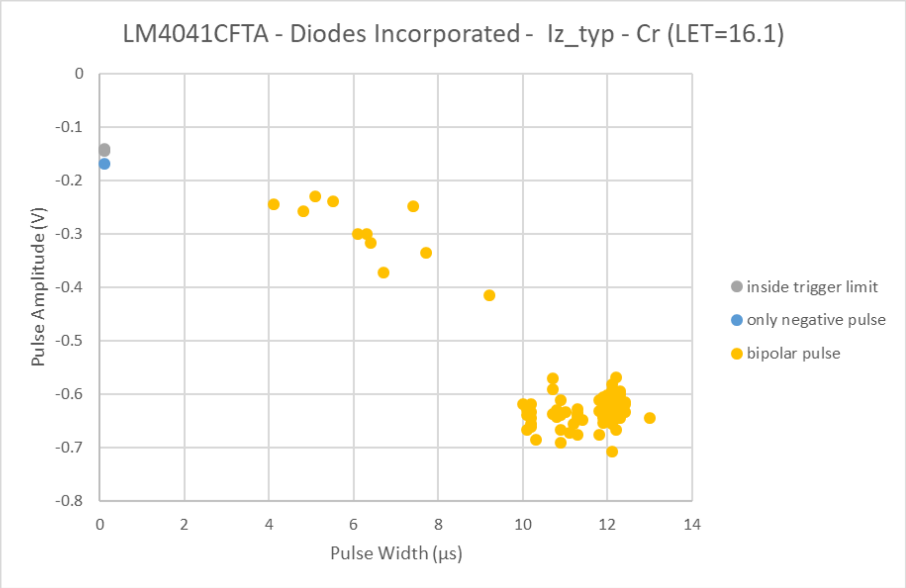
The following plots show all transients for each run on a plot regarding their maximum amplitude and the pulse width. The colour of the groups indicates if the pulse was only negative, positive or bipolar.
The pulses in grey are events, which triggered the scope but do not show any measurement pion outside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



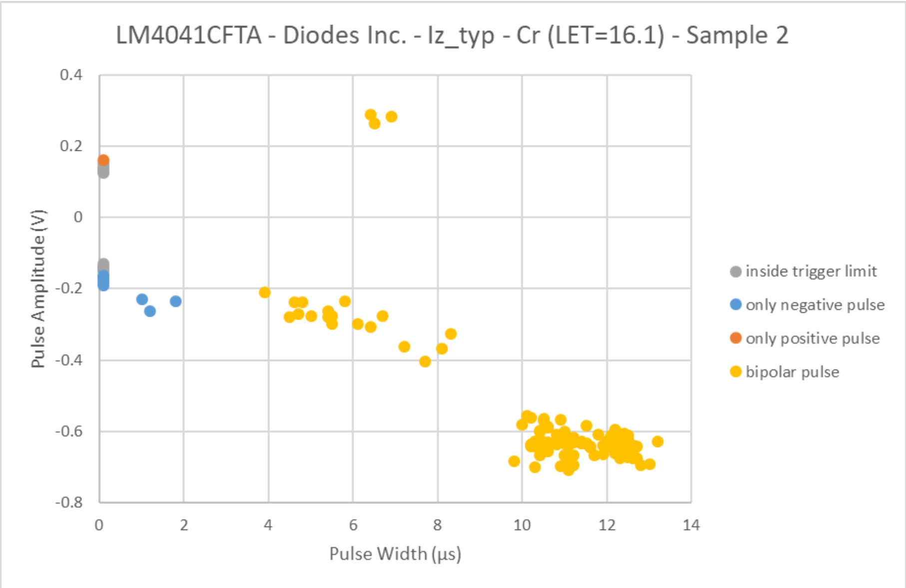



LM4041CFTA - Diodes Incorporated - Iz_max - Xe (LET=62.5)
Pulse Amplitude (V)
Pulse Width (µs)
1.5
1
0.5
0
-0.5
-1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
inside trigger limit
only negative pulse
only positive pulse
bipolar pulse


LM4041CFTA - Diodes Incorporated - Iz_typ - Kr (LET=32.4)
Pulse Amplitude (V)
Pulse Width (µs)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
2
4
6
8
10
12
14
only negative pulse
bipolar pulse

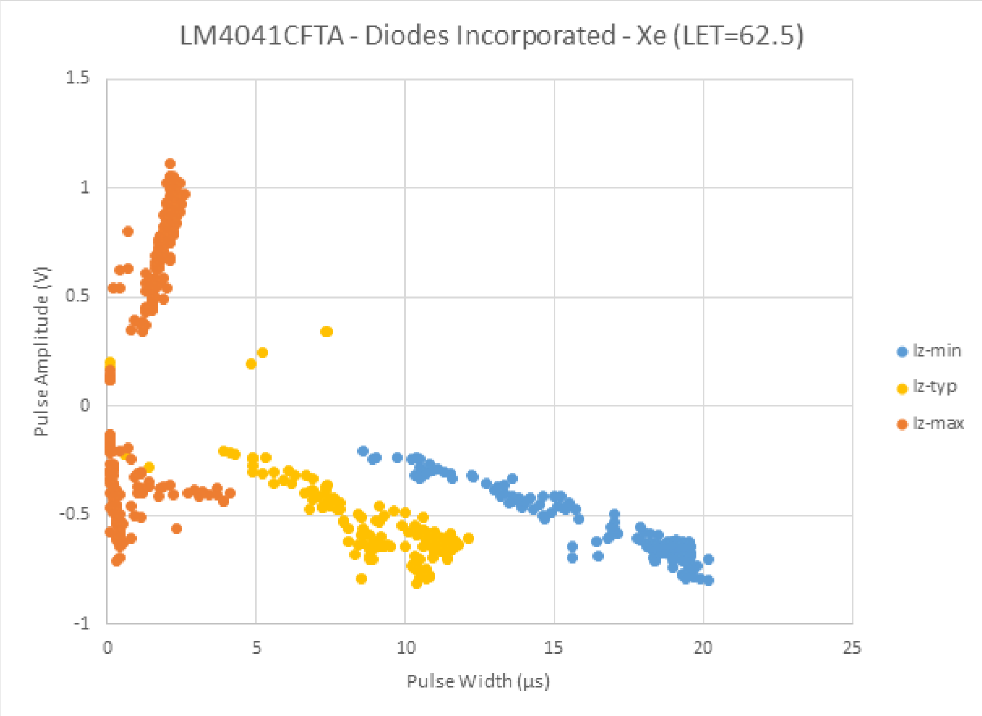


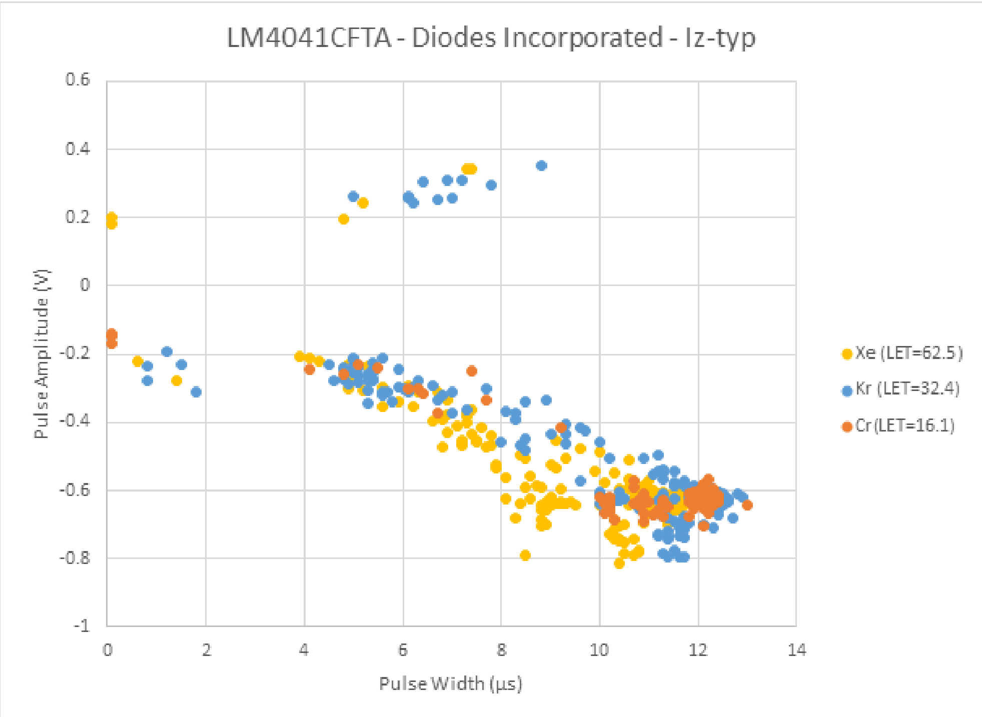
The last plot shows the second sample measured with the same condition at the lowest measured LET. It shows a very similar behaviour then the first sample.



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 20 µs), the higher the Iz the shorter but the higher amplitude (up to 1V)

If SETs up to 200 µs pulse width and amplitudes of 1.2V 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 around 4.0E-04 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.