ESA ESTEC
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands

LM4040_TID_TEST_REPORT

LM4040QAIM3-2.5/NOPB
Date Code: 1907
2.5V Bandgap Voltage Reference
Texas Instruments

LM4040AIX3-2.5+T
Date Code: 1630 and 1506
2.5V Bandgap Voltage Reference
Maxim Integrated

LM4040C25QFTA
Date Code: 2110 and 2026
2.5V Bandgap Voltage Reference
Diodes Incorporated

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1. INTRODUCTION

The current report presents the TID results on the Bandgap Voltage Reference LM4040

- LM4040QAIM3-2.5/NOPB, date code: 1907, Texas Instruments
- LM4040AIX3-2.5+T, date code: 1630 and 1506, Maxim Integrated
- LM4040C25QFTA, date code: 2110 and 2026, Diodes Incorporated

The test campaign was performed between the 24th January and 18th February 2022 at the ESTEC 60Co facility.

Additional information on the context is provided in the test plan [RD01].

2. DOCUMENTS

2.1. Applicable documents

AD01 ESCC22900 Total Dose Steady-state irradiation test method, June 2016

2.2. Reference documents

RD01 TID_COTS_Bandgap-ref_test_plan

RD02 RA0005344 Radiation Test Summary

3. PART & PROCUREMENT INFORMATION

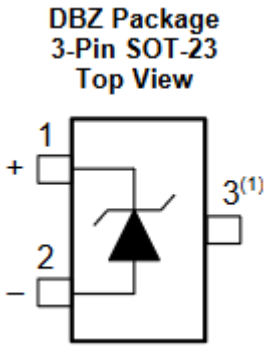
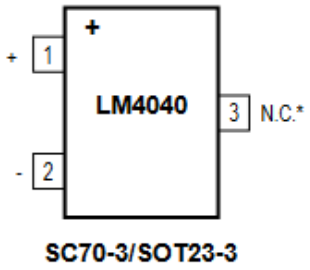
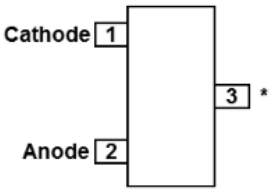
Part number	LM4040QAIM3-2.5/NOPB	LM4040AIX3-2.5+T	LM4040C25QFTA
Manufacturer	Texas Instruments	Maxim Integrated	Diodes Incorporated
Function	2.5V Bandgap Voltage Reference	2.5V Bandgap Voltage Reference	2.5V Bandgap Voltage Reference
Technology	Bipolar	Bipolar	Bipolar
Package		 SC70-3/SOT23-3	 * Pin 3 must be left floating or connected to pin 2 SOT23
Date Code	1907	1630 and 1506	2110 and 2026
Distributor	Mouser	Mouser and Farnell	Mouser and Farnell
Part # (sample n°) date code	5 samples unbiased (n° A00 to A04) 5 samples biased (n° A05 to A09) 1 reference unbiased (n° REF00) 1 reference biased (n° REF50)	2x5 samples unbiased (n° A10 to A14) 1630 (n° A20 to A24) 1506 2x5 samples biased (n° A15 to A19) 1630 (n° A25 to A29) 1506 2x1 reference unbiased (n° REF01) 1630 (n° REF02) 1506 2x1 reference biased (n° REF51) 1630 (n° REF52) 1506	2x5 samples unbiased (n° A40 to A44) 2110 (n° A50 to A54) 2026 2x5 samples biased (n° A45 to A49) 2110 (n° A55 to A59) 2026 2x1 reference unbiased (n° REF04) 2110 (n° REF05) 2026 2x1 reference biased (n° REF54) 2110 (n° REF55) 2026

Table 1: Part & procurement information

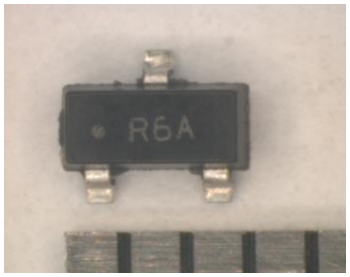
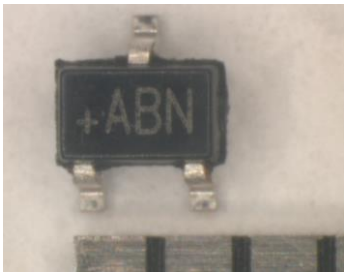
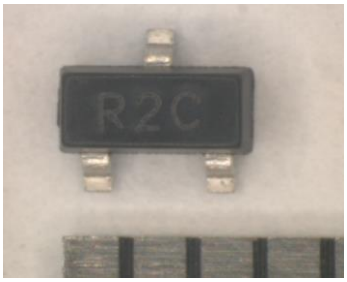
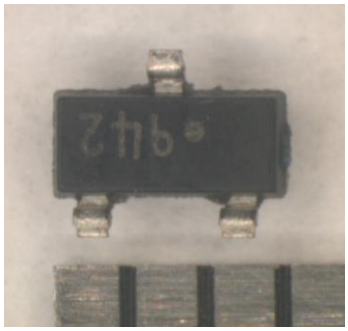
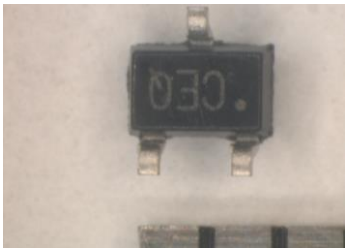
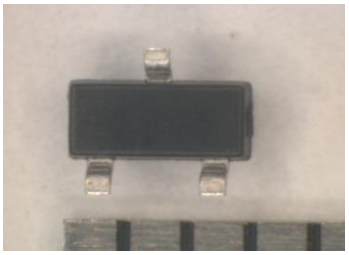
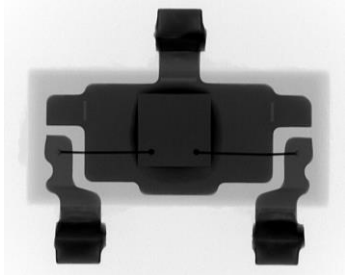
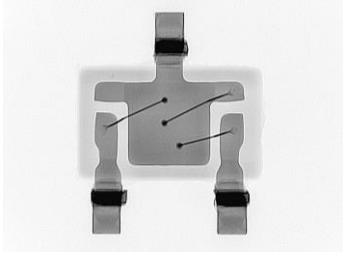
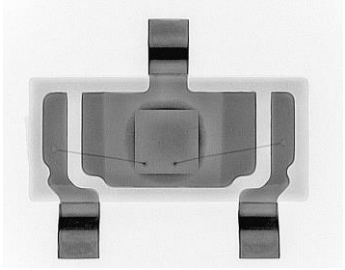
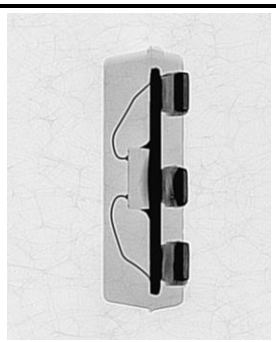
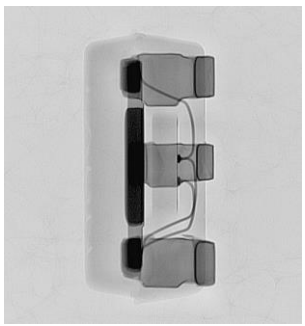
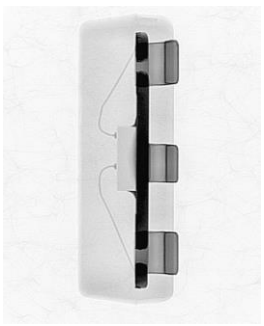
Part number	LM4040QAIM3-2.5/NOPB	LM4040AIX3-2.5+T	LM4040C25QFTA
Package marking top			
Package marking bottom		 date code: 1630  date code: 1506	
X-ray top view			
X-ray side view			

Figure 1: Package marking X-ray of the DUT

4. DOSIMETRY AND IRRADIATION FACILITY

IRRADIATION FACILITY

Source:	C060
Localization:	ESTEC, Netherlands
Dosimetry:	Electrometer: Farmer model 2670 – s/n 491
	Ionisation chamber: PTW TW30012-10 s/n 000417

IRRADIATION TIMING

TID steps (krad(Si))	0, 5, 10, 15, 20, 38.2, 50, 80.5, 100
Dose rate (rad(Si)/h)	240 - 260

ANNEALING TIMING		Condition during annealing
Annealing 22°C	24 h	Biased for those tested biased
		Unbiased for those tested unbiased
Ageing 100°C	168h	ON for those tested ON
		Unbiased for those tested unbiased

Values are provided in TID(H_20), the conversion to TID(Si) is done using the conversion factor of: 0.898.

5. TEST SET-UP

5.1. Test set-up overview

The set-up to measure at specific TID steps outside the irradiation chamber is schematically depicted in the Figure 2. Inside the radiation chamber the component boards with the DUTs on it are connected to the biasing boards which have a determined resistor to create the right value of biasing current (typical current acc. to datasheet) from a 12V supply for each biased component. Additionally to that, there are also 0-Ohm resistors on the biasing boards to connect all pins of the unbiased components.

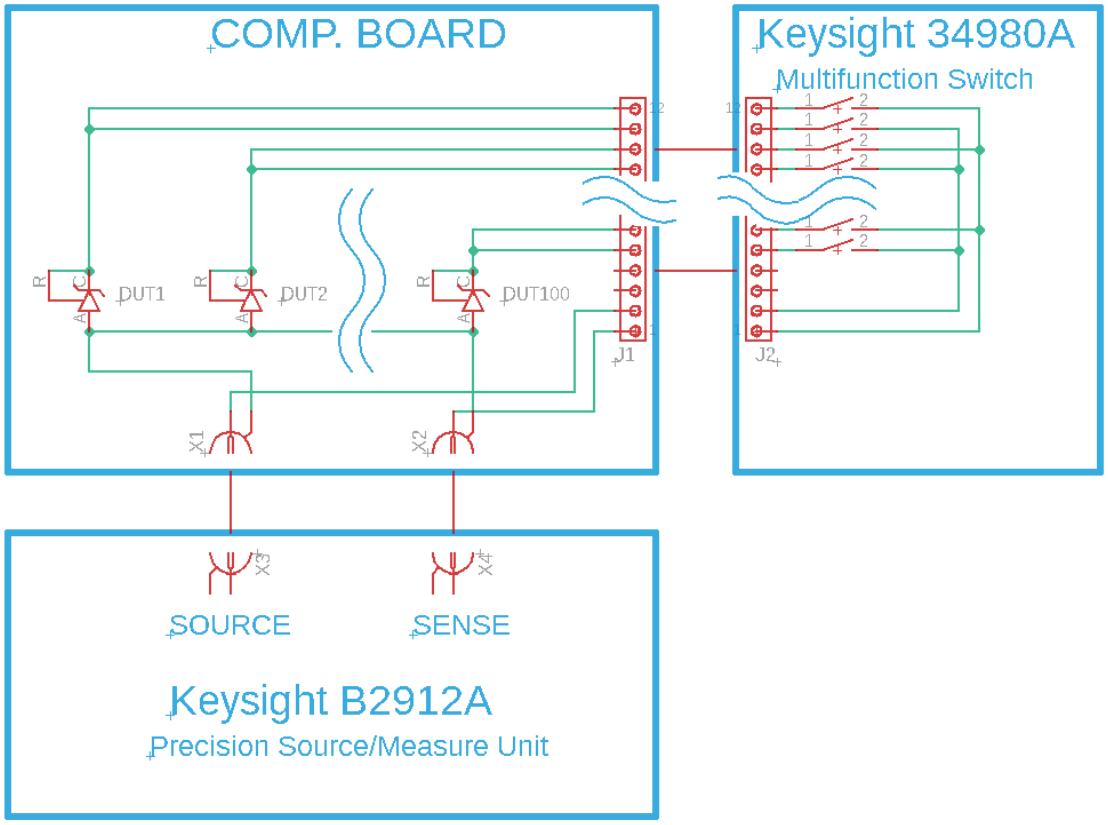


Figure 2: Simplified schematic of the overall test set-up

Four PCBs which were specially designed for this purpose could allow to accommodate both biased and unbiased components for this component and also other bandgap reference components at the same time on a 12*22 cm² PCB. This size of the boards limits the TID variation across board to less than 10%. Set-up pictures are provided in Annex B.

During each defined TID step a PC laptop was used to acquire the voltage (V_Z) as well as the input current (I_Z) of each of the samples from the source measure unit (SMU). The laptop time is synchronised to the time used for controlling the Co60 facility.

5.2. Test equipment

TEST EQUIPMENT	PARAMETER MEASURED
1 x Keysight B2912A 2412A Precision Source/Measure Unit (SMU)	Providing 6 different I_Z currents acc. to datasheet of the components: I_{min}, $0.8xI_{typ}$, I_{typ}, $3.14xI_{typ}$, $10xI_{typ}$, I_{max} V_{max} = 5.0 V
1 x Keysight 34980A Multifunction Switch	Switching through all up to 100 samples solder on one board.
1 x Laptop with LabView	Logging and saving the V_Z and I_Z measurements using an in-house VI.

6. TEST PARAMETERS

The following two parameters are measured:

PARAMETERS	SYMBOLS
Reverse Breakdown Voltage	V_Z
Reverse Current	I_Z

7. BIASING CONDITIONS

All biased samples are continuously biased with the typical value of I_Z according to the datasheet of each part type:

Table 2 summarised the main biasing conditions

PART TYPE	Value	Unit
LM4040QAIM3-2.5/NOPB	100	µA
LM4040AIX3-2.5+T	100	µA
LM4040C25QFTA	100	µA

Table 2: Biasing conditions during irradiation

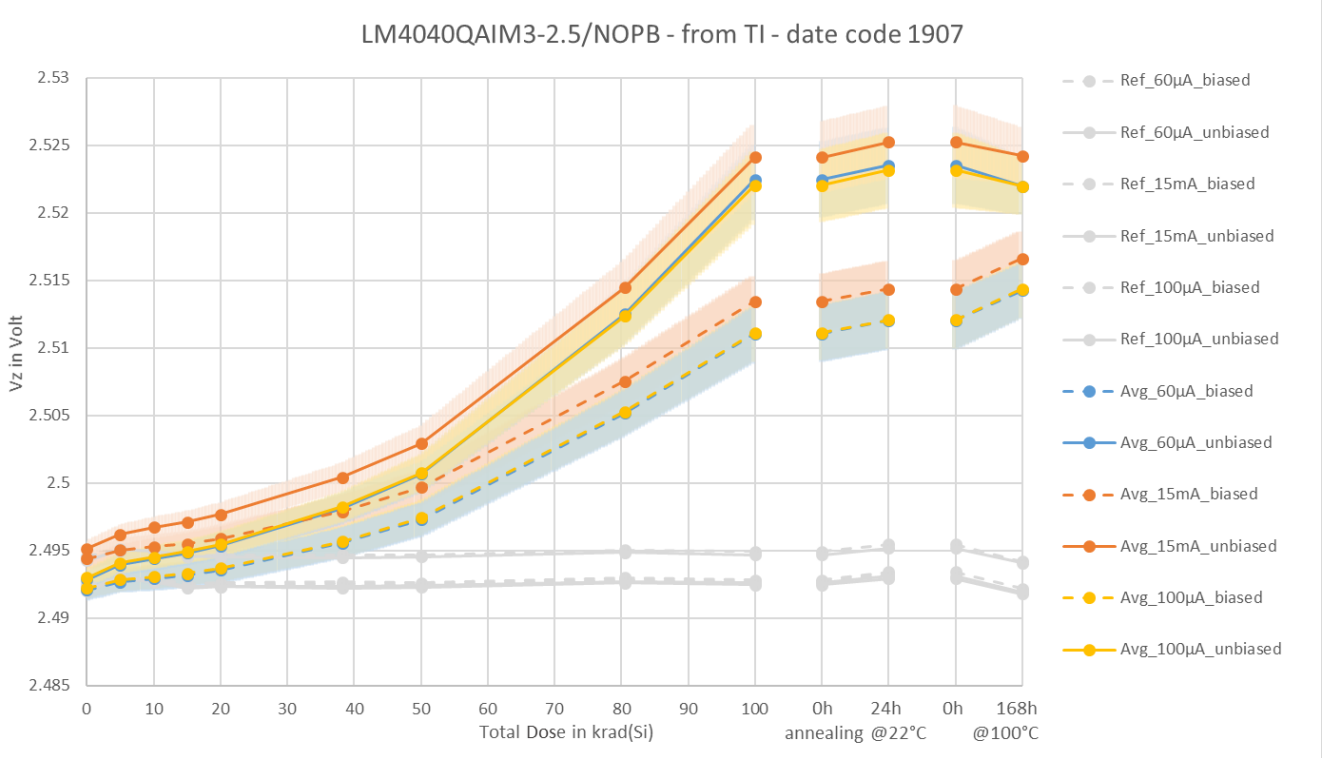
8. TID RESULTS

8.1. TID RESULTS - LM4040QAIM3-2.5/NOPB - from TI - date code 1907

LM4040QAIM3-2.5/NOPB - from TI - date code 1907 - @ I-min 60µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A00	unbiased	2.4933	2.4943	2.4948	2.4951	2.4957	2.4982	2.5006	2.5117	2.5211	2.5221	2.5209
A01		2.4919	2.4929	2.4932	2.4935	2.4939	2.4962	2.4984	2.5092	2.5185	2.5195	2.5190
A02		2.4928	2.4939	2.4944	2.4949	2.4956	2.4990	2.5019	2.5147	2.5250	2.5262	2.5225
A03		2.4937	2.4950	2.4956	2.4959	2.4965	2.4990	2.5013	2.5128	2.5226	2.5237	2.5246
A04		2.4926	2.4937	2.4942	2.4946	2.4952	2.4983	2.5012	2.5142	2.5252	2.5261	2.5228
A05	biased	2.4914	2.4924	2.4928	2.4932	2.4936	2.4959	2.4977	2.5063	2.5126	2.5137	2.5146
A06		2.4920	2.4930	2.4934	2.4936	2.4940	2.4959	2.4976	2.5054	2.5116	2.5127	2.5149
A07		2.4930	2.4931	2.4931	2.4933	2.4935	2.4953	2.4969	2.5043	2.5097	2.5105	2.5145
A08		2.4927	2.4935	2.4939	2.4941	2.4947	2.4969	2.4988	2.5072	2.5132	2.5142	2.5164
A09		2.4912	2.4914	2.4915	2.4917	2.4919	2.4938	2.4953	2.5027	2.5081	2.5091	2.5109
REF00	Ref unbiased	2.4920	2.4929	2.4927	2.4922	2.4923	2.4922	2.4923	2.4926	2.4925	2.4929	2.4918
REF50	Ref biased	2.4924	2.4929	2.4929	2.4924	2.4925	2.4926	2.4925	2.4929	2.4927	2.4932	2.4921

LM4040QAIM3-2.5/NOPB - from TI - date code 1907 - @ I-typ 100µA										Limit acc. DS: Vz = 2.5V ± 0.75% (2.481V – 2.519V)		
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A00	unbiased	2.4934	2.4944	2.4948	2.4952	2.4957	2.4982	2.5006	2.5115	2.5207	2.5217	2.5208
A01		2.4921	2.4930	2.4933	2.4936	2.4940	2.4963	2.4985	2.5092	2.5182	2.5192	2.5191
A02		2.4930	2.4940	2.4946	2.4950	2.4957	2.4991	2.5020	2.5145	2.5246	2.5258	2.5225
A03		2.4939	2.4952	2.4957	2.4960	2.4966	2.4991	2.5014	2.5126	2.5221	2.5234	2.5247
A04		2.4927	2.4938	2.4943	2.4947	2.4954	2.4984	2.5013	2.5140	2.5246	2.5257	2.5228
A05	biased	2.4915	2.4925	2.4930	2.4933	2.4937	2.4960	2.4979	2.5064	2.5127	2.5136	2.5147
A06		2.4922	2.4932	2.4935	2.4937	2.4941	2.4960	2.4977	2.5056	2.5116	2.5127	2.5150
A07		2.4931	2.4933	2.4933	2.4935	2.4937	2.4955	2.4971	2.5045	2.5099	2.5107	2.5147
A08		2.4929	2.4936	2.4940	2.4942	2.4948	2.4970	2.4990	2.5072	2.5132	2.5142	2.5165
A09		2.4914	2.4915	2.4916	2.4919	2.4921	2.4939	2.4955	2.5028	2.5082	2.5092	2.5110
REF00	Ref unbiased	2.4922	2.4930	2.4928	2.4924	2.4923	2.4924	2.4924	2.4927	2.4926	2.4931	2.4919
REF50	Ref biased	2.4925	2.4930	2.4930	2.4926	2.4926	2.4927	2.4926	2.4930	2.4928	2.4934	2.4922

LM4040QAIM3-2.5/NOPB - from TI - date code 1907 - @ I-max 15mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A00	unbiased	2.4954	2.4965	2.4970	2.4974	2.4979	2.5004	2.5028	2.5136	2.5227	2.5238	2.5231
A01		2.4944	2.4953	2.4957	2.4960	2.4963	2.4987	2.5008	2.5114	2.5204	2.5214	2.5214
A02		2.4951	2.4961	2.4967	2.4972	2.4979	2.5013	2.5042	2.5166	2.5266	2.5278	2.5247
A03		2.4959	2.4972	2.4978	2.4982	2.4988	2.5013	2.5036	2.5147	2.5242	2.5254	2.5269
A04		2.4948	2.4958	2.4964	2.4968	2.4975	2.5005	2.5034	2.5160	2.5266	2.5278	2.5250
A05	biased	2.4937	2.4947	2.4951	2.4954	2.4959	2.4981	2.5001	2.5086	2.5149	2.5158	2.5168
A06		2.4943	2.4953	2.4957	2.4958	2.4963	2.4981	2.4999	2.5077	2.5138	2.5149	2.5172
A07		2.4953	2.4955	2.4956	2.4957	2.4960	2.4977	2.4994	2.5068	2.5123	2.5130	2.5170
A08		2.4951	2.4959	2.4963	2.4966	2.4971	2.4994	2.5013	2.5096	2.5156	2.5166	2.5189
A09		2.4935	2.4937	2.4938	2.4940	2.4942	2.4961	2.4977	2.5050	2.5105	2.5114	2.5131
REF00	Ref unbiased	2.4943	2.4951	2.4950	2.4946	2.4945	2.4945	2.4946	2.4949	2.4947	2.4952	2.4941
REF50	Ref biased	2.4946	2.4950	2.4950	2.4946	2.4947	2.4947	2.4947	2.4950	2.4949	2.4955	2.4942



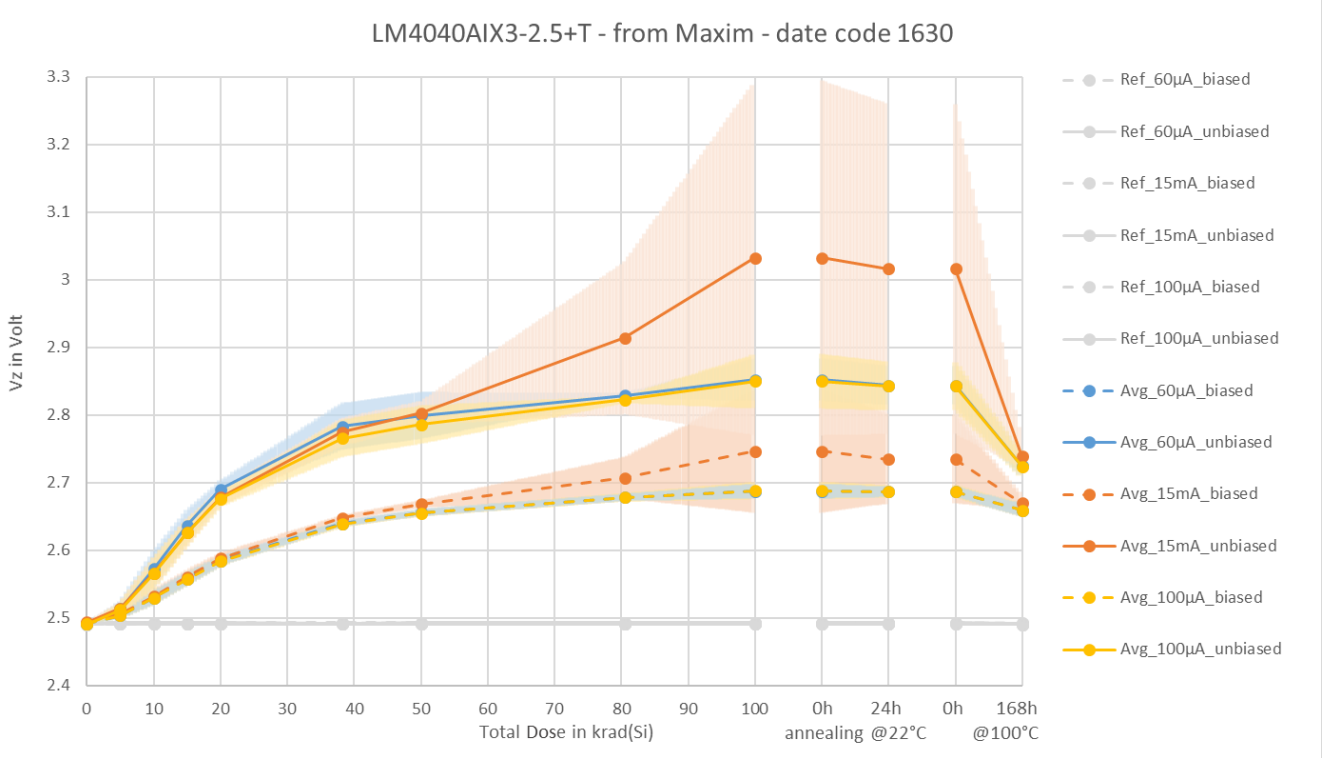
For all curves, which show an average over all measured samples, the coloured interval behind the curves represent +/- one standard deviation.

8.2. TID RESULTS - LM4040AIX3-2.5+T - from Maxim - date code 1630

LM4040AIX3-2.5+T - from Maxim - date code 1630 - @ I-min 60µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A10	unbiased	2.4911	2.5239	2.5965	2.6546	2.6910	2.7429	2.7597	2.8278	2.8945	2.8824	2.7023
A11		2.4916	2.5253	2.6025	2.6614	2.6967	2.7489	2.7638	2.8225	2.8750	2.8645	2.7065
A12		2.4911	2.5047	2.5500	2.6184	2.6827	2.8067	2.8246	2.8301	2.8260	2.8198	2.7382
A13		2.4916	2.5107	2.5667	2.6405	2.7063	2.8134	2.8277	2.8334	2.8360	2.8297	2.7401
A14		2.4904	2.5025	2.5460	2.6098	2.6748	2.8042	2.8203	2.8289	2.8282	2.8213	2.7367
A15	biased	2.4907	2.4995	2.5225	2.5517	2.5799	2.6395	2.6578	2.6752	2.6814	2.6824	2.6590
A16		2.4909	2.5113	2.5474	2.5747	2.5967	2.6347	2.6487	2.6826	2.7049	2.6975	2.6438
A17		2.4916	2.5011	2.5251	2.5519	2.5798	2.6394	2.6567	2.6775	2.6834	2.6833	2.6640
A18		2.4914	2.5027	2.5259	2.5549	2.5823	2.6380	2.6530	2.6713	2.6775	2.6785	2.6595
A19		2.4920	2.5021	2.5273	2.5556	2.5825	2.6467	2.6625	2.6841	2.6897	2.6901	2.6702
REF1	Ref unbiased	2.4904	2.4912	2.4910	2.4906	2.4906	2.4906	2.4907	2.4909	2.4908	2.4912	2.4901
REF51	Ref biased	2.4907	2.4910	2.4910	2.4906	2.4907	2.4907	2.4906	2.4910	2.4908	2.4913	2.4901

LM4040AIX3-2.5+T - from Maxim - date code 1630 - @ I-typ 100µA											Limit acc. DS: Vz = 2.5V ± 0.75% (2.481V – 2.519V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A10	unbiased	2.4911	2.5209	2.5870	2.6405	2.6769	2.7324	2.7533	2.8310	2.9038	2.8910	2.7020
A11		2.4916	2.5227	2.5920	2.6466	2.6829	2.7390	2.7567	2.8230	2.8817	2.8705	2.7061
A12		2.4912	2.5043	2.5463	2.6100	2.6689	2.7842	2.8063	2.8190	2.8169	2.8132	2.7367
A13		2.4916	2.5100	2.5613	2.6298	2.6909	2.7905	2.8107	2.8231	2.8274	2.8240	2.7396
A14		2.4904	2.5020	2.5419	2.6018	2.6612	2.7812	2.8018	2.8173	2.8187	2.8145	2.7362
A15	biased	2.4907	2.4995	2.5223	2.5513	2.5793	2.6385	2.6570	2.6748	2.6817	2.6823	2.6590
A16		2.4909	2.5111	2.5468	2.5741	2.5957	2.6341	2.6487	2.6852	2.7093	2.7009	2.6439
A17		2.4917	2.5010	2.5249	2.5517	2.5792	2.6386	2.6559	2.6772	2.6835	2.6832	2.6641
A18		2.4914	2.5027	2.5256	2.5545	2.5817	2.6366	2.6521	2.6709	2.6776	2.6782	2.6597
A19		2.4920	2.5021	2.5272	2.5552	2.5820	2.6457	2.6618	2.6836	2.6895	2.6898	2.6703
REF1	Ref unbiased	2.4905	2.4912	2.4911	2.4907	2.4906	2.4906	2.4907	2.4909	2.4909	2.4913	2.4902
REF51	Ref biased	2.4907	2.4910	2.4910	2.4906	2.4908	2.4908	2.4906	2.4910	2.4909	2.4913	2.4901

LM4040AIX3-2.5+T - from Maxim - date code 1630 - @ I-max 15mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A10	unbiased	2.4931	2.5225	2.5876	2.6423	2.6814	2.7491	2.7847	3.0840	3.3785	3.3402	2.7170
A11		2.4937	2.5244	2.5922	2.6479	2.6869	2.7558	2.7843	2.9759	3.2519	3.2167	2.7207
A12		2.4932	2.5063	2.5475	2.6097	2.6688	2.7876	2.8146	2.8343	2.8383	2.8355	2.7507
A13		2.4937	2.5122	2.5623	2.6297	2.6913	2.7959	2.8214	2.8426	2.8536	2.8507	2.7542
A14		2.4925	2.5040	2.5431	2.6015	2.6614	2.7851	2.8102	2.8325	2.8387	2.8358	2.7501
A15	biased	2.4928	2.5017	2.5247	2.5543	2.5831	2.6457	2.6668	2.6920	2.7052	2.7050	2.6696
A16		2.4929	2.5134	2.5501	2.5790	2.6025	2.6513	2.6766	2.7614	2.9101	2.8516	2.6535
A17		2.4937	2.5032	2.5273	2.5546	2.5828	2.6457	2.6655	2.6942	2.7066	2.7056	2.6747
A18		2.4935	2.5049	2.5280	2.5574	2.5853	2.6439	2.6620	2.6888	2.7018	2.7018	2.6700
A19		2.4940	2.5043	2.5294	2.5580	2.5855	2.6525	2.6708	2.6990	2.7099	2.7096	2.6806
REF1	Ref unbiased	2.4925	2.4933	2.4931	2.4927	2.4927	2.4926	2.4927	2.4930	2.4930	2.4933	2.4922
REF51	Ref biased	2.4927	2.4930	2.4930	2.4927	2.4928	2.4928	2.4926	2.4930	2.4929	2.4933	2.4922

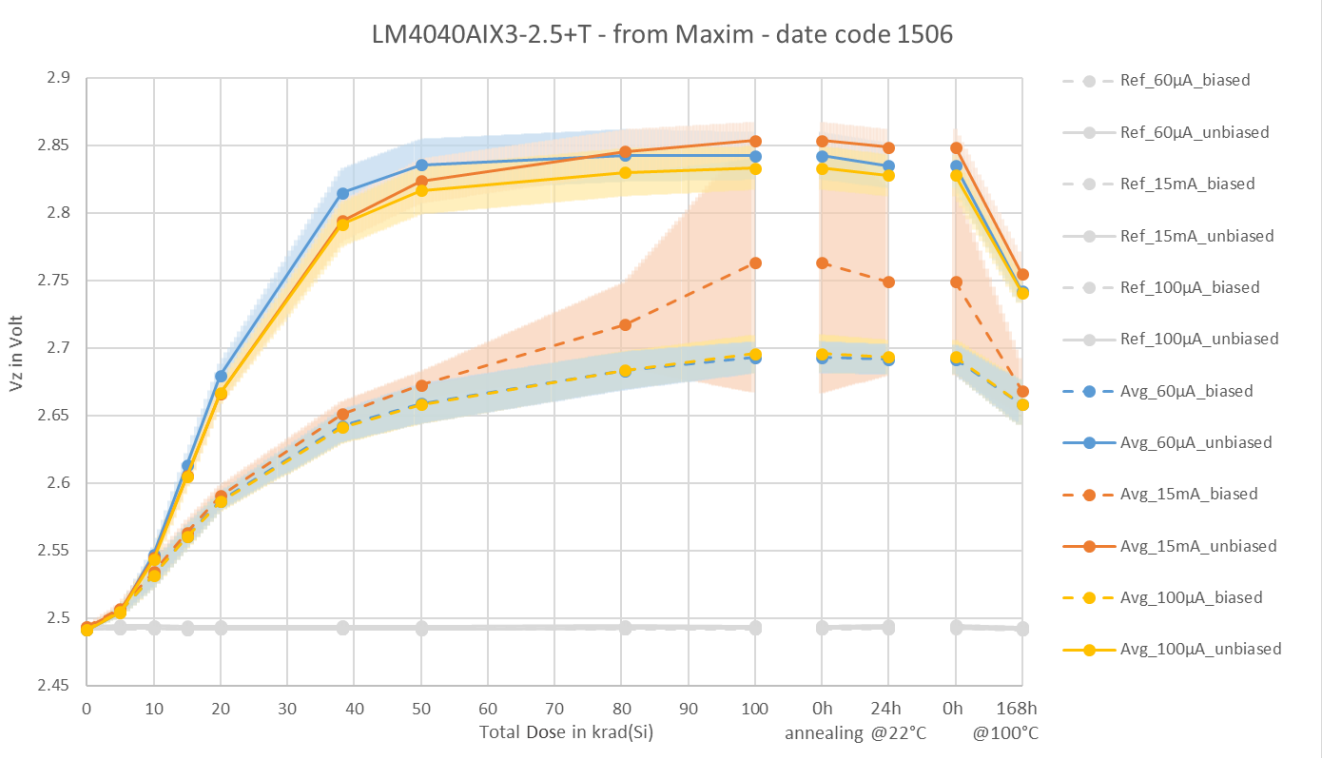


8.3. TID RESULTS - LM4040AIX3-2.5+T - from Maxim - date code 1506

LM4040AIX3-2.5+T - from Maxim - date code 1506 - @ I-min 60µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A20	unbiased	2.4914	2.5030	2.5402	2.6003	2.6641	2.8089	2.8367	2.8440	2.8449	2.8379	2.7328
A21		2.4919	2.5056	2.5453	2.6124	2.6819	2.8303	2.8532	2.8646	2.8615	2.8539	2.7548
A22		2.4908	2.5052	2.5489	2.6164	2.6828	2.8024	2.8207	2.8287	2.8295	2.8232	2.7392
A23		2.4908	2.5032	2.5469	2.6137	2.6850	2.8368	2.8549	2.8569	2.8553	2.8462	2.7544
A24		2.4912	2.5061	2.5538	2.6241	2.6843	2.7956	2.8114	2.8178	2.8194	2.8135	2.7279
A25	biased	2.4911	2.5049	2.5345	2.5611	2.5855	2.6308	2.6438	2.6643	2.6764	2.6759	2.6407
A26		2.4922	2.5116	2.5460	2.5735	2.5938	2.6321	2.6454	2.6812	2.7048	2.6951	2.6424
A27		2.4910	2.5013	2.5214	2.5505	2.5770	2.6425	2.6629	2.6842	2.6921	2.6927	2.6707
A28		2.4911	2.5015	2.5281	2.5561	2.5849	2.6451	2.6618	2.6812	2.6880	2.6877	2.6572
A29		2.4925	2.5051	2.5296	2.5611	2.5922	2.6607	2.6800	2.7045	2.7037	2.7062	2.6800
REF2	Ref unbiased	2.4917	2.4925	2.4923	2.4919	2.4919	2.4919	2.4919	2.4922	2.4922	2.4925	2.4914
REF52	Ref biased	2.4917	2.4920	2.4920	2.4917	2.4918	2.4918	2.4917	2.4921	2.4919	2.4924	2.4913

LM4040AIX3-2.5+T - from Maxim - date code 1506 - @ I-typ 100µA											Limit acc. DS: Vz = 2.5V ± 0.75% (2.481V – 2.519V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A20	unbiased	2.4913	2.5026	2.5373	2.5935	2.6526	2.7857	2.8168	2.8313	2.8351	2.8300	2.7320
A21		2.4920	2.5050	2.5426	2.6038	2.6691	2.8057	2.8331	2.8511	2.8516	2.8458	2.7536
A22		2.4909	2.5045	2.5446	2.6078	2.6692	2.7800	2.8035	2.8170	2.8211	2.8162	2.7389
A23		2.4908	2.5027	2.5436	2.6048	2.6714	2.8116	2.8348	2.8427	2.8448	2.8380	2.7534
A24		2.4912	2.5057	2.5491	2.6142	2.6701	2.7741	2.7947	2.8080	2.8128	2.8082	2.7270
A25	biased	2.4911	2.5048	2.5342	2.5607	2.5848	2.6300	2.6436	2.6652	2.6782	2.6774	2.6407
A26		2.4923	2.5115	2.5455	2.5729	2.5931	2.6314	2.6456	2.6839	2.7098	2.6989	2.6425
A27		2.4910	2.5013	2.5214	2.5503	2.5765	2.6414	2.6618	2.6835	2.6919	2.6919	2.6705
A28		2.4911	2.5016	2.5279	2.5557	2.5842	2.6439	2.6609	2.6807	2.6881	2.6874	2.6571
A29		2.4925	2.5050	2.5293	2.5610	2.5919	2.6597	2.6788	2.7045	2.7103	2.7108	2.6800
REF2	Ref unbiased	2.4917	2.4925	2.4923	2.4919	2.4919	2.4919	2.4920	2.4923	2.4922	2.4926	2.4914
REF52	Ref biased	2.4918	2.4922	2.4921	2.4917	2.4918	2.4918	2.4917	2.4921	2.4920	2.4924	2.4913

LM4040AIX3-2.5+T - from Maxim - date code 1506 - @ I-max 15mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A20	unbiased	2.4933	2.5047	2.5388	2.5942	2.6526	2.7879	2.8231	2.8461	2.8560	2.8516	2.7455
A21		2.4940	2.5070	2.5439	2.6043	2.6687	2.8071	2.8406	2.8653	2.8698	2.8650	2.7676
A22		2.4929	2.5065	2.5459	2.6082	2.6691	2.7834	2.8105	2.8331	2.8426	2.8377	2.7524
A23		2.4928	2.5047	2.5450	2.6052	2.6712	2.8128	2.8395	2.8566	2.8624	2.8559	2.7670
A24		2.4932	2.5075	2.5500	2.6139	2.6699	2.7785	2.8041	2.8258	2.8374	2.8331	2.7411
A25	biased	2.4931	2.5069	2.5369	2.5643	2.5897	2.6408	2.6595	2.7015	2.7323	2.7275	2.6505
A26		2.4942	2.5136	2.5485	2.5775	2.5998	2.6492	2.6749	2.7715	2.9345	2.8717	2.6517
A27		2.4930	2.5034	2.5235	2.5528	2.5797	2.6477	2.6702	2.6963	2.7081	2.7076	2.6807
A28		2.4932	2.5037	2.5303	2.5586	2.5880	2.6513	2.6708	2.6982	2.7122	2.7106	2.6673
A29		2.4945	2.5072	2.5315	2.5637	2.5954	2.6663	2.6873	2.7178	2.7275	2.7276	2.6904
REF2	Ref unbiased	2.4938	2.4946	2.4944	2.4940	2.4939	2.4940	2.4940	2.4943	2.4942	2.4946	2.4935
REF52	Ref biased	2.4938	2.4941	2.4941	2.4937	2.4938	2.4939	2.4937	2.4942	2.4940	2.4944	2.4933

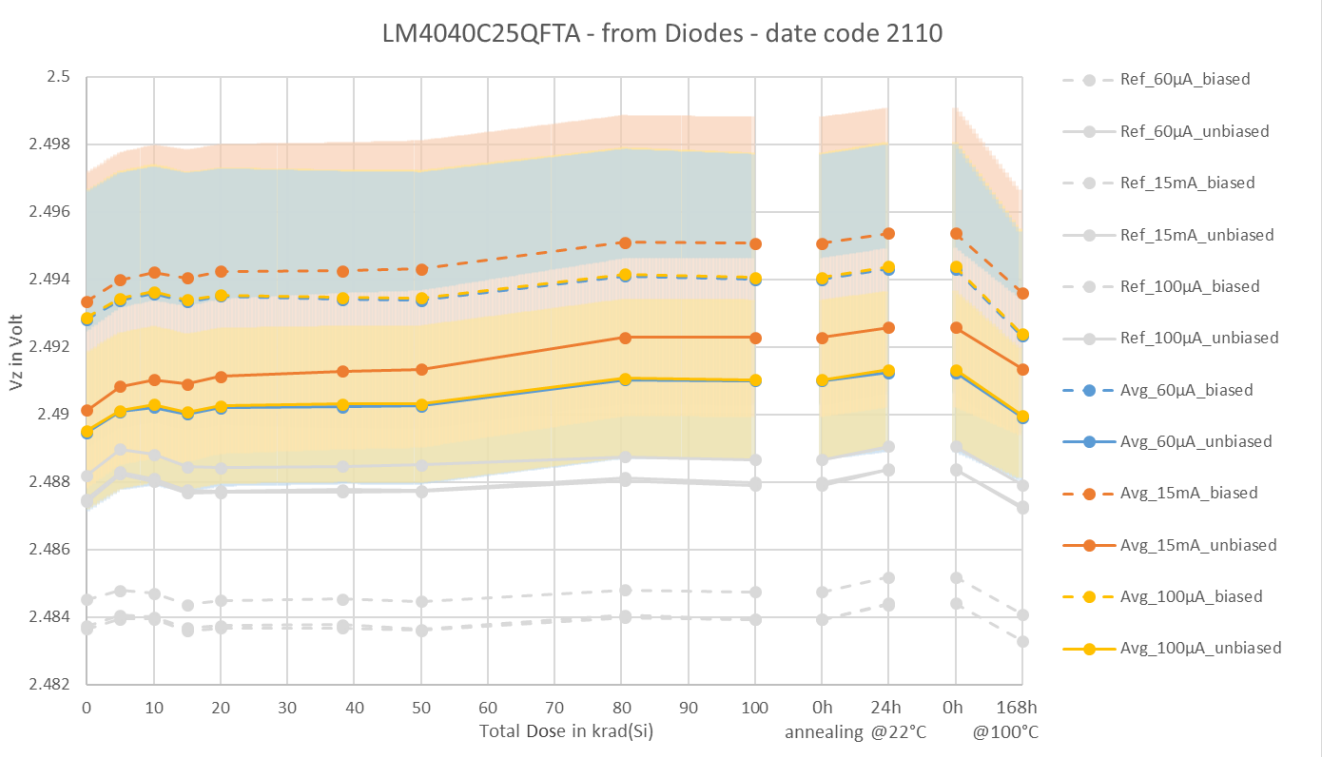


8.1. TID RESULTS - LM4040C25QFTA - from Diodes - date code 2110

LM4040C25QFTA - from Diodes - date code 2110 - @ I-min 60µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A40	unbiased	2.4899	2.4905	2.4906	2.4904	2.4906	2.4906	2.4906	2.4914	2.4913	2.4915	2.4909
A41		2.4866	2.4872	2.4874	2.4872	2.4874	2.4875	2.4874	2.4882	2.4882	2.4884	2.4880
A42		2.4882	2.4888	2.4890	2.4888	2.4889	2.4890	2.4890	2.4898	2.4897	2.4899	2.4881
A43		2.4897	2.4904	2.4905	2.4903	2.4905	2.4905	2.4905	2.4913	2.4912	2.4916	2.4900
A44		2.4929	2.4935	2.4936	2.4934	2.4936	2.4936	2.4937	2.4945	2.4945	2.4947	2.4926
A45	biased	2.4907	2.4912	2.4914	2.4911	2.4913	2.4912	2.4911	2.4919	2.4922	2.4925	2.4913
A46		2.4944	2.4949	2.4951	2.4949	2.4950	2.4950	2.4949	2.4957	2.4955	2.4958	2.4936
A47		2.4892	2.4898	2.4900	2.4898	2.4900	2.4899	2.4898	2.4905	2.4904	2.4907	2.4883
A48		2.4912	2.4918	2.4920	2.4917	2.4919	2.4917	2.4918	2.4925	2.4922	2.4926	2.4922
A49		2.4987	2.4992	2.4994	2.4993	2.4994	2.4993	2.4993	2.4999	2.4997	2.5000	2.4963
REF4	Ref unbiased	2.4874	2.4882	2.4880	2.4877	2.4877	2.4877	2.4877	2.4880	2.4879	2.4884	2.4872
REF54	Ref biased	2.4837	2.4839	2.4840	2.4836	2.4837	2.4837	2.4836	2.4840	2.4839	2.4844	2.4833

LM4040C25QFTA - from Diodes - date code 2110 - @ I-typ 100µA											Limit acc. DS: Vz = 2.5V ± 1.16% (2.471V – 2.529V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A40	unbiased	2.4899	2.4905	2.4907	2.4905	2.4906	2.4908	2.4907	2.4914	2.4914	2.4916	2.4910
A41		2.4866	2.4873	2.4875	2.4873	2.4874	2.4875	2.4875	2.4882	2.4882	2.4885	2.4881
A42		2.4883	2.4889	2.4891	2.4888	2.4890	2.4890	2.4890	2.4898	2.4898	2.4900	2.4882
A43		2.4898	2.4904	2.4906	2.4904	2.4906	2.4905	2.4906	2.4914	2.4913	2.4916	2.4900
A44		2.4929	2.4935	2.4937	2.4935	2.4937	2.4937	2.4938	2.4946	2.4946	2.4948	2.4926
A45	biased	2.4908	2.4912	2.4914	2.4911	2.4913	2.4912	2.4912	2.4919	2.4922	2.4925	2.4914
A46		2.4944	2.4950	2.4951	2.4950	2.4951	2.4950	2.4950	2.4957	2.4955	2.4959	2.4937
A47		2.4892	2.4899	2.4901	2.4898	2.4900	2.4899	2.4899	2.4906	2.4905	2.4908	2.4883
A48		2.4913	2.4918	2.4921	2.4918	2.4919	2.4918	2.4918	2.4926	2.4923	2.4927	2.4922
A49		2.4987	2.4993	2.4995	2.4993	2.4994	2.4993	2.4993	2.5000	2.4998	2.5001	2.4964
REF4	Ref unbiased	2.4875	2.4883	2.4881	2.4878	2.4877	2.4878	2.4878	2.4881	2.4880	2.4884	2.4873
REF54	Ref biased	2.4837	2.4841	2.4840	2.4837	2.4837	2.4838	2.4836	2.4841	2.4839	2.4844	2.4833

LM4040C25QFTA - from Diodes - date code 2110 - @ I-max 15mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A40	unbiased	2.4905	2.4912	2.4914	2.4913	2.4915	2.4916	2.4917	2.4926	2.4926	2.4929	2.4924
A41		2.4874	2.4881	2.4883	2.4882	2.4884	2.4886	2.4886	2.4896	2.4896	2.4898	2.4897
A42		2.4887	2.4894	2.4895	2.4894	2.4897	2.4898	2.4898	2.4908	2.4908	2.4911	2.4892
A43		2.4906	2.4912	2.4914	2.4913	2.4916	2.4917	2.4918	2.4927	2.4927	2.4930	2.4915
A44		2.4935	2.4943	2.4945	2.4943	2.4945	2.4947	2.4948	2.4958	2.4958	2.4960	2.4941
A45	biased	2.4914	2.4919	2.4921	2.4919	2.4922	2.4921	2.4921	2.4931	2.4934	2.4936	2.4928
A46		2.4948	2.4955	2.4957	2.4955	2.4957	2.4958	2.4959	2.4966	2.4966	2.4968	2.4948
A47		2.4897	2.4905	2.4907	2.4905	2.4907	2.4908	2.4908	2.4916	2.4915	2.4918	2.4897
A48		2.4916	2.4923	2.4925	2.4923	2.4924	2.4924	2.4925	2.4933	2.4931	2.4934	2.4931
A49		2.4993	2.4999	2.5001	2.5000	2.5001	2.5002	2.5003	2.5010	2.5009	2.5012	2.4977
REF4	Ref unbiased	2.4882	2.4890	2.4888	2.4885	2.4884	2.4885	2.4885	2.4888	2.4887	2.4891	2.4879
REF54	Ref biased	2.4845	2.4848	2.4847	2.4844	2.4845	2.4845	2.4845	2.4848	2.4848	2.4852	2.4841

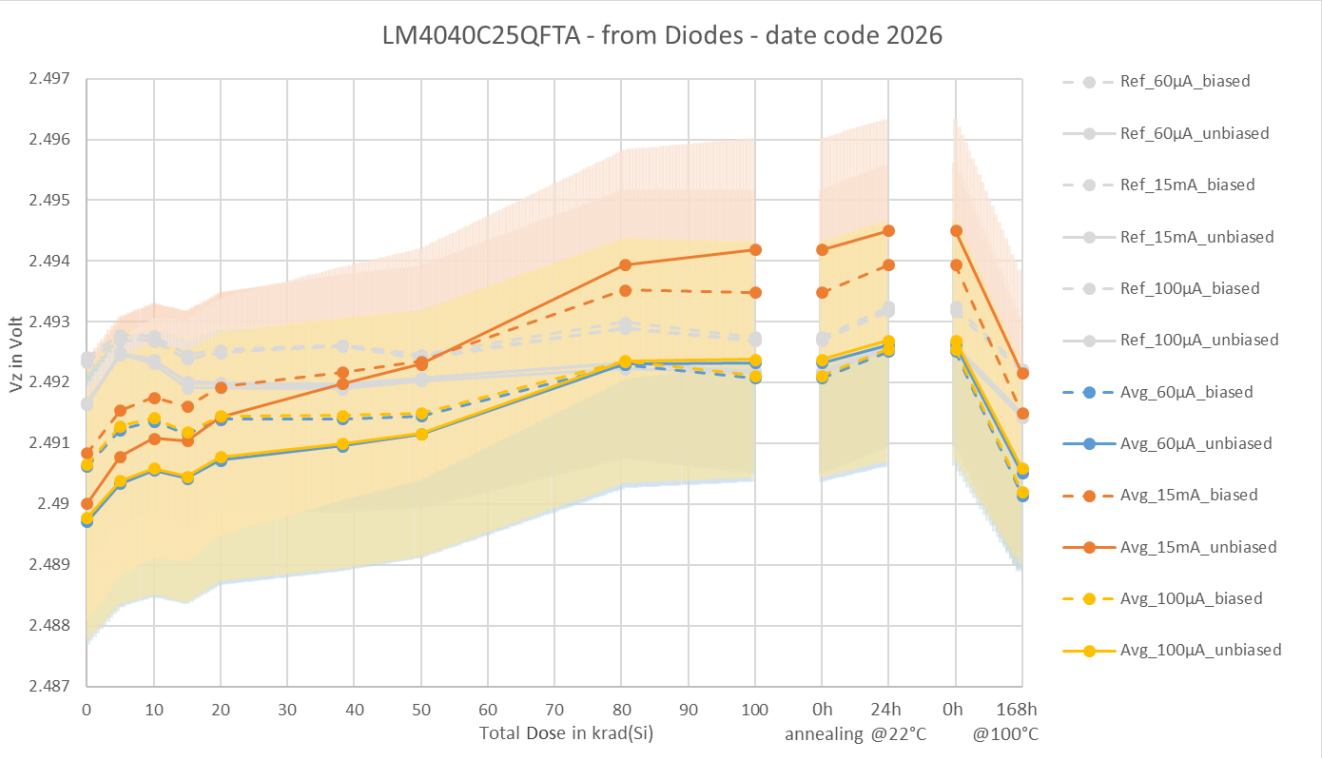


8.1. TID RESULTS - LM4040C25QFTA - from Diodes - date code 2026

LM4040C25QFTA - from Diodes - date code 2026 - @ I-min 60µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A50	unbiased	2.4869	2.4875	2.4877	2.4876	2.4879	2.4883	2.4885	2.4897	2.4899	2.4902	2.4879
A51		2.4920	2.4926	2.4929	2.4928	2.4931	2.4933	2.4935	2.4946	2.4946	2.4949	2.4912
A52		2.4896	2.4901	2.4904	2.4902	2.4904	2.4906	2.4907	2.4918	2.4917	2.4920	2.4900
A53		2.4913	2.4920	2.4922	2.4921	2.4923	2.4927	2.4928	2.4941	2.4941	2.4945	2.4923
A54		2.4888	2.4895	2.4897	2.4895	2.4899	2.4900	2.4902	2.4913	2.4914	2.4917	2.4912
A55	biased	2.4913	2.4920	2.4921	2.4920	2.4922	2.4922	2.4922	2.4930	2.4927	2.4932	2.4901
A56		2.4920	2.4926	2.4928	2.4926	2.4928	2.4928	2.4928	2.4937	2.4935	2.4940	2.4919
A57		2.4909	2.4915	2.4917	2.4914	2.4917	2.4917	2.4917	2.4926	2.4923	2.4928	2.4902
A58		2.4881	2.4887	2.4888	2.4886	2.4889	2.4888	2.4889	2.4897	2.4894	2.4899	2.4881
A59		2.4908	2.4914	2.4915	2.4913	2.4915	2.4917	2.4917	2.4926	2.4924	2.4928	2.4905
REF5	Ref unbiased	2.4916	2.4925	2.4923	2.4919	2.4919	2.4919	2.4920	2.4922	2.4922	2.4925	2.4914
REF55	Ref biased	2.4923	2.4928	2.4927	2.4924	2.4925	2.4926	2.4924	2.4929	2.4927	2.4932	2.4922

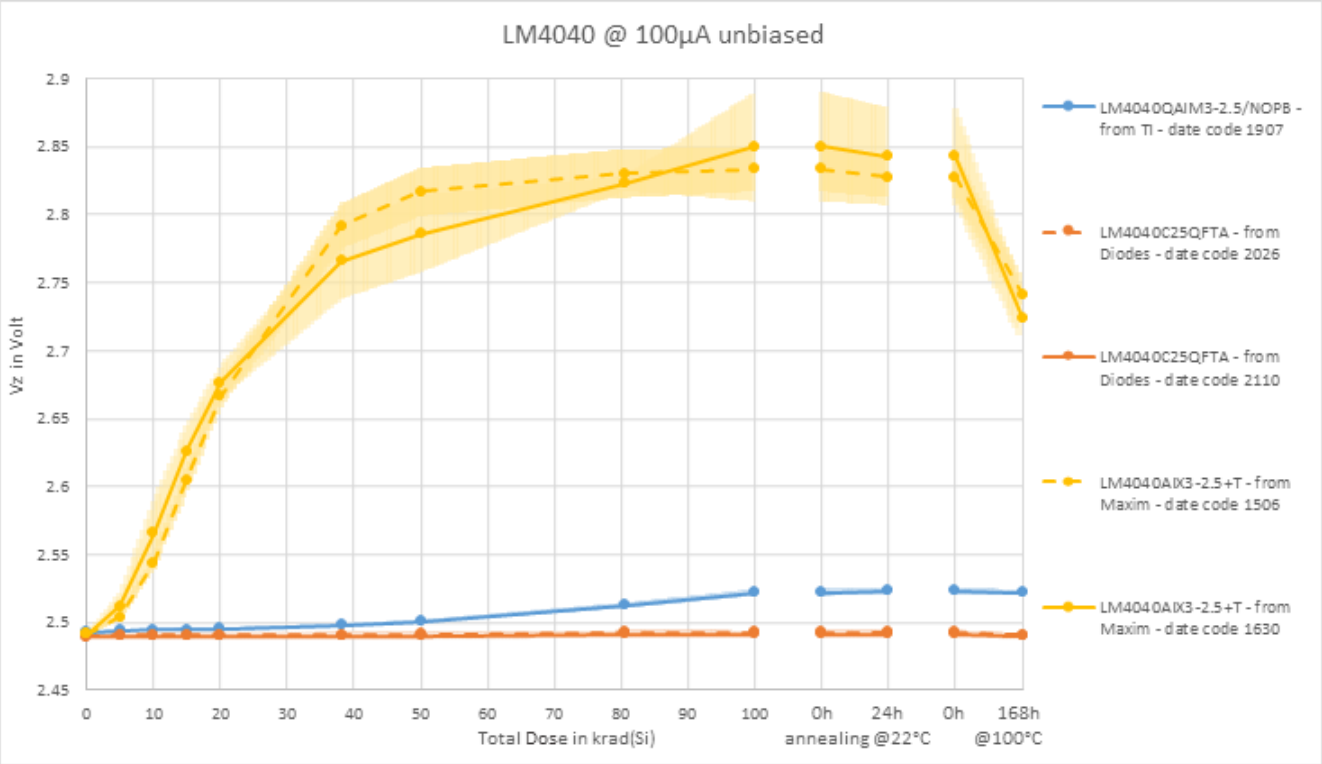
LM4040C25QFTA - from Diodes - date code 2026 - @ I-typ 100µA											Limit acc. DS: Vz = 2.5V ± 1.16% (2.471V – 2.529V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A50	unbiased	2.4870	2.4876	2.4877	2.4876	2.4880	2.4883	2.4885	2.4898	2.4900	2.4903	2.4880
A51		2.4921	2.4926	2.4929	2.4928	2.4931	2.4934	2.4935	2.4947	2.4946	2.4949	2.4912
A52		2.4896	2.4902	2.4904	2.4902	2.4905	2.4906	2.4908	2.4918	2.4918	2.4920	2.4900
A53		2.4914	2.4920	2.4923	2.4921	2.4924	2.4927	2.4929	2.4941	2.4941	2.4945	2.4924
A54		2.4889	2.4895	2.4897	2.4896	2.4899	2.4901	2.4903	2.4914	2.4914	2.4917	2.4913
A55	biased	2.4914	2.4920	2.4922	2.4920	2.4922	2.4922	2.4922	2.4931	2.4928	2.4932	2.4902
A56		2.4921	2.4927	2.4928	2.4926	2.4928	2.4929	2.4928	2.4938	2.4936	2.4940	2.4919
A57		2.4910	2.4916	2.4917	2.4915	2.4917	2.4917	2.4918	2.4926	2.4924	2.4928	2.4903
A58		2.4881	2.4887	2.4888	2.4886	2.4890	2.4888	2.4889	2.4897	2.4895	2.4899	2.4881
A59		2.4908	2.4914	2.4916	2.4913	2.4916	2.4917	2.4918	2.4926	2.4924	2.4929	2.4905
REF5	Ref unbiased	2.4916	2.4925	2.4924	2.4920	2.4920	2.4919	2.4921	2.4923	2.4922	2.4926	2.4915
REF55	Ref biased	2.4924	2.4928	2.4928	2.4925	2.4925	2.4926	2.4925	2.4930	2.4928	2.4933	2.4922

LM4040C25QFTA - from Diodes - date code 2026 - @ I-max 15mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
A50	unbiased	2.4873	2.4881	2.4884	2.4883	2.4888	2.4894	2.4899	2.4917	2.4921	2.4924	2.4898
A51		2.4923	2.4931	2.4934	2.4934	2.4938	2.4943	2.4947	2.4964	2.4965	2.4968	2.4929
A52		2.4897	2.4905	2.4908	2.4907	2.4911	2.4915	2.4918	2.4932	2.4934	2.4937	2.4915
A53		2.4914	2.4922	2.4925	2.4925	2.4928	2.4934	2.4938	2.4954	2.4957	2.4961	2.4937
A54		2.4893	2.4901	2.4904	2.4904	2.4908	2.4913	2.4915	2.4931	2.4933	2.4936	2.4930
A55	biased	2.4916	2.4924	2.4926	2.4925	2.4928	2.4930	2.4932	2.4944	2.4943	2.4948	2.4916
A56		2.4923	2.4930	2.4932	2.4931	2.4934	2.4937	2.4939	2.4951	2.4952	2.4956	2.4934
A57		2.4910	2.4917	2.4919	2.4917	2.4921	2.4923	2.4925	2.4937	2.4936	2.4940	2.4915
A58		2.4883	2.4890	2.4892	2.4890	2.4893	2.4895	2.4897	2.4908	2.4907	2.4912	2.4892
A59		2.4910	2.4917	2.4919	2.4917	2.4921	2.4924	2.4926	2.4937	2.4936	2.4942	2.4918
REF5	Ref unbiased	2.4917	2.4925	2.4924	2.4920	2.4920	2.4920	2.4921	2.4923	2.4922	2.4926	2.4915
REF55	Ref biased	2.4924	2.4927	2.4927	2.4924	2.4925	2.4926	2.4924	2.4929	2.4927	2.4932	2.4922



8.1. Comparison Manufacturer and Date Code

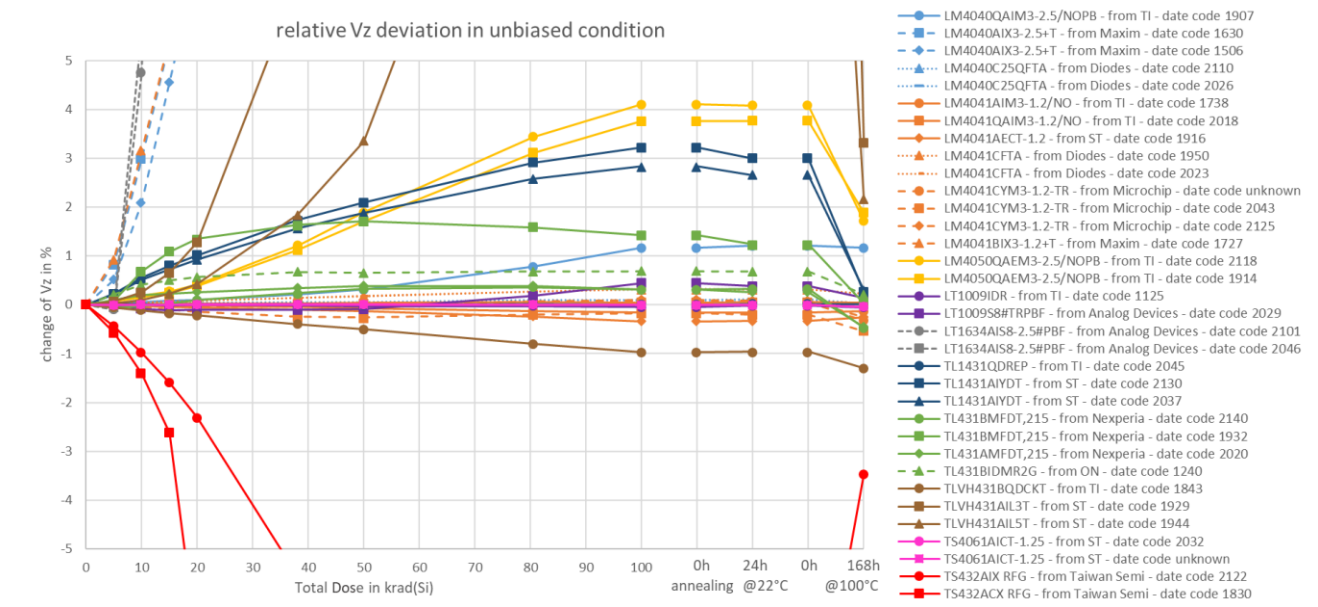
The following graph shows the different behaviour of all measured LM4040 voltage references from different manufacturers and with a different date code.

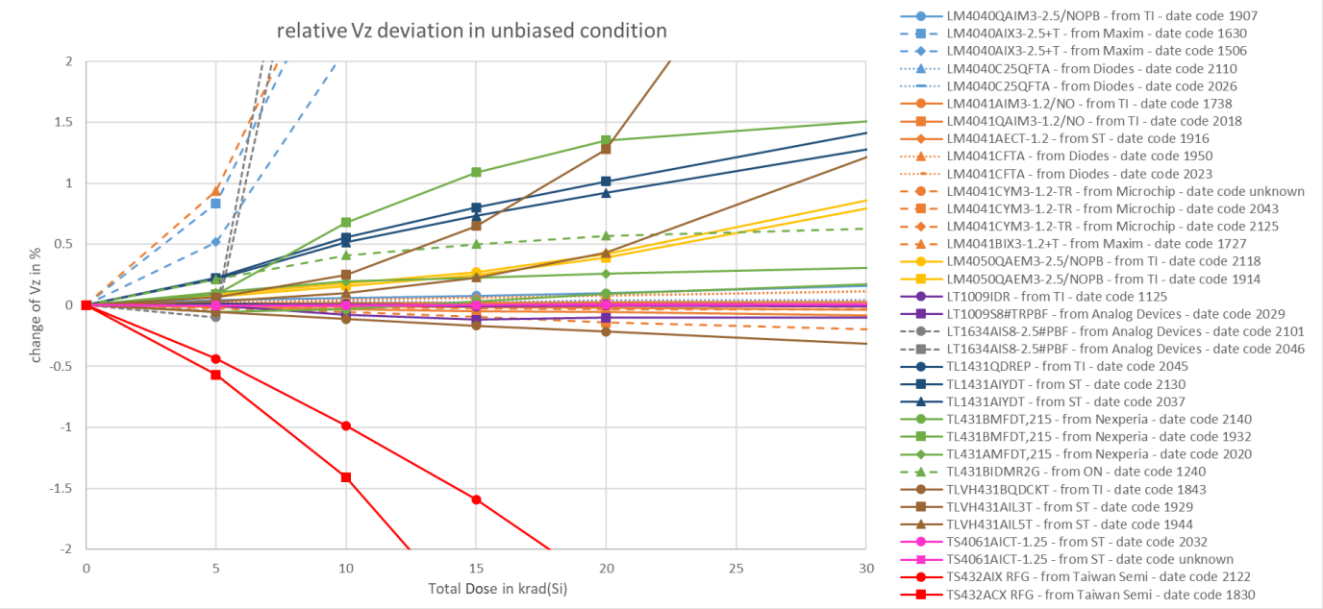


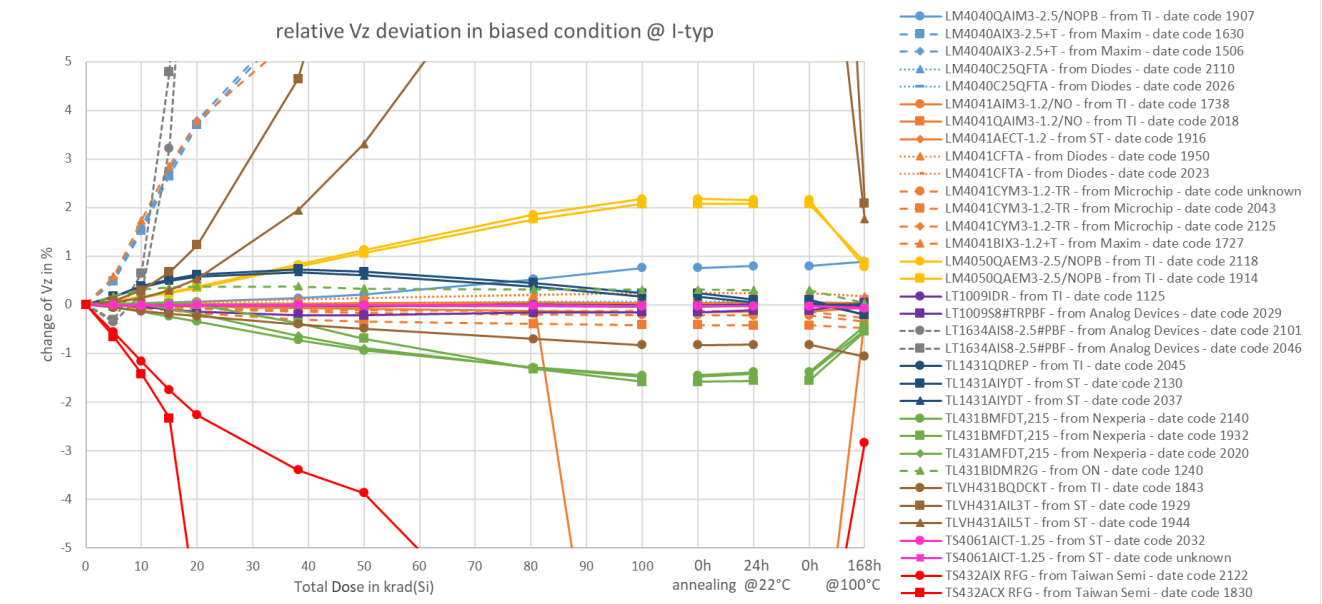
All curves plotted show the average value of all unbiased tested samples (worst case) and the interval behind the curves represent +/- one standard deviation.

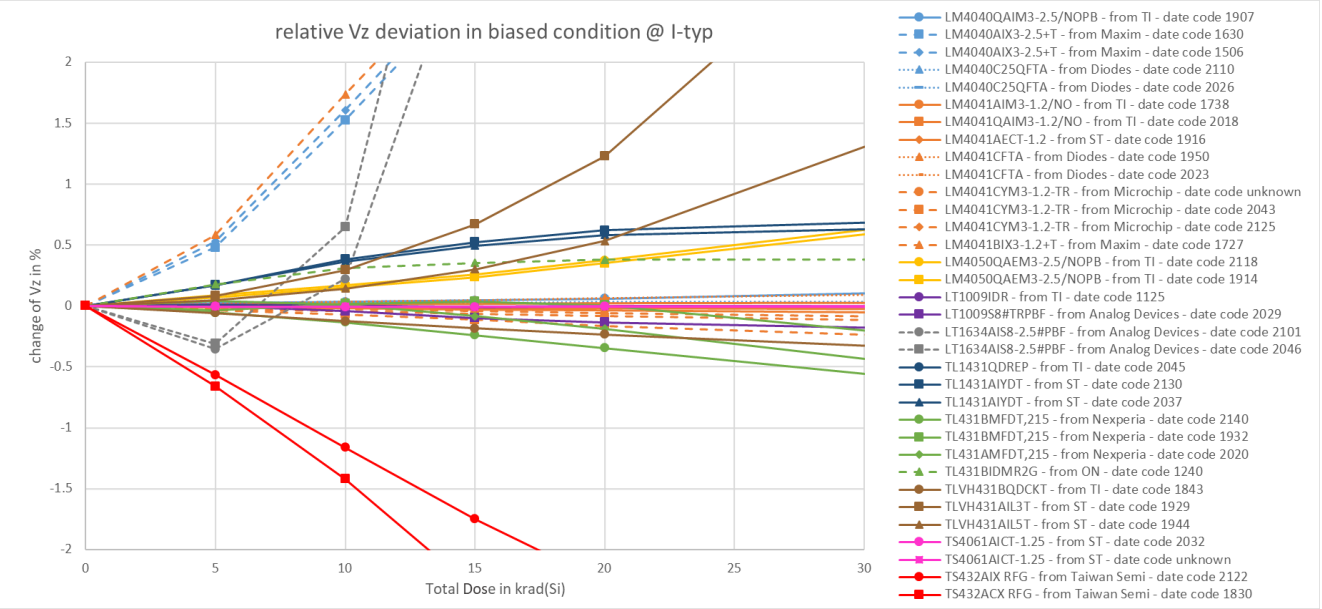
8.2. Comparison with other tested Bandgap References

The following four graphs show the results of the LM4040 Bandgap Voltage References compared to different Bandgap References part types, which were tested at the same time with the same test setup than the LM4040. Additional information on these tests is provided in the Radiation Test Summary [RD02].






relative Vz deviation in biased condition @ I-typ
change of Vz in %
Total Dose in krad(Si)
0h
24h
0h
168h
annealing @22°C
@100°C
LM4040QAIM3-2.5/NOPB - from TI - date code 1907
LM4040AIX3-2.5+T - from Maxim - date code 1630
LM4040AIX3-2.5+T - from Maxim - date code 1506
LM4040C25QFTA - from Diodes - date code 2110
LM4040C25QFTA - from Diodes - date code 2026
LM4041AIM3-1.2/NO - from TI - date code 1738
LM4041QAIM3-1.2/NO - from TI - date code 2018
LM4041AECT-1.2 - from ST - date code 1916
LM4041CFTA - from Diodes - date code 1950
LM4041CFTA - from Diodes - date code 2023
LM4041CYM3-1.2-TR - from Microchip - date code unknown
LM4041CYM3-1.2-TR - from Microchip - date code 2043
LM4041CYM3-1.2-TR - from Microchip - date code 2125
LM4041BIX3-1.2+T - from Maxim - date code 1727
LM4050QAEM3-2.5/NOPB - from TI - date code 2118
LM4050QAEM3-2.5/NOPB - from TI - date code 1914
LT1009IDR - from TI - date code 1125
LT1009S8#TRPBF - from Analog Devices - date code 2029
LT1634AIS8-2.5#PBF - from Analog Devices - date code 2101
LT1634AIS8-2.5#PBF - from Analog Devices - date code 2046
TL1431QDREP - from TI - date code 2045
TL1431AIYDT - from ST - date code 2130
TL1431AIYDT - from ST - date code 2037
TL431BMFDT,215 - from Nexperia - date code 2140
TL431BMFDT,215 - from Nexperia - date code 1932
TL431AMFDT,215 - from Nexperia - date code 2020
TL431BIDMR2G - from ON - date code 1240
TLVH431BQDCKT - from TI - date code 1843
TLVH431AIL3T - from ST - date code 1929
TLVH431AIL5T - from ST - date code 1944
TS4061AICT-1.25 - from ST - date code 2032
TS4061AICT-1.25 - from ST - date code unknown
TS432AIX RFG - from Taiwan Semi - date code 2122
TS432ACX RFG - from Taiwan Semi - date code 1830


relative Vz deviation in biased condition @ I-typ
change of Vz in %
Total Dose in krad(Si)
LM4040QAIM3-2.5/NOPB - from TI - date code 1907
LM4040AIX3-2.5+T - from Maxim - date code 1630
LM4040AIX3-2.5+T - from Maxim - date code 1506
LM4040C25QFTA - from Diodes - date code 2110
LM4040C25QFTA - from Diodes - date code 2026
LM4041AIM3-1.2/NO - from TI - date code 1738
LM4041QAIM3-1.2/NO - from TI - date code 2018
LM4041AECT-1.2 - from ST - date code 1916
LM4041CFTA - from Diodes - date code 1950
LM4041CFTA - from Diodes - date code 2023
LM4041CYM3-1.2-TR - from Microchip - date code unknown
LM4041CYM3-1.2-TR - from Microchip - date code 2043
LM4041CYM3-1.2-TR - from Microchip - date code 2125
LM4041BIX3-1.2+T - from Maxim - date code 1727
LM4050QAEM3-2.5/NOPB - from TI - date code 2118
LM4050QAEM3-2.5/NOPB - from TI - date code 1914
LT1009IDR - from TI - date code 1125
LT1009S8#TRPBF - from Analog Devices - date code 2029
LT1634AIS8-2.5#PBF - from Analog Devices - date code 2101
LT1634AIS8-2.5#PBF - from Analog Devices - date code 2046
TL1431QDREP - from TI - date code 2045
TL1431AIYDT - from ST - date code 2130
TL1431AIYDT - from ST - date code 2037
TL431BMFDT,215 - from Nexperia - date code 2140
TL431BMFDT,215 - from Nexperia - date code 1932
TL431AMFDT,215 - from Nexperia - date code 2020
TL431BIDMR2G - from ON - date code 1240
TLVH431BQDCKT - from TI - date code 1843
TLVH431AIL3T - from ST - date code 1929
TLVH431AIL5T - from ST - date code 1944
TS4061AICT-1.25 - from ST - date code 2032
TS4061AICT-1.25 - from ST - date code unknown
TS432AIX RFG - from Taiwan Semi - date code 2122
TS432ACX RFG - from Taiwan Semi - date code 1830

9. CONCLUSION

Based on the application of the voltage references the acceptable deviation of the reference voltage can be very different.

As we consider a deviation of up to 2% as acceptable than LM4040 references from two out of three tested manufacturers would pass this criteria up to 100 krad and all of the tested LM4040 would pass up to a dose of 5 krad.

It was also noticed that this deviation could lead to a higher but also a lower reference voltage.

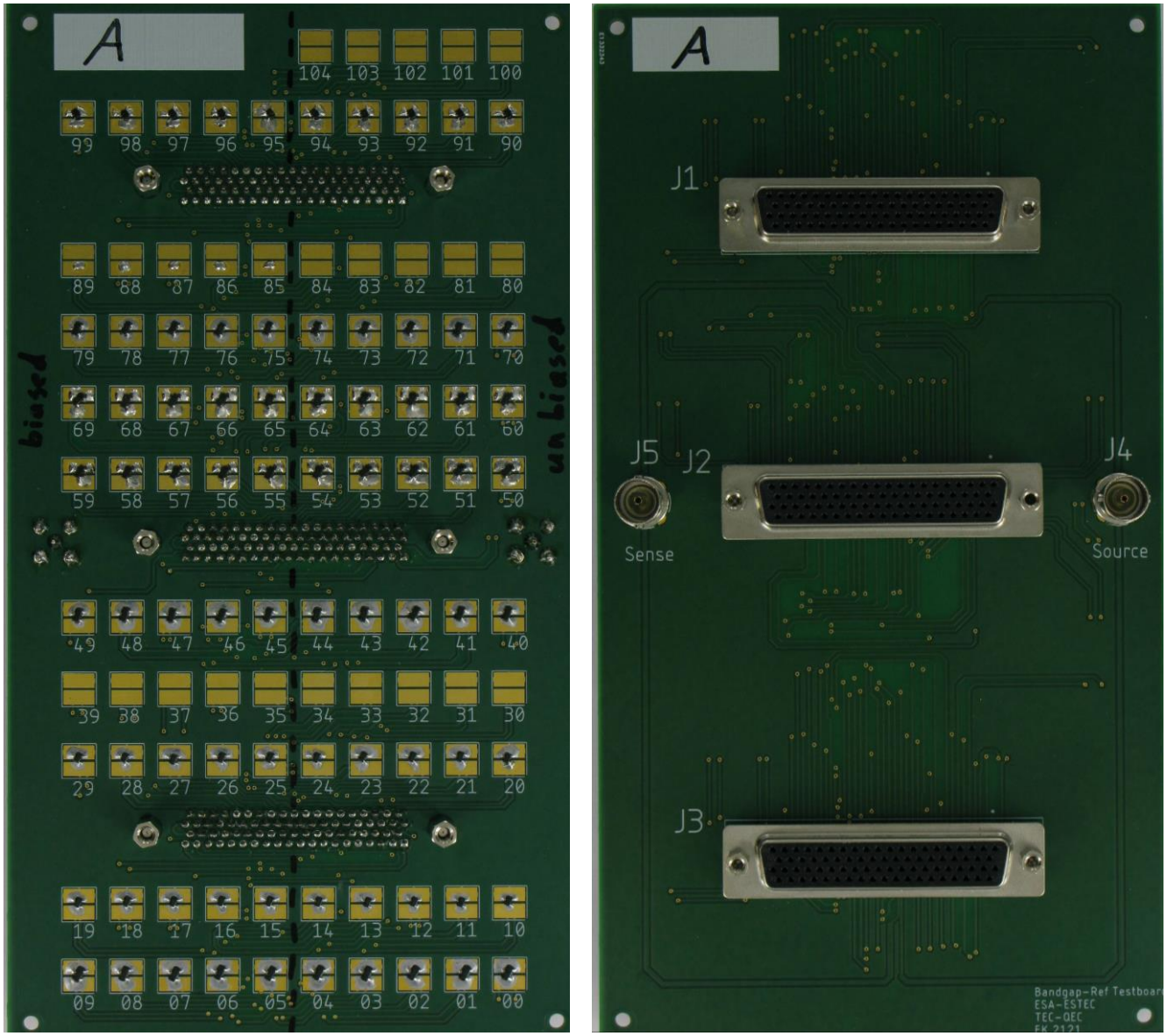
In general, a higher deviation was found for the unbiased samples.

ANNEX A – DATASHEET

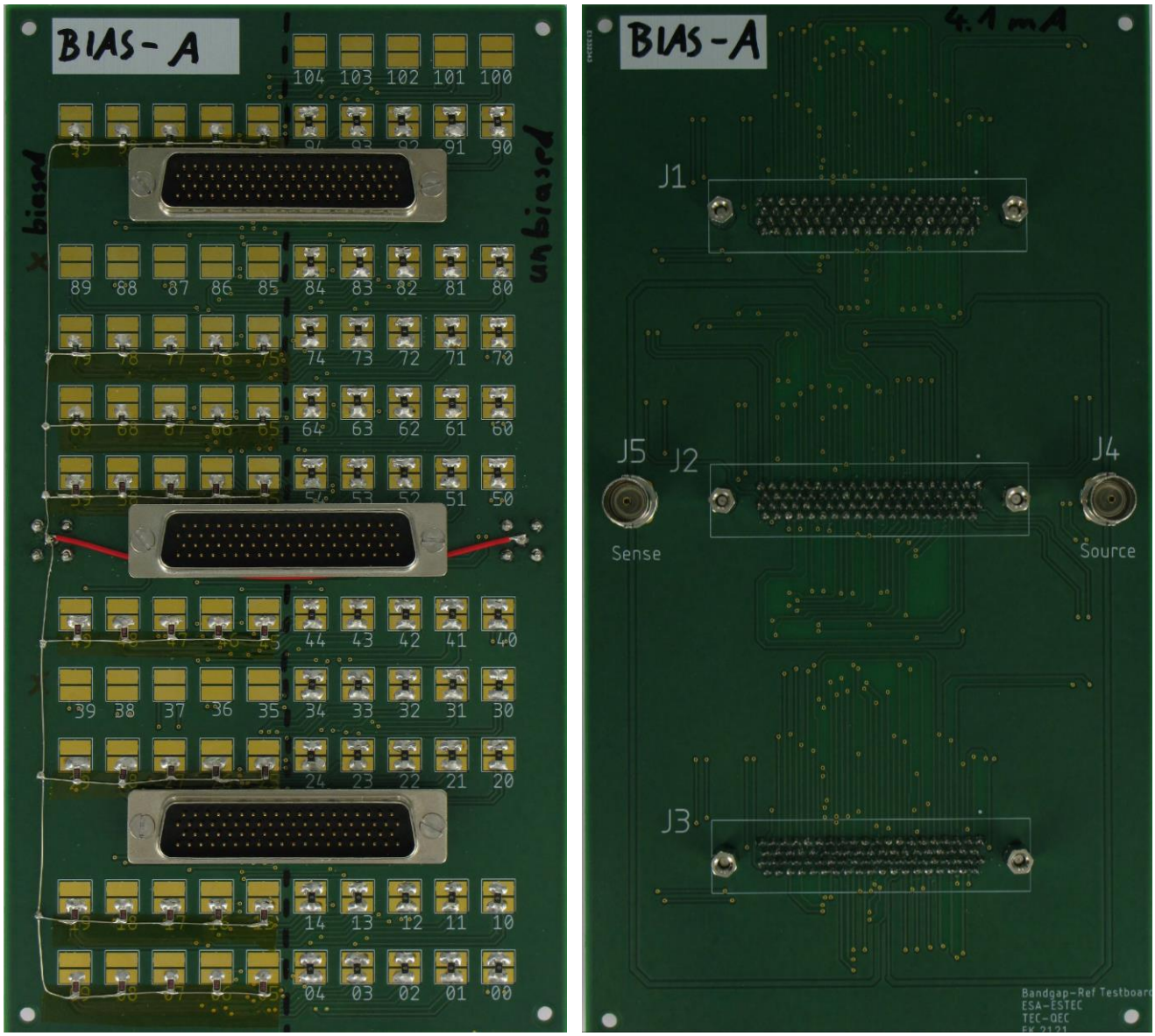
Part Type	Manufacturer	Link to Datasheet
LM4040QAIM3-2.5/NOPB	Texas Instruments	https://www.ti.com/lit/ds/symlink/lm4040-n-q1.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1617895488524
LM4040AIX3-2.5+T	Maxim Integrated	https://datasheets.maximintegrated.com/en/ds/LM4040-LM4040D.pdf
LM4040C25QFTA	Diodes Inc.	https://www.diodes.com/assets/Datasheets/LM4040.pdf

ANNEX B – SET-UP

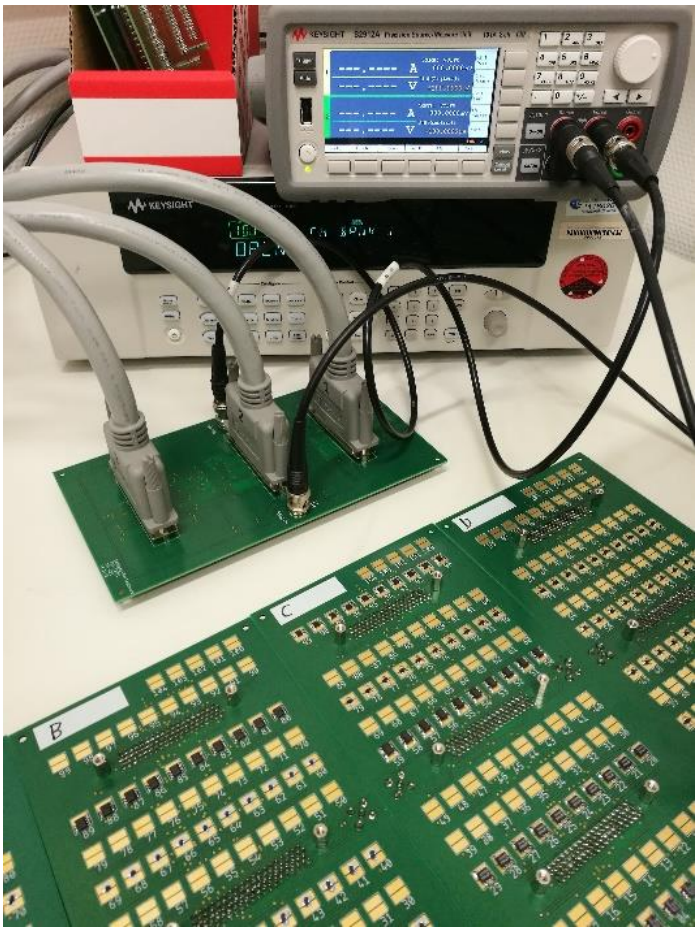
Test board front- and backside with the LM4040 on position 00 to 59:



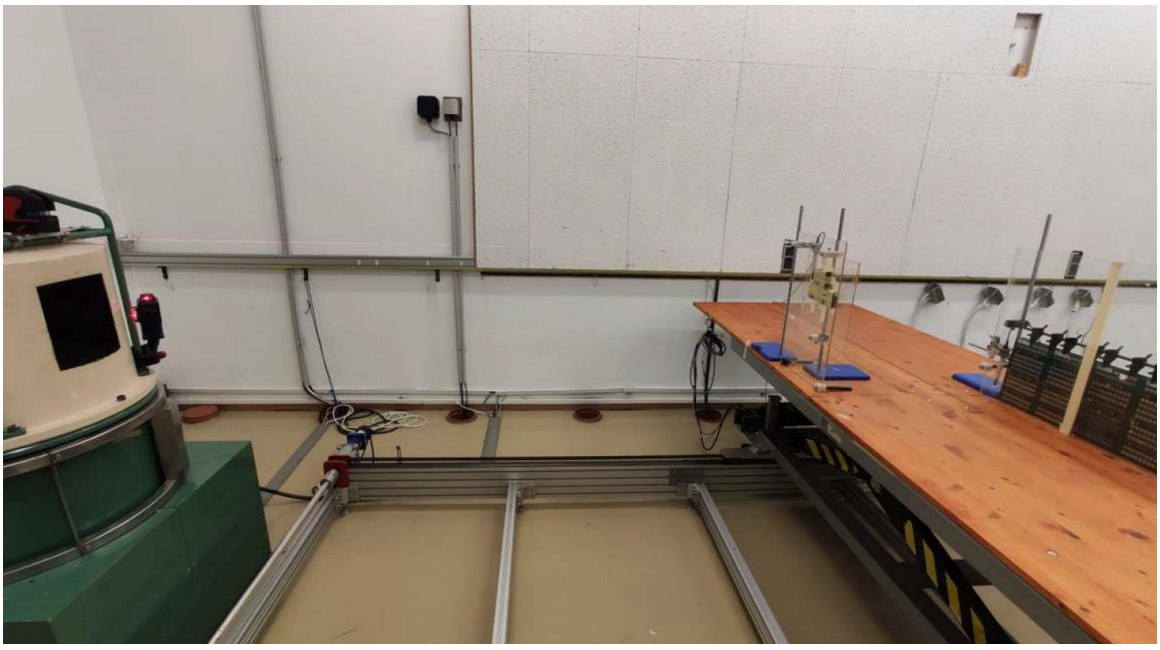
Biasing board front- and backside with the biasing resistors on it:

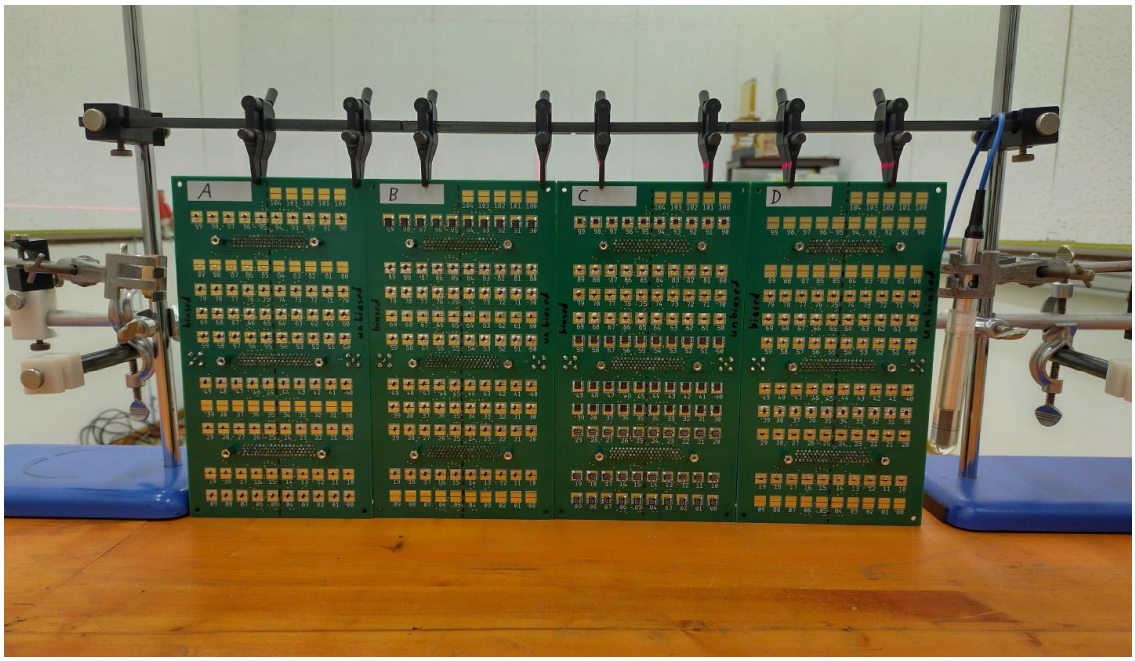


Measurement setup with the cable connection from the Test Board to the Switching Matrix and the Source Measure Unit:



Position of the boards inside the Co60 irradiation chamber:





ANNEX C – RADIATION TEST SUMMARY – IRRADIATION STEPS

Irr. Run	Start Date & Time (CET)	End Date & Time (CET)	Total Ionising Dose (water)	Dose Rate (water)
1	24-01-2022 18:11:39	25-01-2022 13:37:10	55.69 Gy	2.867 Gy/h
2	25-01-2022 15:13:42	26-01-2022 11:52:43	55.67 Gy	2.696 Gy/h
3	26-01-2022 13:30:18	27-01-2022 10:16:45	55.68 Gy	2.680 Gy/h
4	27-01-2022 12:11:47	28-01-2022 08:55:59	55.68 Gy	2.685 Gy/h
5	28-01-2022 10:31:55	31-01-2022 09:30:00	202.3 Gy	2.851 Gy/h
6	31-01-2022 11:18:44	02-02-2022 09:21:12	131.8 Gy	2.863 Gy/h
7	02-02-2022 11:05:44	07-02-2022 09:55:08	339.6 Gy	2.858 Gy/h
8	07-02-2022 11:41:36	10-02-2022 15:46:14	217.1 Gy	2.854 Gy/h
		Total	1.114 kGy	

Note: *The uncertainty budgets (according to TEC-QEC/PR001 section 12) are: 4.2 % (k=2) for absorbed dose to water and 4.4% (k=2) for absorbed dose rate to water*

	units	Min.	Max.	Time-weighted Average
Temperature	°C	20.9	21.2	20.93
Pressure	mbar	996.6	1034.5	1019.01
Relative Humidity	%	47.1	54	51.45

Dosimeter position relative to ^{60}Co source		
X	cm	36.5
Y	cm	292
Z	cm	-21

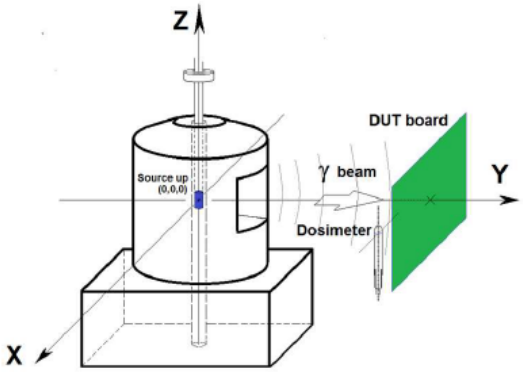


Figure 1 Co-60 irradiator head and board positioning sketch

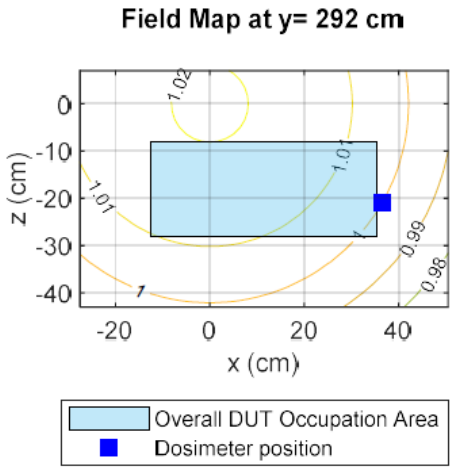


Figure 2: Qualitative indication of dose rate distribution normalized to dosemeter readings. Axes origin located at source centre. Graphs for information only, of the run with highest dose rate.