ESA ESTEC
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands

TL431_TID_TEST_REPORT

TL431BMFDT,215
Date Code: 2140 and 1932
2.5V Adjustable voltage reference
Nexperia

TL431AMFDT,215
Date Code: 2020
2.5V Adjustable voltage reference
Nexperia

TL431BIDMR2G
Date Code: 1240
2.5V Adjustable voltage reference
ON Semiconductor

Prepared by	Florian Krimmel
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CHANGE LOG

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Creation		11/05/2022	All	All

DISTRIBUTION

Name/Organisational Unit

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1. INTRODUCTION

The current report presents the TID results on the Bandgap Voltage Reference TL431

- TL431BMFDT,215, date code: 2140 and 1932, Nexperia
- TL431AMFDT,215, date code: 2020, Nexperia
- TL431BIDMR2G, date code: 1240, ON Semiconductor

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

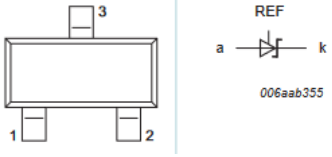
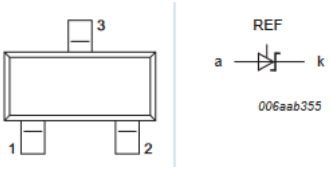
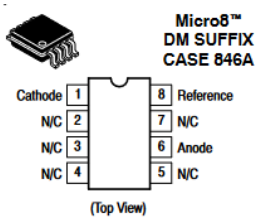
Part number	TL431BMFDT,215	TL431AMFDT,215	TL431BIDMR2G
Manufacturer	Nexperia	Nexperia	ON Semiconductor
Function	2.5V Adjustable voltage reference	2.5V Adjustable voltage reference	2.5V Adjustable voltage reference
Technology	Bipolar	Bipolar	Bipolar
Package			
Date Code [yyww]	2140 and 1932	2020	1240
Distributor	DigiKey and Farnell	Mouser	Mouser
Part # (sample n°) date code	5 samples unbiased (n° C60 to C64) (n° C70 to C74) 5 samples biased (n° C65 to C69) (n° C75 to C79) 1 reference unbiased (n° REF26) (n° REF27) 1 reference biased (n° REF76) (n° REF77)	5 samples unbiased (n° C80 to C84) 5 samples biased (n° C85 to C89) 1 reference unbiased (n° REF28) 1 reference biased (n° REF78)	5 samples unbiased (n° C90 to C94) 5 samples biased (n° C95 to C99) 1 reference unbiased (n° REF29) 1 reference biased (n° REF79)

Table 1: Part & procurement information

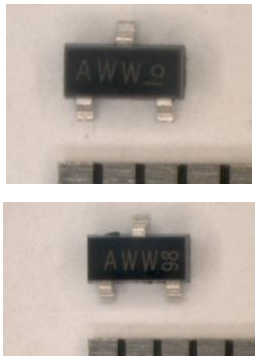
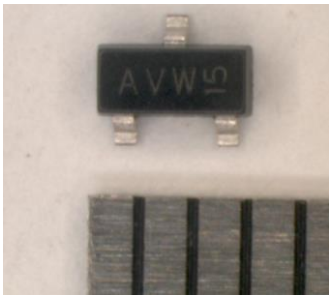
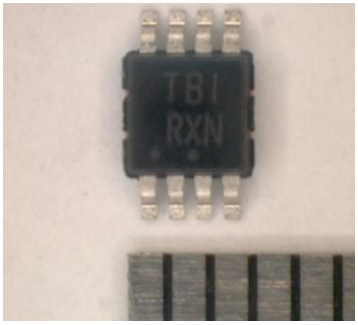
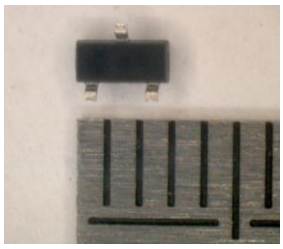
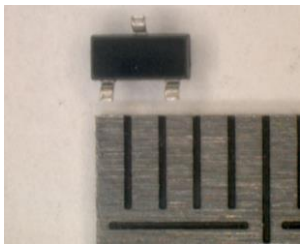
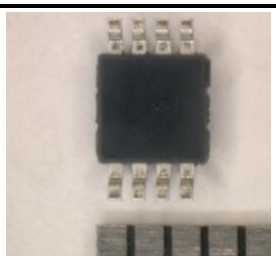
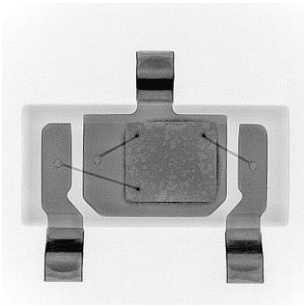
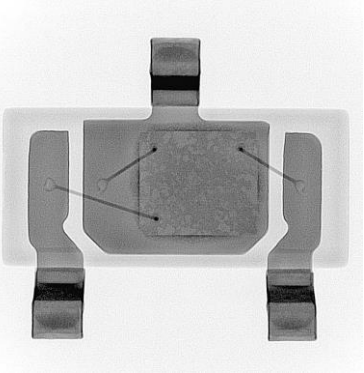
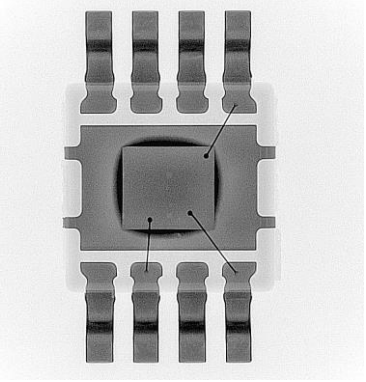
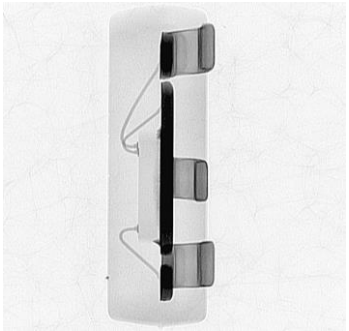
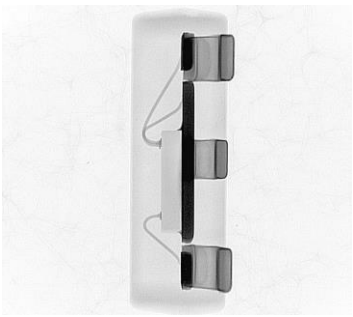
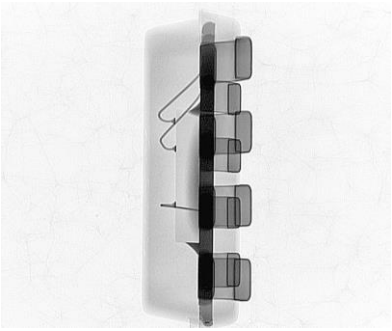
Part number	TL431BMFDT,215	TL431AMFDT,215	TL431BIDMR2G
Package marking top			
Package marking bottom			
X-ray top view			
X-ray side view			

Table 2: 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 1. 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.

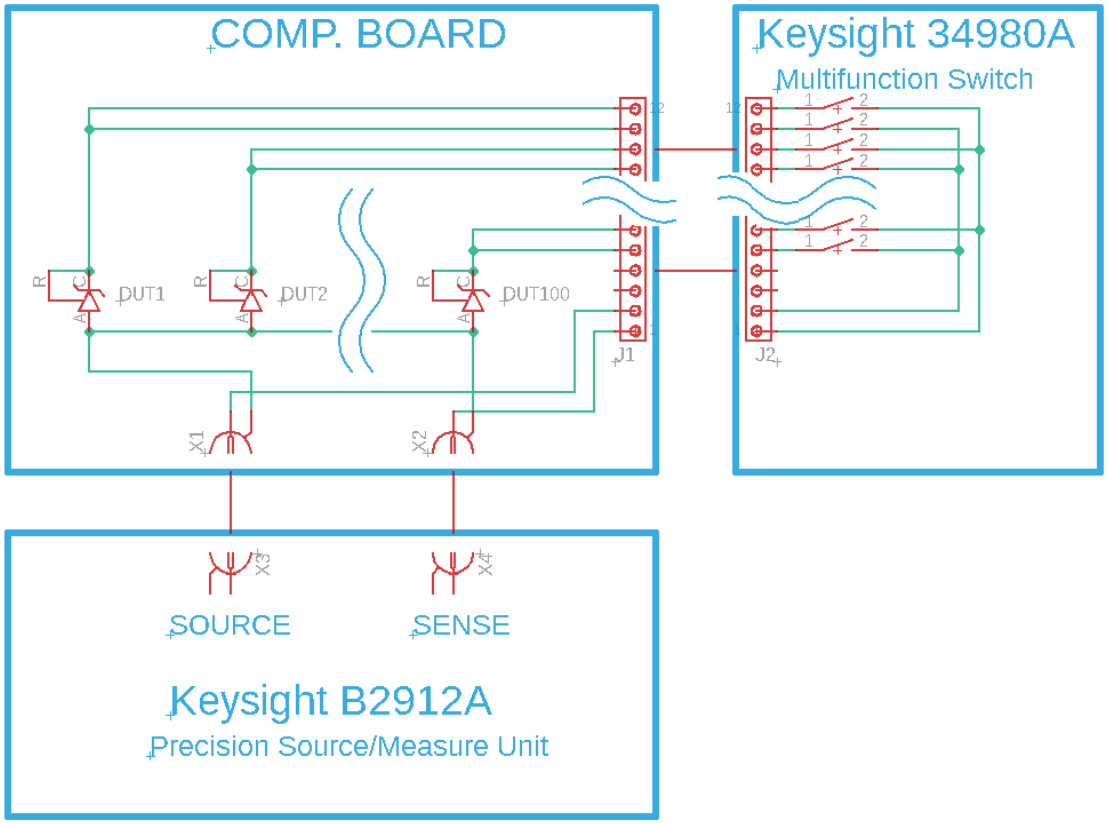


Figure 1: Simplified schematic of the overall test set-up

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 x 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 summarised the main biasing conditions

PART TYPE	Value	Unit
TL431BMFDT,215	10	mA
TL431AMFDT,215	10	mA
TL431BIDMR2G	10	mA

Table 2: Biasing conditions during irradiation

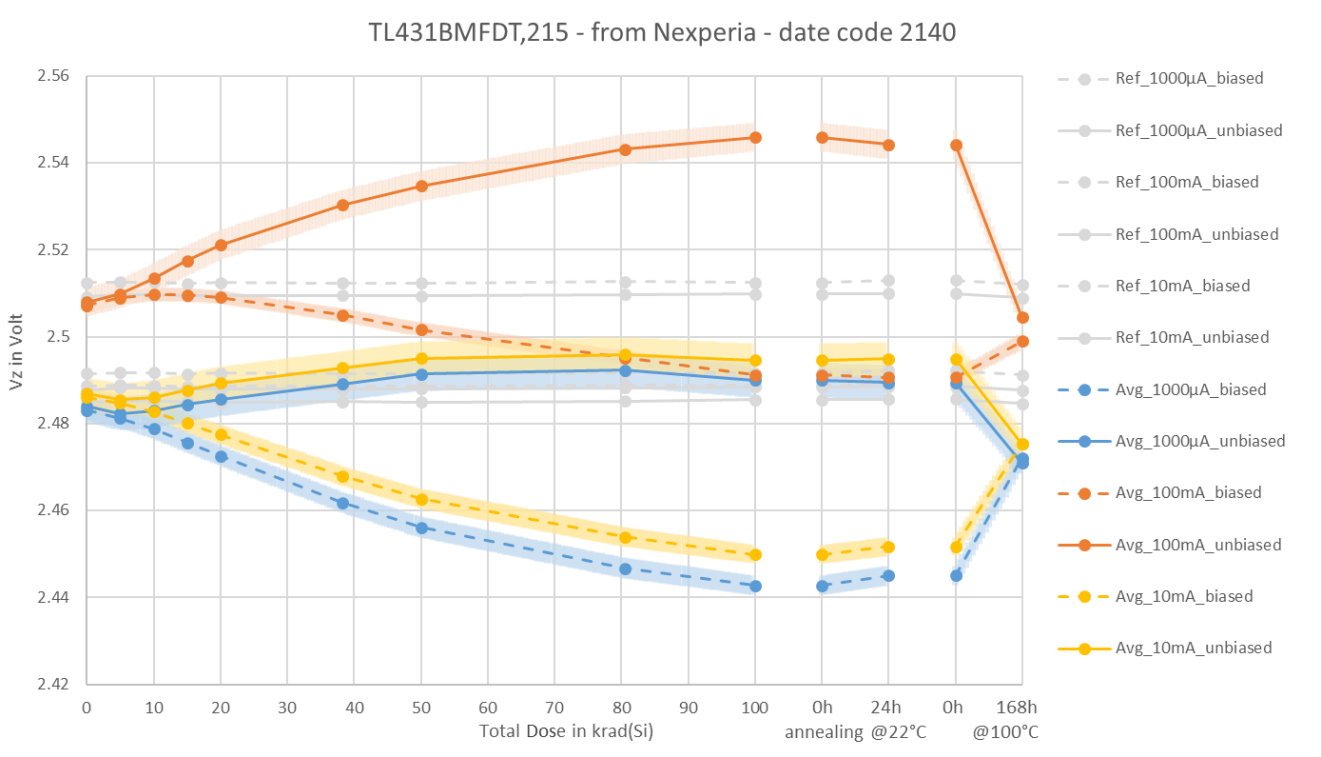
8. TID RESULTS

8.1. TID RESULTS - TL431BMFDT,215 - from Nexperia - date code 2140

TL431BMFDT,215 - from Nexperia - date code 2140 - @ I-min 1000µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C60	unbiased	2.4839	2.4819	2.4823	2.4837	2.4851	2.4892	2.4919	2.4933	2.4917	2.4913	2.4717
C61		2.4851	2.4831	2.4832	2.4847	2.4862	2.4898	2.4922	2.4939	2.4919	2.4915	2.4722
C62		2.4885	2.4872	2.4882	2.4895	2.4906	2.4935	2.4957	2.4965	2.4937	2.4933	2.4745
C63		2.4784	2.4766	2.4771	2.4786	2.4798	2.4830	2.4851	2.4858	2.4836	2.4831	2.4665
C64		2.4841	2.4827	2.4840	2.4854	2.4864	2.4900	2.4922	2.4922	2.4889	2.4880	2.4695
C65	biased	2.4857	2.4840	2.4816	2.4787	2.4756	2.4649	2.4592	2.4498	2.4457	2.4480	2.4753
C66		2.4797	2.4779	2.4754	2.4722	2.4692	2.4583	2.4526	2.4432	2.4395	2.4418	2.4688
C67		2.4830	2.4814	2.4791	2.4759	2.4728	2.4619	2.4561	2.4469	2.4429	2.4452	2.4720
C68		2.4836	2.4812	2.4785	2.4753	2.4722	2.4618	2.4561	2.4466	2.4426	2.4448	2.4718
C69		2.4838	2.4818	2.4792	2.4763	2.4732	2.4626	2.4570	2.4474	2.4432	2.4456	2.4728
REF26	Ref unbiased	2.4848	2.4852	2.4853	2.4850	2.4849	2.4850	2.4850	2.4852	2.4855	2.4856	2.4846
REF76	Ref biased	2.4887	2.4889	2.4888	2.4885	2.4887	2.4885	2.4886	2.4889	2.4888	2.4893	2.4883

TL431BMFDT,215 - from Nexperia - date code 2140 - @ I-typ 10mA											Limit acc. DS: Vz = 2.495V ± 0.72% (2.477V – 2.513V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C60	unbiased	2.4869	2.4851	2.4854	2.4870	2.4888	2.4927	2.4953	2.4967	2.4960	2.4966	2.4761
C61		2.4881	2.4864	2.4865	2.4881	2.4899	2.4935	2.4959	2.4975	2.4964	2.4969	2.4768
C62		2.4913	2.4902	2.4912	2.4928	2.4941	2.4973	2.4993	2.5000	2.4982	2.4986	2.4789
C63		2.4814	2.4799	2.4803	2.4820	2.4835	2.4868	2.4886	2.4895	2.4883	2.4888	2.4710
C64		2.4870	2.4859	2.4871	2.4887	2.4901	2.4937	2.4957	2.4960	2.4940	2.4938	2.4738
C65	biased	2.4885	2.4873	2.4855	2.4830	2.4803	2.4708	2.4655	2.4567	2.4527	2.4545	2.4785
C66		2.4827	2.4814	2.4795	2.4768	2.4742	2.4646	2.4594	2.4506	2.4468	2.4486	2.4722
C67		2.4859	2.4848	2.4830	2.4802	2.4776	2.4679	2.4625	2.4538	2.4499	2.4517	2.4752
C68		2.4866	2.4848	2.4827	2.4799	2.4773	2.4681	2.4628	2.4540	2.4500	2.4517	2.4752
C69		2.4867	2.4852	2.4831	2.4807	2.4780	2.4687	2.4635	2.4545	2.4503	2.4521	2.4760
REF26	Ref unbiased	2.4877	2.4883	2.4883	2.4880	2.4879	2.4879	2.4880	2.4883	2.4884	2.4886	2.4877
REF76	Ref biased	2.4916	2.4918	2.4917	2.4914	2.4917	2.4914	2.4914	2.4918	2.4916	2.4922	2.4912

TL431BMFDT,215 - from Nexperia - date code 2140 - @ I-max 100mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C60	unbiased	2.5080	2.5096	2.5127	2.5166	2.5204	2.5299	2.5346	2.5433	2.5467	2.5453	2.5052
C61		2.5095	2.5109	2.5140	2.5179	2.5217	2.5310	2.5355	2.5445	2.5473	2.5460	2.5062
C62		2.5117	2.5138	2.5177	2.5219	2.5254	2.5343	2.5386	2.5467	2.5491	2.5474	2.5074
C63		2.5028	2.5046	2.5082	2.5124	2.5159	2.5250	2.5291	2.5375	2.5405	2.5387	2.5006
C64		2.5080	2.5102	2.5144	2.5185	2.5221	2.5314	2.5354	2.5436	2.5459	2.5435	2.5027
C65	biased	2.5089	2.5107	2.5115	2.5114	2.5108	2.5066	2.5032	2.4968	2.4929	2.4925	2.5014
C66		2.5045	2.5064	2.5074	2.5073	2.5069	2.5028	2.4995	2.4929	2.4892	2.4885	2.4964
C67		2.5068	2.5086	2.5095	2.5091	2.5085	2.5040	2.5005	2.4941	2.4903	2.4899	2.4983
C68		2.5086	2.5098	2.5105	2.5103	2.5098	2.5061	2.5029	2.4964	2.4926	2.4920	2.4998
C69		2.5073	2.5090	2.5098	2.5098	2.5093	2.5054	2.5021	2.4954	2.4912	2.4906	2.4990
REF26	Ref unbiased	2.5091	2.5097	2.5096	2.5094	2.5093	2.5095	2.5094	2.5097	2.5098	2.5099	2.5090
REF76	Ref biased	2.5125	2.5126	2.5126	2.5123	2.5125	2.5123	2.5123	2.5126	2.5124	2.5129	2.5120



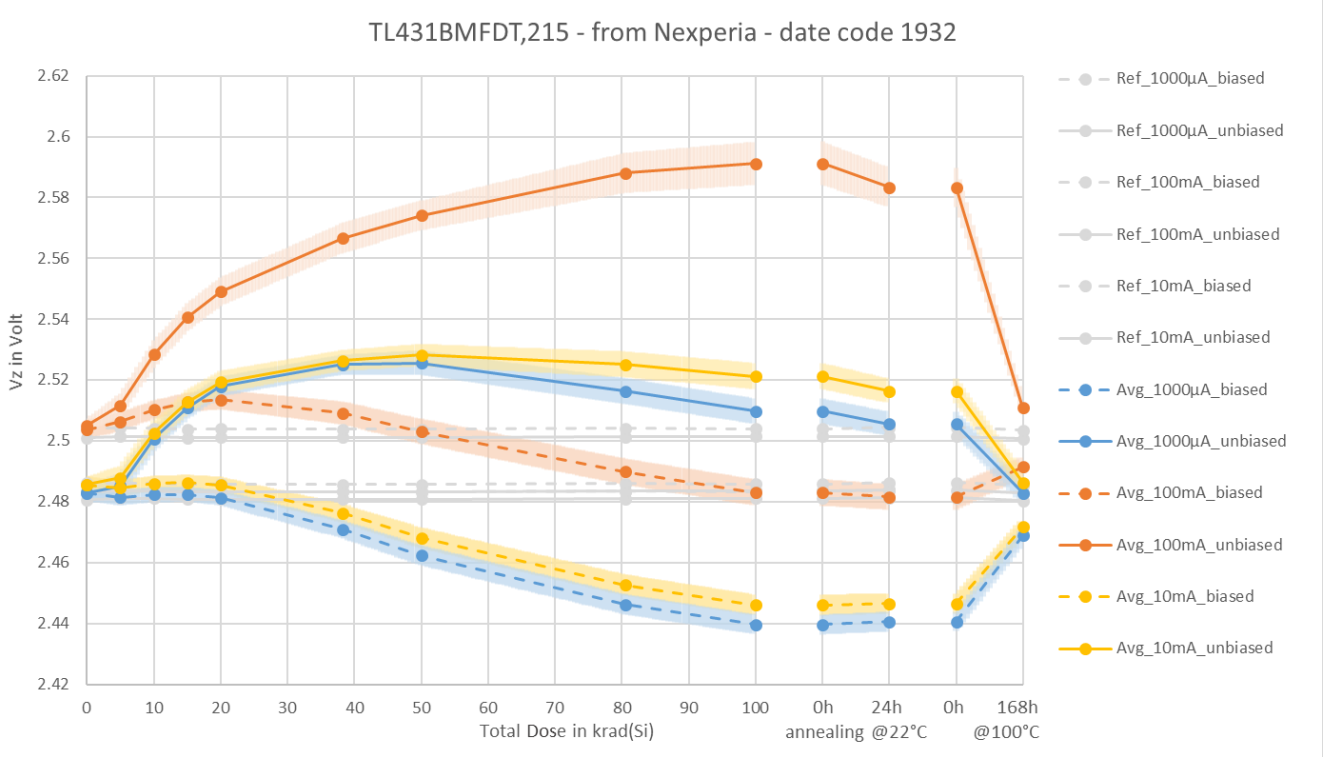
For all curves, which show an average over all measured samples, the coloured interval behind the curves represent +/- one standard deviation.

8.2. TID RESULTS - TL431BMFDT,215 - from Nexperia - date code 1932

TL431BMFDT,215 - from Nexperia - date code 1932 - @ I-min 1000µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C70	unbiased	2.4850	2.4886	2.5038	2.5138	2.5205	2.5261	2.5260	2.5183	2.5123	2.5082	2.4861
C71		2.4821	2.4827	2.4977	2.5081	2.5152	2.5220	2.5224	2.5127	2.5066	2.5032	2.4821
C72		2.4867	2.4901	2.5057	2.5158	2.5223	2.5285	2.5293	2.5210	2.5143	2.5101	2.4870
C73		2.4811	2.4842	2.4995	2.5095	2.5161	2.5214	2.5208	2.5112	2.5043	2.5003	2.4802
C74		2.4808	2.4809	2.4967	2.5076	2.5155	2.5275	2.5299	2.5189	2.5113	2.5066	2.4788
C75	biased	2.4818	2.4805	2.4816	2.4816	2.4803	2.4693	2.4605	2.4441	2.4375	2.4385	2.4677
C76		2.4872	2.4850	2.4854	2.4853	2.4844	2.4751	2.4671	2.4515	2.4449	2.4458	2.4740
C77		2.4806	2.4791	2.4800	2.4800	2.4788	2.4678	2.4589	2.4431	2.4369	2.4378	2.4664
C78		2.4811	2.4795	2.4805	2.4808	2.4797	2.4699	2.4613	2.4454	2.4387	2.4397	2.4675
C79		2.4841	2.4830	2.4845	2.4847	2.4837	2.4730	2.4642	2.4476	2.4406	2.4415	2.4692
REF27	Ref unbiased	2.4807	2.4812	2.4812	2.4808	2.4809	2.4808	2.4808	2.4810	2.4813	2.4814	2.4804
REF77	Ref biased	2.4837	2.4837	2.4835	2.4832	2.4834	2.4833	2.4833	2.4836	2.4834	2.4840	2.4829

TL431BMFDT,215 - from Nexperia - date code 1932 - @ I-typ 10mA											Limit acc. DS: Vz = 2.495V ± 0.72% (2.477V – 2.513V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C70	unbiased	2.4876	2.4913	2.5061	2.5161	2.5226	2.5290	2.5301	2.5287	2.5255	2.5202	2.4895
C71		2.4846	2.4854	2.4993	2.5097	2.5164	2.5227	2.5242	2.5206	2.5173	2.5132	2.4855
C72		2.4893	2.4926	2.5076	2.5177	2.5239	2.5307	2.5323	2.5301	2.5261	2.5211	2.4904
C73		2.4838	2.4869	2.5017	2.5118	2.5178	2.5236	2.5246	2.5214	2.5174	2.5123	2.4837
C74		2.4836	2.4837	2.4984	2.5089	2.5161	2.5264	2.5299	2.5253	2.5201	2.5154	2.4822
C75	biased	2.4843	2.4837	2.4852	2.4856	2.4846	2.4747	2.4663	2.4506	2.4440	2.4446	2.4705
C76		2.4899	2.4883	2.4891	2.4894	2.4889	2.4805	2.4731	2.4581	2.4516	2.4520	2.4769
C77		2.4833	2.4824	2.4835	2.4840	2.4831	2.4732	2.4647	2.4494	2.4432	2.4436	2.4694
C78		2.4835	2.4825	2.4839	2.4844	2.4838	2.4748	2.4667	2.4514	2.4447	2.4453	2.4702
C79		2.4866	2.4862	2.4881	2.4886	2.4879	2.4782	2.4699	2.4539	2.4470	2.4475	2.4720
REF27	Ref unbiased	2.4832	2.4837	2.4836	2.4833	2.4835	2.4834	2.4833	2.4835	2.4837	2.4838	2.4829
REF77	Ref biased	2.4862	2.4862	2.4860	2.4857	2.4859	2.4858	2.4858	2.4861	2.4859	2.4864	2.4854

TL431BMFDT,215 - from Nexperia - date code 1932 - @ I-max 100mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C70	unbiased	2.5071	2.5155	2.5329	2.5452	2.5540	2.5723	2.5793	2.5961	2.6003	2.5916	2.5146
C71		2.5036	2.5085	2.5243	2.5365	2.5446	2.5610	2.5678	2.5809	2.5845	2.5775	2.5096
C72		2.5080	2.5159	2.5330	2.5453	2.5536	2.5711	2.5785	2.5932	2.5964	2.5881	2.5146
C73		2.5035	2.5113	2.5284	2.5407	2.5487	2.5661	2.5731	2.5874	2.5907	2.5825	2.5088
C74		2.5038	2.5077	2.5239	2.5358	2.5442	2.5630	2.5717	2.5829	2.5844	2.5768	2.5073
C75	biased	2.5026	2.5057	2.5099	2.5122	2.5129	2.5081	2.5018	2.4883	2.4815	2.4800	2.4903
C76		2.5088	2.5108	2.5143	2.5169	2.5180	2.5148	2.5095	2.4968	2.4902	2.4886	2.4973
C77		2.5016	2.5042	2.5080	2.5104	2.5111	2.5061	2.4997	2.4866	2.4799	2.4785	2.4891
C78		2.5009	2.5033	2.5070	2.5094	2.5103	2.5059	2.4998	2.4866	2.4797	2.4785	2.4890
C79		2.5045	2.5079	2.5123	2.5148	2.5158	2.5112	2.5049	2.4912	2.4841	2.4825	2.4918
REF27	Ref unbiased	2.5010	2.5015	2.5014	2.5011	2.5013	2.5012	2.5012	2.5014	2.5016	2.5016	2.5007
REF77	Ref biased	2.5043	2.5044	2.5041	2.5039	2.5040	2.5039	2.5038	2.5042	2.5040	2.5045	2.5035

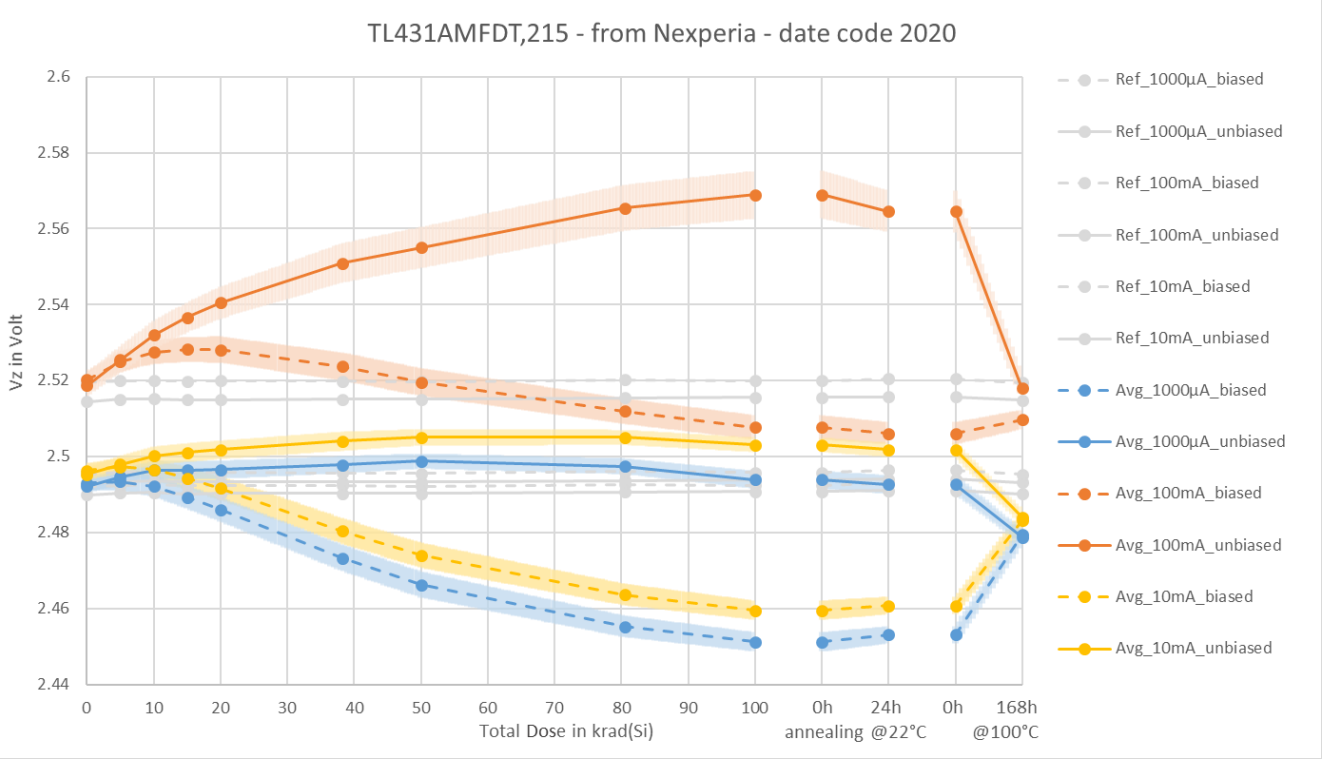


8.3. TID RESULTS - TL431AMFDT,215 - from Nexperia - date code 2020

TL431AMFDT,215 - from Nexperia - date code 2020 - @ I-min 1000µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C80	unbiased	2.4916	2.4956	2.4981	2.4985	2.4986	2.4999	2.5003	2.4983	2.4946	2.4932	2.4800
C81		2.4915	2.4955	2.4972	2.4967	2.4966	2.4975	2.4982	2.4955	2.4911	2.4895	2.4781
C82		2.4926	2.4932	2.4939	2.4935	2.4936	2.4953	2.4967	2.4959	2.4925	2.4915	2.4785
C83		2.4948	2.4974	2.4992	2.4992	2.4991	2.5004	2.5014	2.5005	2.4973	2.4960	2.4811
C84		2.4904	2.4920	2.4940	2.4944	2.4948	2.4963	2.4975	2.4971	2.4941	2.4931	2.4763
C85	biased	2.4907	2.4903	2.4884	2.4853	2.4820	2.4692	2.4623	2.4521	2.4483	2.4504	2.4767
C86		2.4919	2.4918	2.4903	2.4872	2.4838	2.4710	2.4641	2.4536	2.4497	2.4518	2.4779
C87		2.4940	2.4947	2.4934	2.4902	2.4868	2.4732	2.4659	2.4545	2.4506	2.4525	2.4797
C88		2.4936	2.4948	2.4942	2.4915	2.4887	2.4760	2.4689	2.4576	2.4531	2.4549	2.4800
C89		2.4952	2.4958	2.4948	2.4922	2.4893	2.4774	2.4705	2.4589	2.4545	2.4559	2.4828
REF28	Ref unbiased	2.4899	2.4905	2.4906	2.4902	2.4903	2.4904	2.4903	2.4907	2.4908	2.4911	2.4902
REF78	Ref biased	2.4921	2.4925	2.4926	2.4923	2.4925	2.4924	2.4922	2.4927	2.4925	2.4932	2.4921

TL431AMFDT,215 - from Nexperia - date code 2020 - @ I-typ 10mA											Limit acc. DS: Vz = 2.495V ± 0.72% (2.477V – 2.513V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C80	unbiased	2.4944	2.4983	2.5014	2.5027	2.5034	2.5058	2.5063	2.5056	2.5033	2.5019	2.4848
C81		2.4950	2.4991	2.5015	2.5019	2.5027	2.5049	2.5058	2.5053	2.5027	2.5006	2.4839
C82		2.4960	2.4967	2.4979	2.4983	2.4990	2.5013	2.5028	2.5032	2.5015	2.5006	2.4837
C83		2.4980	2.5007	2.5030	2.5037	2.5044	2.5067	2.5076	2.5080	2.5062	2.5050	2.4864
C84		2.4935	2.4951	2.4974	2.4986	2.4995	2.5015	2.5029	2.5033	2.5018	2.5009	2.4812
C85	biased	2.4941	2.4943	2.4929	2.4904	2.4877	2.4763	2.4700	2.4604	2.4567	2.4581	2.4805
C86		2.4952	2.4957	2.4946	2.4922	2.4893	2.4780	2.4716	2.4617	2.4578	2.4593	2.4816
C87		2.4975	2.4989	2.4983	2.4958	2.4929	2.4811	2.4743	2.4635	2.4594	2.4607	2.4837
C88		2.4966	2.4984	2.4982	2.4960	2.4938	2.4826	2.4761	2.4655	2.4610	2.4623	2.4835
C89		2.4985	2.4996	2.4990	2.4970	2.4948	2.4844	2.4781	2.4673	2.4630	2.4638	2.4866
REF28	Ref unbiased	2.4929	2.4935	2.4936	2.4933	2.4933	2.4934	2.4933	2.4937	2.4938	2.4941	2.4932
REF78	Ref biased	2.4955	2.4958	2.4958	2.4956	2.4958	2.4957	2.4956	2.4960	2.4959	2.4965	2.4954

TL431AMFDT,215 - from Nexperia - date code 2020 - @ I-max 100mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C80	unbiased	2.5154	2.5230	2.5301	2.5352	2.5393	2.5499	2.5533	2.5625	2.5651	2.5609	2.5164
C81		2.5209	2.5295	2.5368	2.5418	2.5463	2.5583	2.5628	2.5742	2.5778	2.5722	2.5219
C82		2.5203	2.5257	2.5311	2.5351	2.5386	2.5488	2.5534	2.5648	2.5689	2.5648	2.5182
C83		2.5217	2.5283	2.5347	2.5393	2.5429	2.5533	2.5573	2.5678	2.5714	2.5670	2.5206
C84		2.5158	2.5213	2.5274	2.5319	2.5354	2.5445	2.5484	2.5581	2.5615	2.5580	2.5128
C85	biased	2.5189	2.5228	2.5248	2.5250	2.5249	2.5200	2.5159	2.5088	2.5048	2.5035	2.5078
C86		2.5189	2.5230	2.5253	2.5258	2.5254	2.5206	2.5164	2.5089	2.5049	2.5035	2.5078
C87		2.5231	2.5290	2.5323	2.5331	2.5330	2.5281	2.5236	2.5152	2.5106	2.5087	2.5119
C88		2.5186	2.5235	2.5265	2.5273	2.5274	2.5230	2.5190	2.5112	2.5067	2.5054	2.5083
C89		2.5220	2.5264	2.5289	2.5298	2.5302	2.5269	2.5232	2.5157	2.5115	2.5097	2.5132
REF28	Ref unbiased	2.5145	2.5152	2.5153	2.5150	2.5150	2.5151	2.5151	2.5155	2.5156	2.5158	2.5148
REF78	Ref biased	2.5197	2.5199	2.5200	2.5198	2.5200	2.5199	2.5198	2.5202	2.5200	2.5205	2.5195

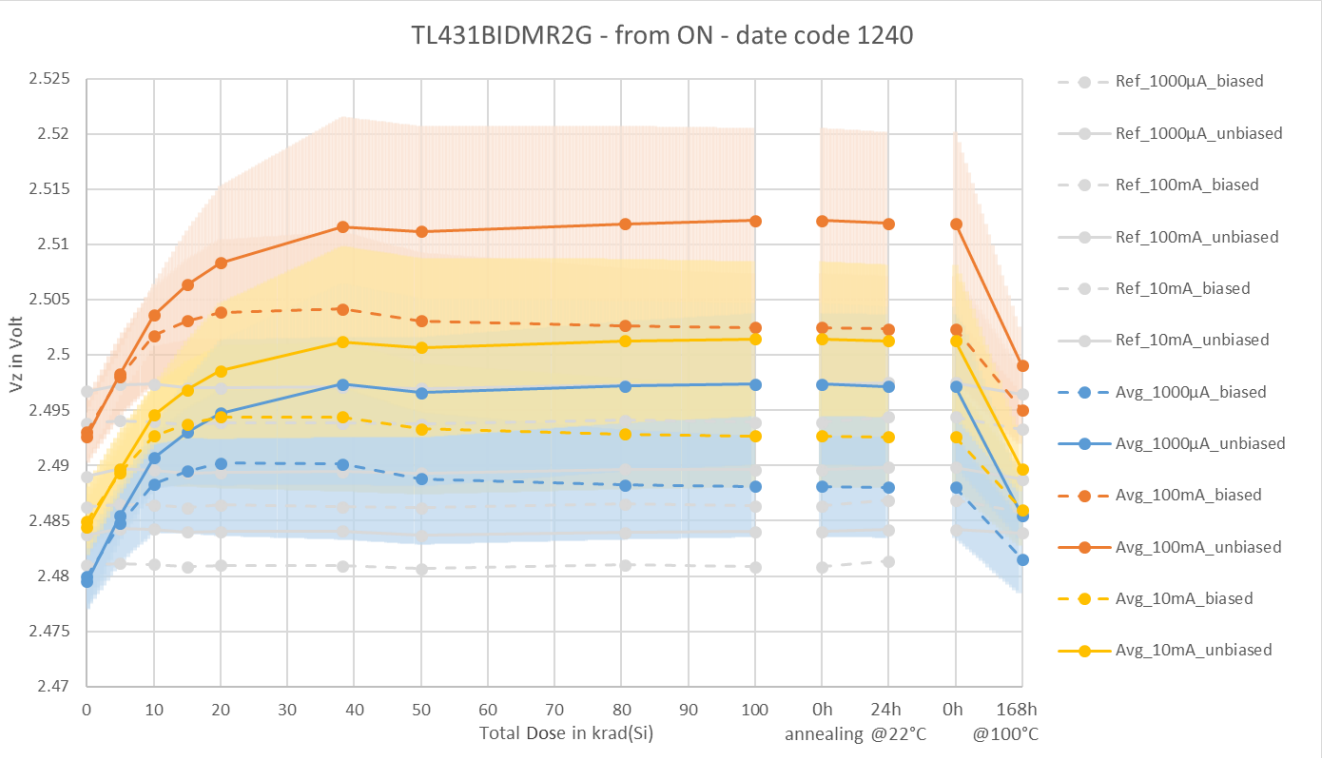


8.4. TID RESULTS - TL431BIDMR2G - from ON - date code 1240

TL431BIDMR2G - from ON - date code 1240 - @ I-min 1000µA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C90	unbiased	2.4783	2.4860	2.4930	2.4980	2.5019	2.5080	2.5065	2.5061	2.5058	2.5055	2.4868
C91		2.4778	2.4852	2.4922	2.4971	2.5009	2.5061	2.5047	2.5044	2.5041	2.5038	2.4863
C92		2.4836	2.4886	2.4929	2.4935	2.4937	2.4944	2.4940	2.4952	2.4956	2.4955	2.4881
C93		2.4799	2.4848	2.4887	2.4892	2.4895	2.4903	2.4900	2.4912	2.4917	2.4915	2.4844
C94		2.4778	2.4828	2.4867	2.4873	2.4876	2.4882	2.4879	2.4891	2.4896	2.4895	2.4818
C95	biased	2.4782	2.4840	2.4890	2.4918	2.4936	2.4931	2.4910	2.4895	2.4889	2.4889	2.4804
C96		2.4793	2.4831	2.4858	2.4858	2.4858	2.4857	2.4850	2.4852	2.4853	2.4853	2.4809
C97		2.4777	2.4818	2.4846	2.4847	2.4846	2.4845	2.4838	2.4841	2.4842	2.4841	2.4779
C98		2.4849	2.4909	2.4956	2.4983	2.5002	2.5009	2.4983	2.4963	2.4956	2.4955	2.4871
C99		2.4799	2.4839	2.4867	2.4868	2.4868	2.4867	2.4860	2.4863	2.4864	2.4864	2.4814
REF29	Ref unbiased	2.4838	2.4843	2.4843	2.4840	2.4840	2.4841	2.4837	2.4840	2.4840	2.4842	2.4839
REF79	Ref biased	2.4810	2.4812	2.4811	2.4809	2.4810	2.4809	2.4807	2.4810	2.4809	2.4813	2.4810

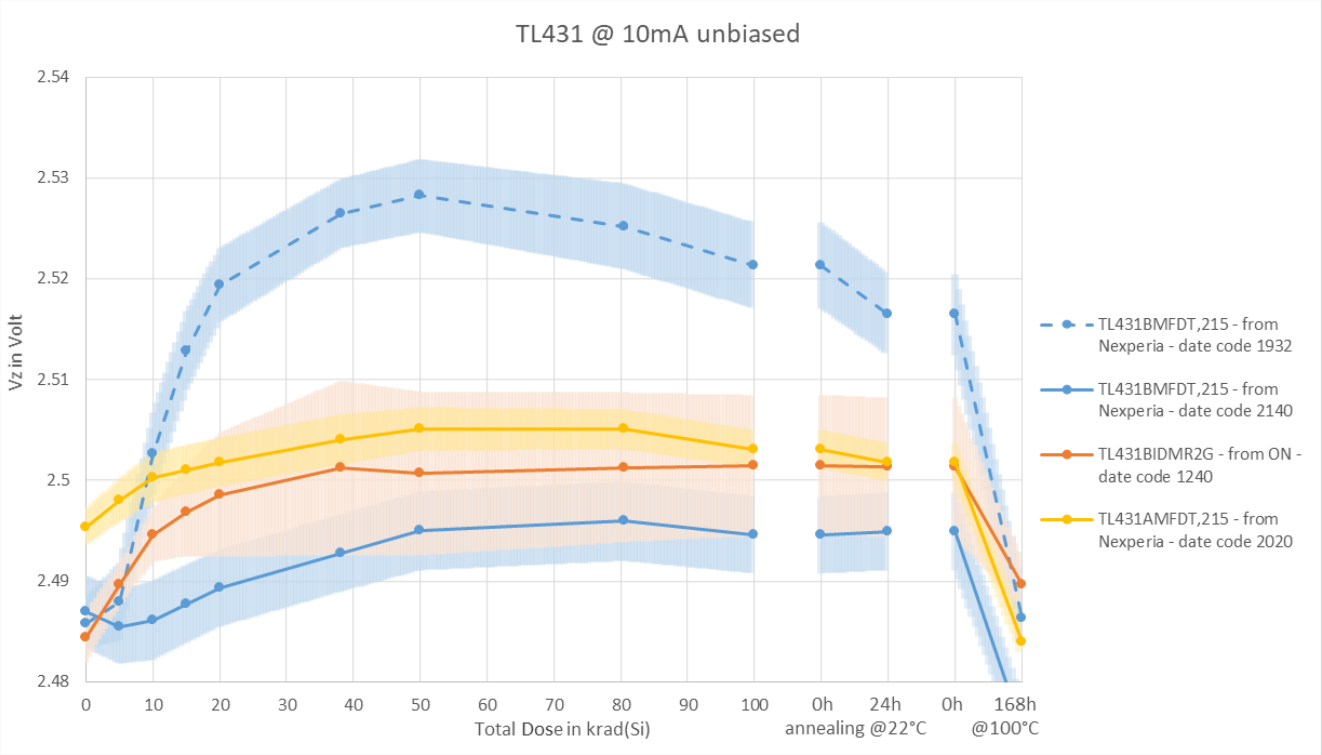
TL431BIDMR2G - from ON - date code 1240 - @ I-typ 10mA											Limit acc. DS: Vz = 2.495V ± 0.52% (2.482V – 2.508V)	
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C90	unbiased	2.4831	2.4898	2.4965	2.5013	2.5053	2.5112	2.5100	2.5098	2.5095	2.5092	2.4909
C91		2.4827	2.4892	2.4959	2.5006	2.5043	2.5095	2.5084	2.5082	2.5079	2.5076	2.4905
C92		2.4886	2.4931	2.4969	2.4977	2.4979	2.4986	2.4985	2.4995	2.5000	2.4999	2.4923
C93		2.4849	2.4891	2.4928	2.4933	2.4937	2.4944	2.4942	2.4954	2.4960	2.4959	2.4886
C94		2.4828	2.4871	2.4908	2.4914	2.4916	2.4924	2.4923	2.4934	2.4939	2.4939	2.4861
C95	biased	2.4833	2.4887	2.4933	2.4959	2.4976	2.4971	2.4953	2.4939	2.4934	2.4933	2.4850
C96		2.4838	2.4873	2.4898	2.4899	2.4899	2.4897	2.4893	2.4896	2.4897	2.4896	2.4849
C97		2.4826	2.4864	2.4889	2.4890	2.4890	2.4889	2.4884	2.4886	2.4888	2.4887	2.4823
C98		2.4903	2.4957	2.5001	2.5027	2.5043	2.5050	2.5028	2.5010	2.5004	2.5003	2.4919
C99		2.4850	2.4887	2.4913	2.4914	2.4913	2.4913	2.4908	2.4911	2.4911	2.4911	2.4860
REF29	Ref unbiased	2.4890	2.4897	2.4896	2.4893	2.4894	2.4895	2.4893	2.4897	2.4896	2.4899	2.4888
REF79	Ref biased	2.4863	2.4865	2.4864	2.4862	2.4865	2.4863	2.4862	2.4865	2.4864	2.4869	2.4858

TL431BIDMR2G - from ON - date code 1240 - @ I-max 100mA												
DUT No.	krad (Si)	0	5	10	15	20	38.2	50	80.5	100	Room Temp. annealing	100°C annealing
C90	unbiased	2.4918	2.4990	2.5063	2.5118	2.5162	2.5234	2.5225	2.5224	2.5221	2.5217	2.5013
C91		2.4911	2.4981	2.5053	2.5107	2.5149	2.5211	2.5202	2.5202	2.5200	2.5196	2.5004
C92		2.4963	2.5011	2.5052	2.5062	2.5066	2.5075	2.5075	2.5087	2.5093	2.5091	2.5008
C93		2.4930	2.4977	2.5016	2.5025	2.5029	2.5039	2.5038	2.5051	2.5058	2.5056	2.4977
C94		2.4910	2.4957	2.4997	2.5005	2.5010	2.5020	2.5018	2.5031	2.5037	2.5036	2.4952
C95	biased	2.4912	2.4972	2.5023	2.5053	2.5072	2.5072	2.5055	2.5040	2.5035	2.5033	2.4940
C96		2.4921	2.4962	2.4990	2.4992	2.4992	2.4992	2.4988	2.4991	2.4992	2.4991	2.4939
C97		2.4912	2.4955	2.4984	2.4987	2.4988	2.4989	2.4984	2.4987	2.4988	2.4987	2.4919
C98		2.4980	2.5042	2.5091	2.5120	2.5139	2.5151	2.5129	2.5112	2.5105	2.5103	2.5008
C99		2.4929	2.4972	2.5001	2.5003	2.5004	2.5003	2.5000	2.5003	2.5004	2.5004	2.4947
REF29	Ref unbiased	2.4967	2.4973	2.4974	2.4970	2.4970	2.4971	2.4970	2.4973	2.4974	2.4975	2.4965
REF79	Ref biased	2.4938	2.4941	2.4940	2.4937	2.4939	2.4938	2.4937	2.4941	2.4939	2.4944	2.4933



8.1. Comparison Manufacturer and Date Code

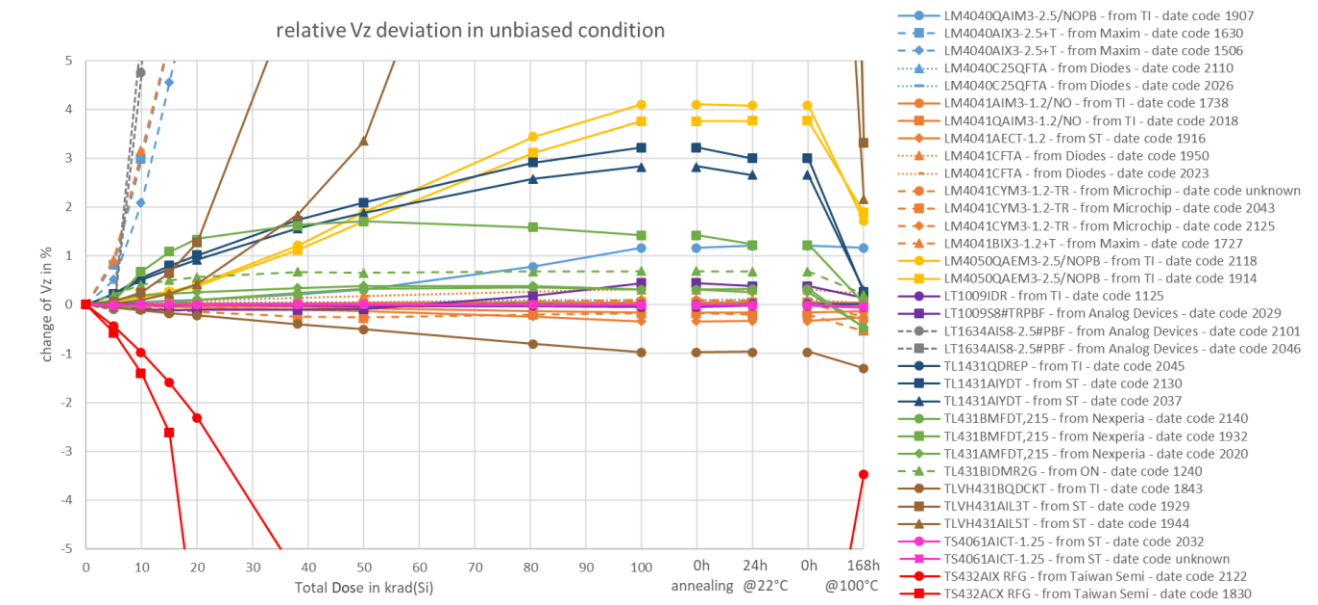
The following graph shows the different behaviour of all measured TL431 voltage references with different date codes and from different manufacturers.

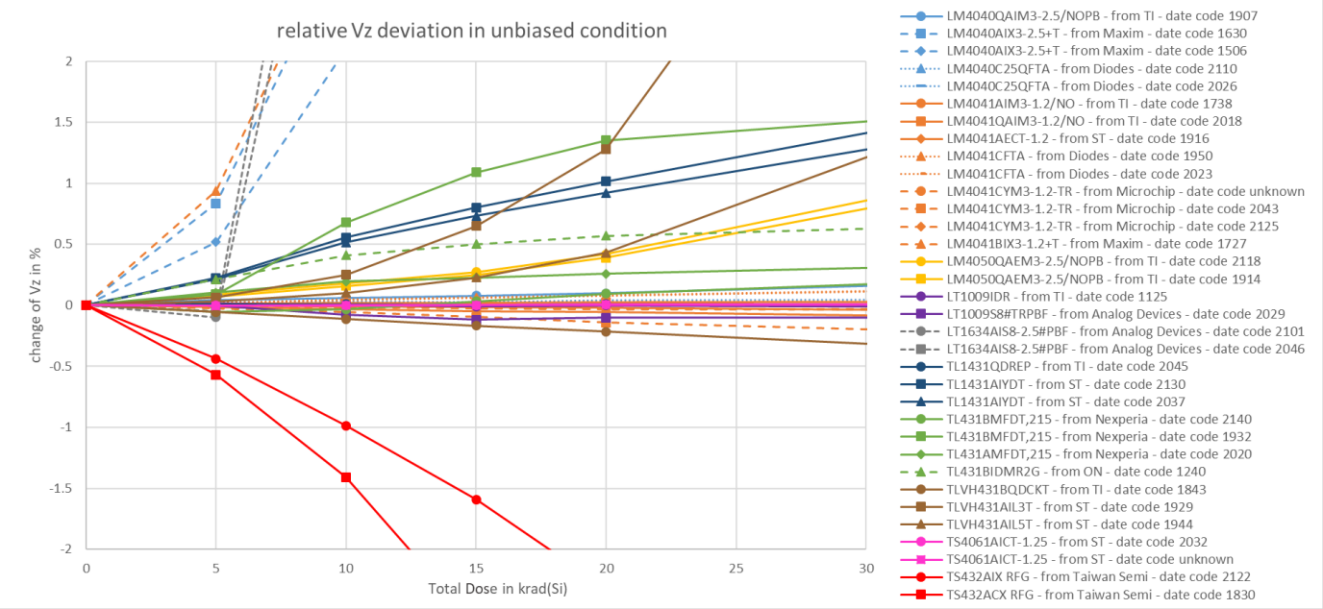


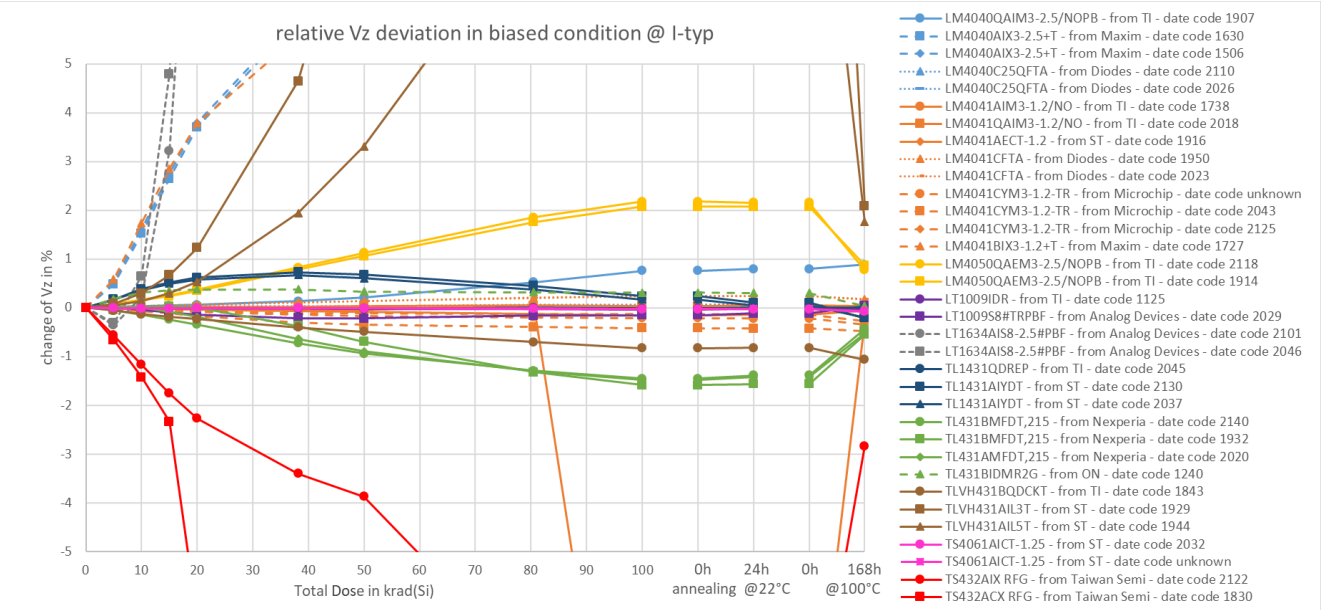
All curves plotted show the average value of all unbiased tested samples (worst case) and the interval behind the curves represent +/- one standard deviation.

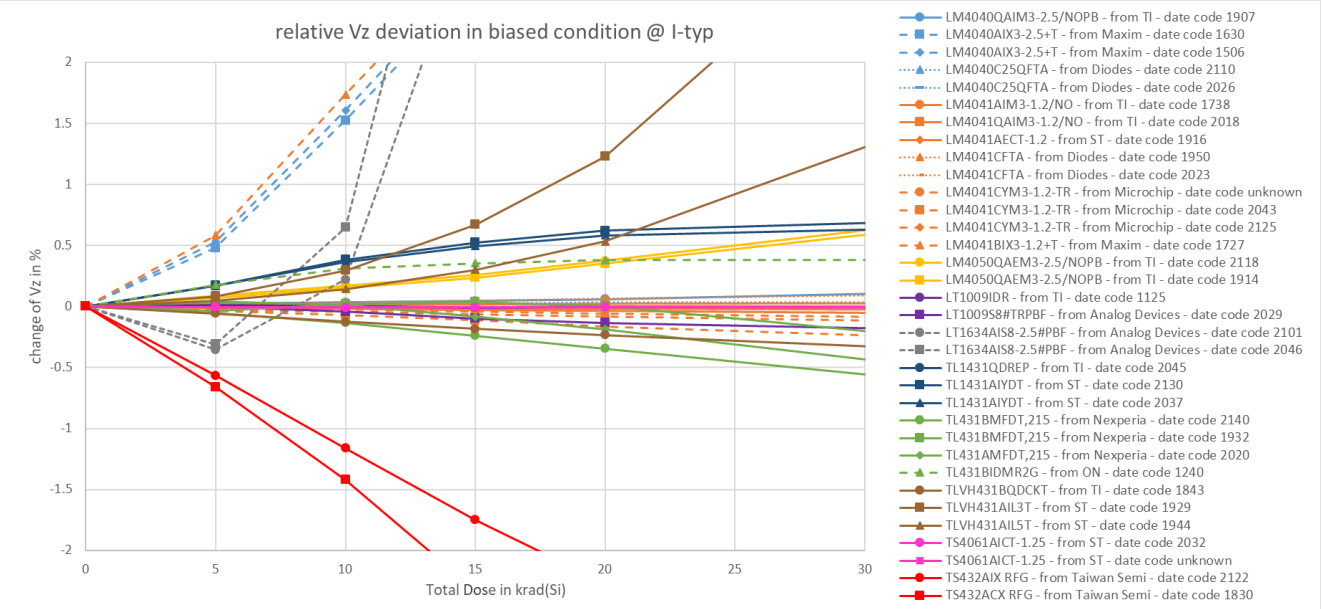
8.2. Comparison with other tested Bandgap References

The following four graphs show the results of the TL431 Bandgap Voltage References compared to different Bandgap References part types, which were tested at the same time with the same test setup than the TL431. 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

All tested components with different date codes and from different manufacturers stayed inside specification limits up to a dose around 10 krad.

The deviation of tested components from the two different date codes show a different behaviour in respect of TID effects.
The deviation of tested components from the two different manufactures show a slightly different behaviour as well.

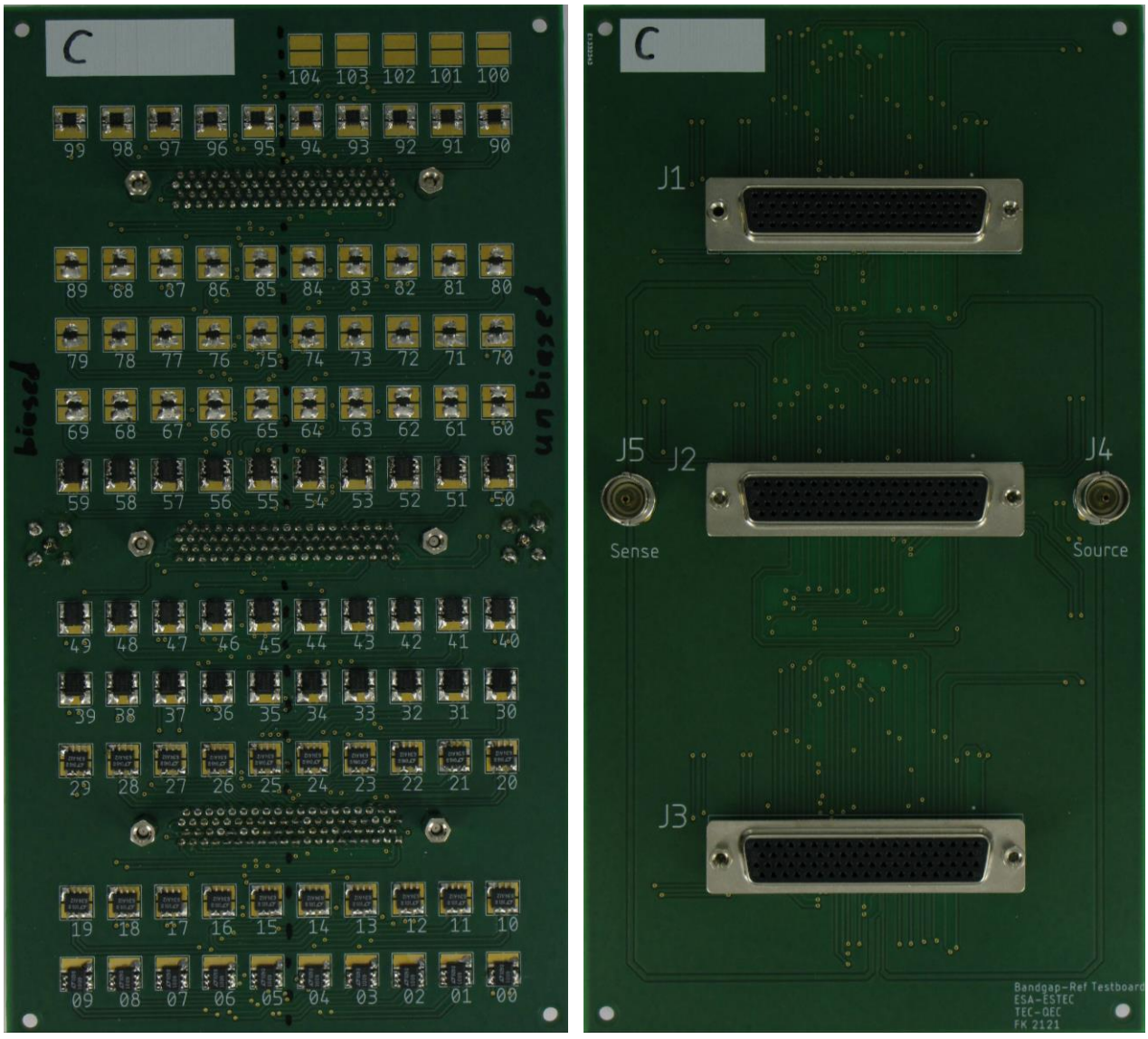
In general, a higher deviation was found for the unbiased samples.

ANNEX A – DATASHEET

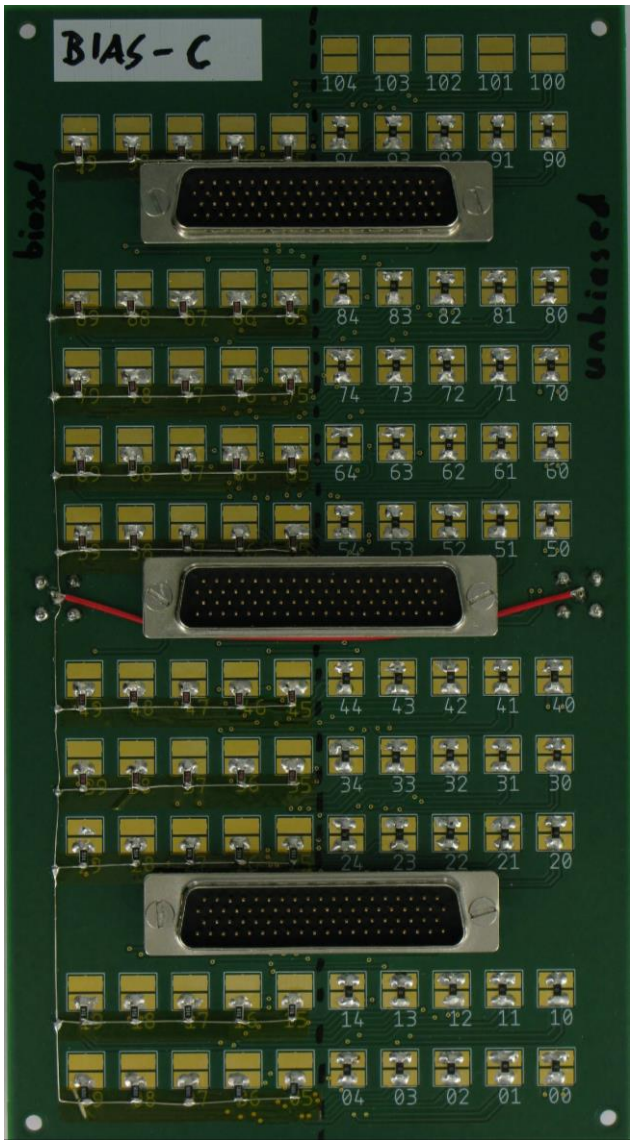
Part Type	Manufacturer	Link to Datasheet
TL431BMFDT,215 TL431AMFDT,215	Nexperia	https://media.digikey.com/pdf/Data%20Sheets/Nexperia/TL431_Family.pdf
TL431BIDMR2G	ON Semiconductor	https://www.onsemi.com/pdf/datasheet/tl431-d.pdf

ANNEX B – SET-UP

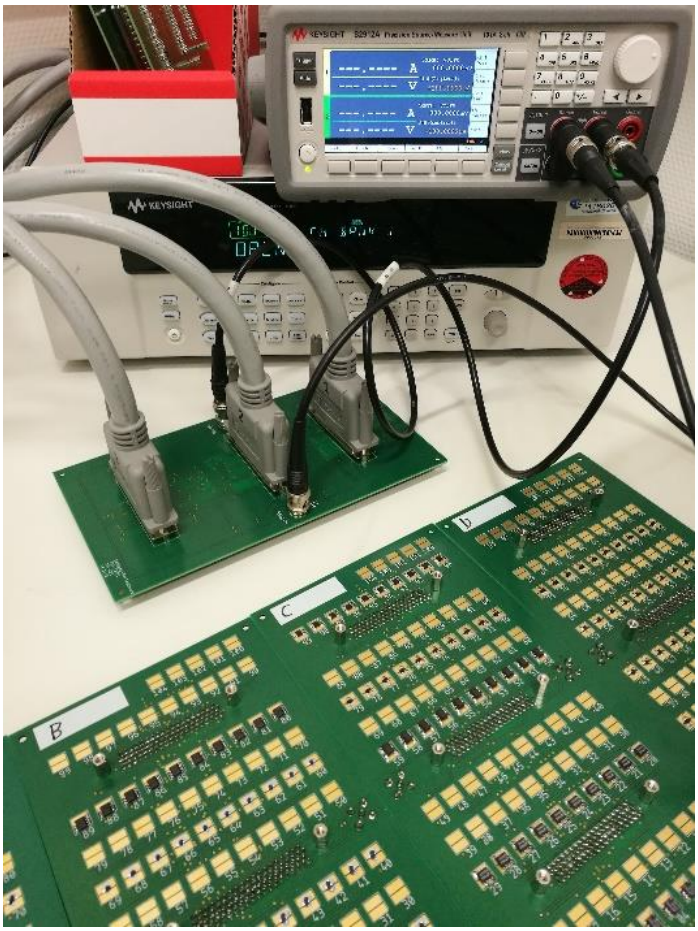
Test board front- and backside with the TL431 on position 60 to 99 on board C:



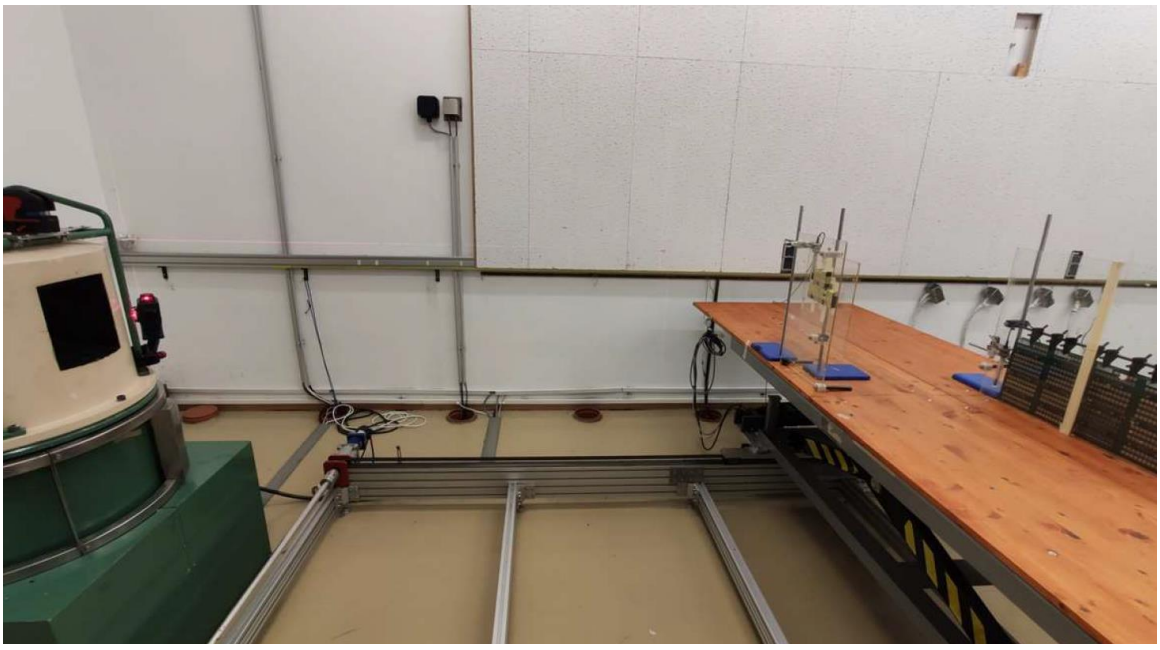
Biasing board front- and backside with the biasing resistors on it:

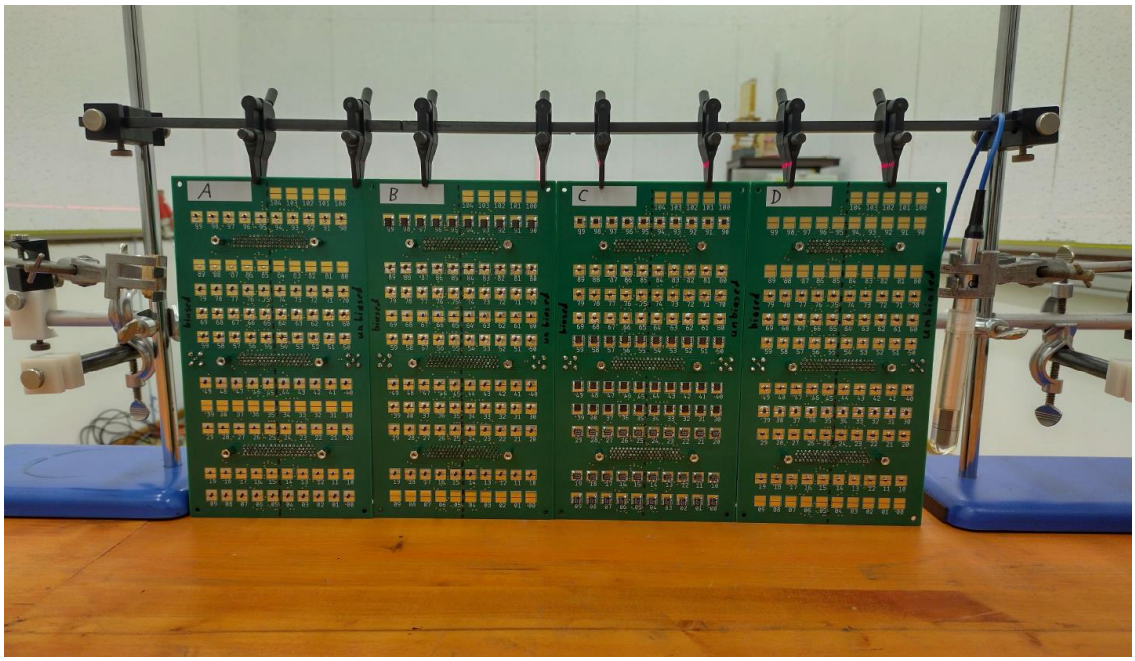


Measurement setup with the cable connection from the Test Board to the Switching Matrix and the Source Measure Unit:



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

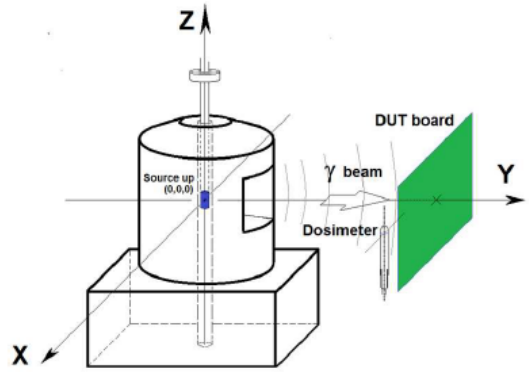


Figure 1 Co-60 irradiator head and board positioning sketch

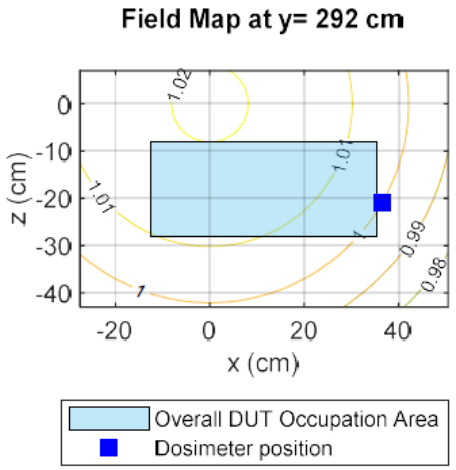


Figure 2: Qualitative indication of dose rate distribution normalized to dosemeter readings. Axes origin located at source centre. Graphs for information only, of the run with highest dose rate.