esa DOCUMENT

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RESULTS ON ^{60}Co TID TEST OF PART TYPE: PWM CONTROLLER 80900832

CONTRACT: 20775/NL/PA/07

prepared by/*préparé par* M.Muschitiello TEQ-QEC

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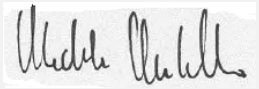
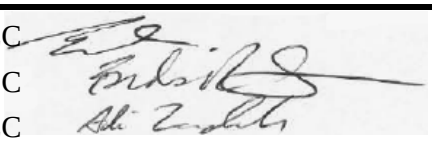
author *auteur*	Michele Muschitiello TEC-QEC		date *date* 8th May 2009

approved by *approuvé by*	Nat Carthew Fredrik Sturesson Ali Zadeh	TEC-QEC TEC-QEC TEC-QEC		8th May 2009

CHANGE LOG

reason for change /*raison du changement*	issue/*issue*	revision/*revision*	date/*date*
New document	1	1	17th February 2009

CHANGE RECORD

Issue: 1 Revision: 2

reason for change/*raison du changement*	page(s)/*page(s)*	paragraph(s)/*paragraph(s)*
Clarify that later revisions of Applicable documents includes update of TID drift limits of specific parameters		1 and 5
Clarify discrepancy in measurement of 5V reference voltage parameter		4.1 and 4.4

Table Of Contents

Test Report Number	**ESA_QCA0811T_I**
Project	ECI
SCC Component no.	***n/a***
Component Designation	PWM Controller
Irradiation Spec. no.	ESA/SCC 22900
Family	Hybrid
Group	Silicon
Package	84 pins CQFP – Metal Lid
Component Specification	Thales Alenia Space ETCA - 8090.832-1 detail specification, issue 2.2 date 04.03.08
Test House Name	ESA / ESTEC
Irradiation Test Plan Number	***ESA_QCA0811T_I***
Manufacturer name	Thales Alenia Space ETCA
Application type of Acceptance	n/a
Serial Number of samples	#11, #03, #05, #10, #13
Manufacturing Date Code	0731
Irradiation Measurement schedule: Biased: Unbiased: Circuit Reference: Supply Voltage: Temp ^{o}C: Duration:	0, 10, 15, 20, 25, 30, 40, 45, 50 krad(Si) Total Dose Yes, devices #03, #05, #13 Yes, device #10 Fig.1 (paragraph 4.8 of detail specification) 30 V Room temperature 20 ± 3 About 1300 hours
Electrical Measurement Parameters	(1.1 and 1.4) Primary Consumption, (1.5) Consumption on 5V_DIG, (1.6) Secondary Consumption, (2.1) Vaux Supply voltage, (3.1) 2.5V output voltage, (4.1) 5V reference voltage, (5.1) UVP Threshold Voltage, (5.2) UVP Hysteresis, (6.1) OVP Threshold Voltage, (9.1) Clock Frequency. *(Reference to parameter nr. in table 2 of ETCA 8090.0832-1 detail specification)*
Facility Source: Energy: Dose Rate: Absorbing Material: Thickness: Temperature ^{o}C:	ESA/ESTEC ^{60}Co (gamma) 1.173 MeV 1.332 MeV 0.65 Rad(Si)/min N/A N/A 20 ± 3
Dosimetry / Calibration method.	A calibrated NE2571, 0.6cc air ionisation chamber read by a calibrated Farmer 2670 dosimeter.
Anneal Test Biased Unbiased Bias Circuit Reference Supply Voltage Duration	Yes – performed at ETCA facility Yes 24 hrs at room temperature followed by 168 hrs at 100 °C == Fig.1 (paragraph 4.8 of detail specification) 30 V 24 hrs at room temperature followed by 168 hrs at 100 °C

1 INTRODUCTION

The following document contains the TID Radiation Test results for the 8090.0832-1G02 PWM Controller, manufactured by Thales Alenia Space ETCA.

Note that the radiation test results in this report are compared to parameters specified in the revisions of Detail specification and the User Manual document mentioned under Applicable Documents. Both these documents have later been replaced by new issues with updated TID drift limits on specific parameters (8090.0832 issue 2.5, 23.03.2009 and PWM-PSU-ETCA-UM-0027 issue 1.8, 14.11.2008)

2 APPLICABLE DOCUMENTS

- AD1- ESA/SCC 22900 “Total Dose Steady-State Irradiation Test Method”, issue 3.
- ThalesAleniaSpace ECTA Detail Specification 8090.0832 issue 2.2 04.03.2008.
- ThalesAleniaSpace ETCA User Manual - PWM-PSU-ETCA-UM-0027 issue 1.4, paragraph 2.4

2.1 Reference Documents

- ThalesAleniaSpace ECTA PWM controller, TP2 Transient investigation Procedure PWM-PSU-TP-0033
- ThalesAleniaSpace ETCA Post-irradiation test report PWM-PSU-TR-0064

3 TEST DESCRIPTION

Five devices PWM Controllers 8090.0832-G02 and one Burn-in Board, to accommodate three biased device during irradiation, have been received from THALES Alenia Space ETCA, for TID irradiation testing at the ESTEC ^{60}Co facility. All irradiation tests were performed at a dose rate of 0.65 rad(Si)/min on average. Bias condition used was as in paragraph 4.8.2. of detail spec.

The serial numbers of received parts are 011, 03, 05, 10 and 13. Table 1 summarizes their use.

Table 1 received samples

S/n	
11	Reference device (not irradiated) - Electrically tested before and after each intermediate measurement run at irradiation step completion
03	Biased during ^{60}Co irradiation
05	Biased during ^{60}Co irradiation
10	Un-Biased during ^{60}Co irradiation - EM device from RGA (not hermetic)
13	Biased during ^{60}Co irradiation

4 RADIATION TEST PLAN

The radiation test plan is reported in table 2.

Table 2

Irradiation Step	Total Dose krad (Si)	Dose Rate (Si)Rad/min
(Pre irradiation) 0	0	0
1	9	0.65
2	12.5	0.65
3	19.1	0.65
4	25.7	0.65
5	31.4	0.60
6	38.0	0.65
7	45.0	0.65
8	49.5	0.65

During the irradiation test, voltages between the ground and test points: Alim (A, B and C) and VPWM (A, B and C) of the burn-in board accommodating the biased devices, were recorded. At the completion of each irradiation step, intermediate electrical measurements were carried out according to the next paragraph. Fig.1 shows the schematic of each Burn-in Board position.

At the end of the final irradiation run, all devices were sent to ETCA for complete electrical characterization followed by the annealing at room temperature (24 hours) and at 100°C (168 hrs).

After the high temperature annealing, devices were tested comprehensively by ETCA (all electrical parameters according to detailed specification, see Appendix E) and returned to ESA-ESTEC for final measurements.
At ESTEC all parts were re-tested with the same set-up used during irradiation runs. The final ESA measurements were performed to correlate ESA / ETCA measurements.

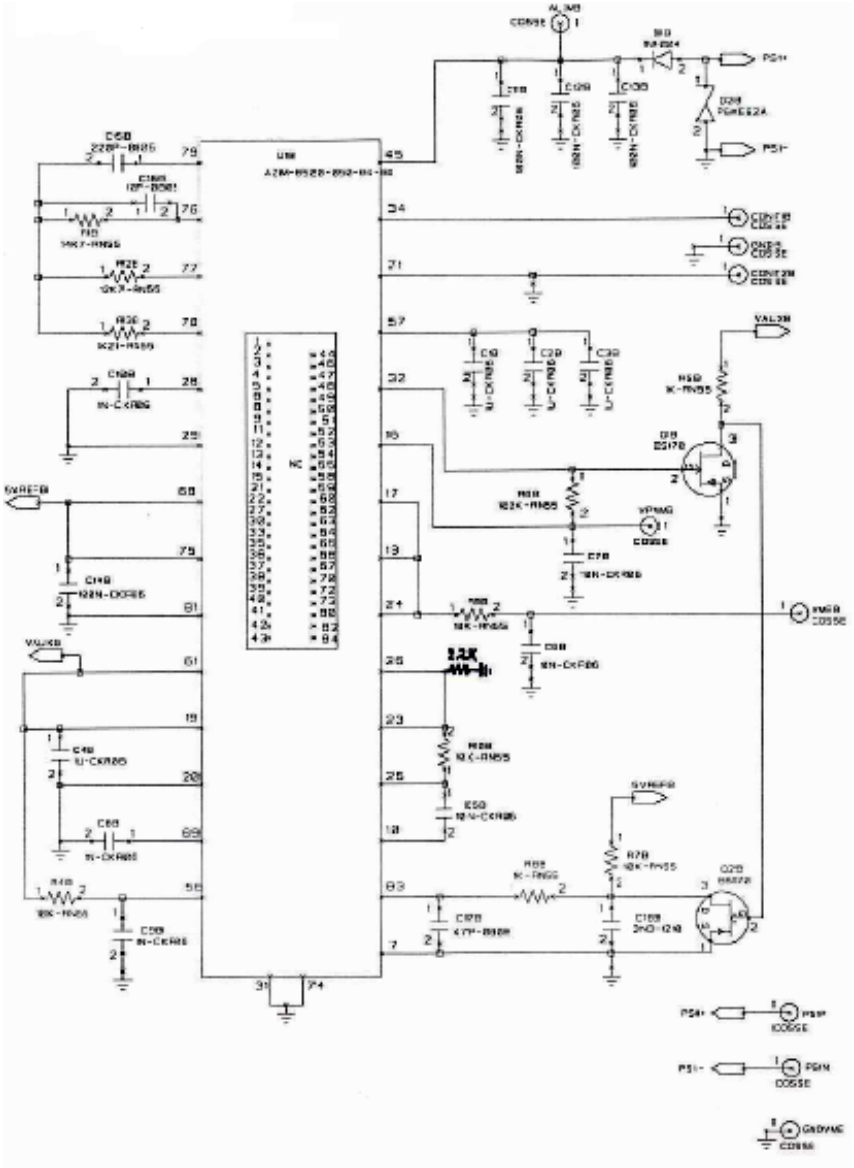


Fig.1 Burn-in Board schematic diagram (paragraph 4.8. of det.spec.)

4.1 Measurement set-up

No in-situ measurements were performed during irradiation.

To save time and resources, electrical measurements at ESTEC were carried out using a SEE test board developed by ETCA (see Fig.2). The SEE board was not intended to perform measurements of all parameters required. Thus, the SEE board was modified, in agreement with ETCA, enabling measurement of the required parameters, according to table 2 of detail specification 80900832 issue 2.2 04.03.2008.

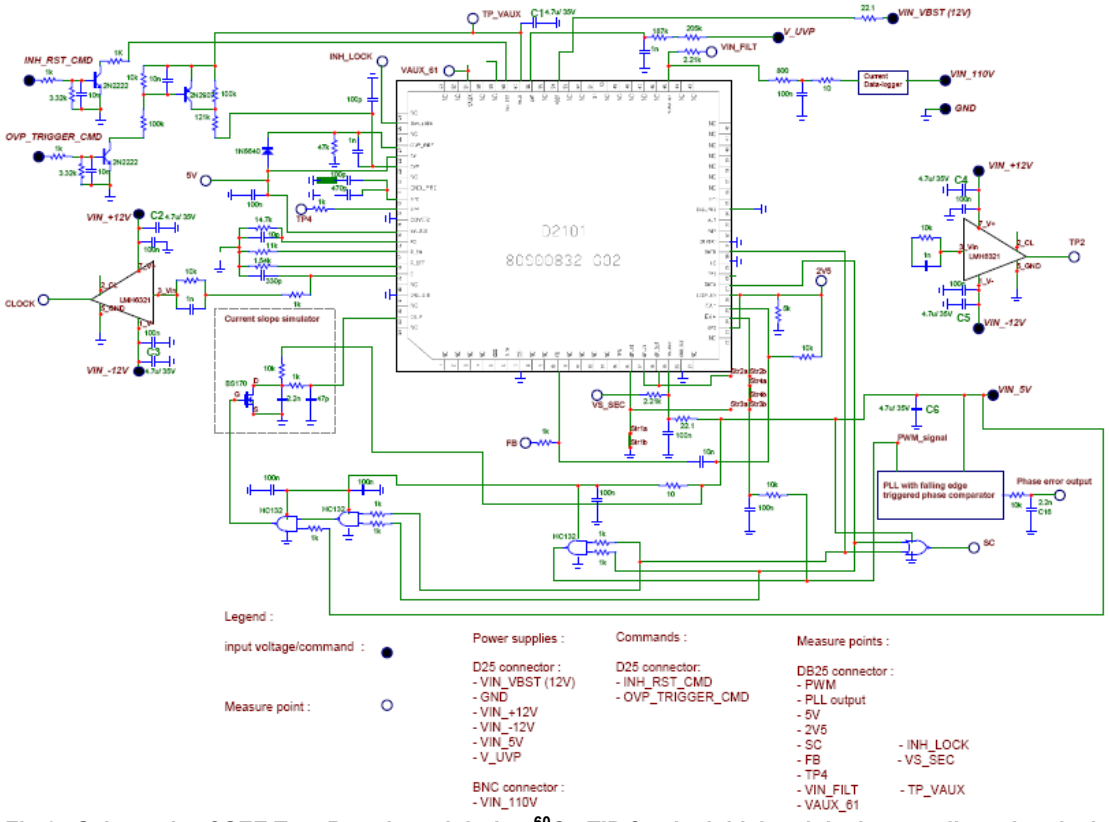


Fig.2 Schematic of SEE Test Board used during ^{60}Co TID for the initial and the intermediate electrical measurements at Irradiation Test Facility.

A specific power-up sequence was required prior to initiation of each measurement. Fig.3, illustrates the initial power-up sequence and the power conditions applied for the various measurements. Each point in the graph represents a measurement point in the step sequence as listed in table 3a.

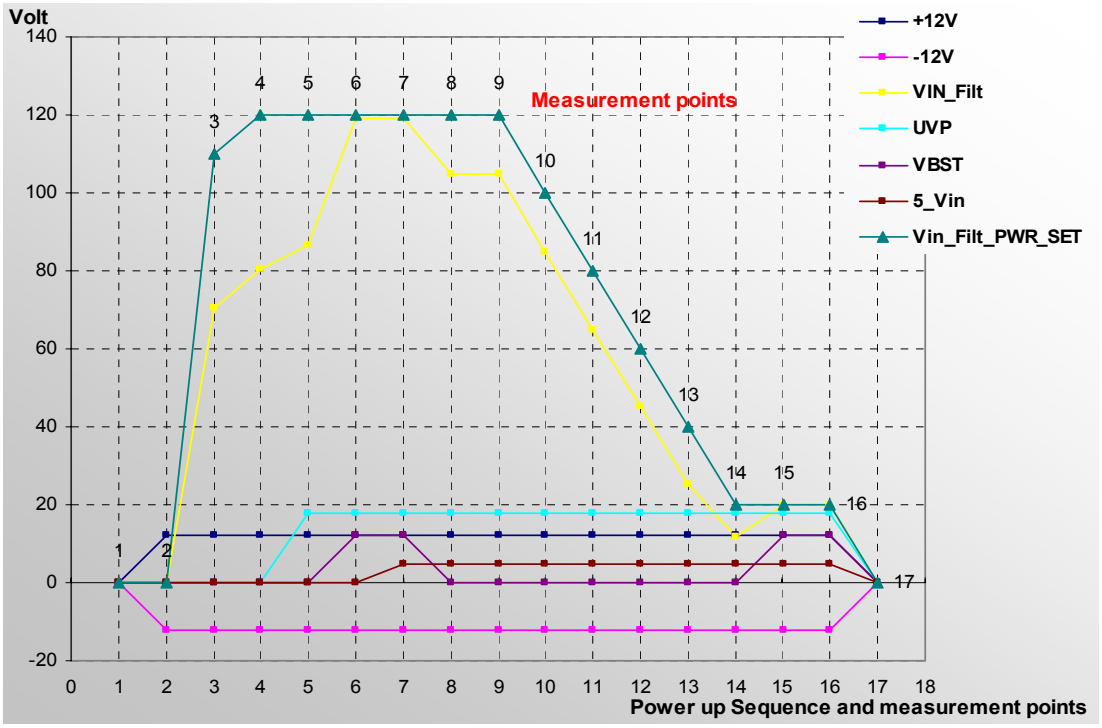


Fig.3 PWM power-up sequence during electrical measurements.

In figure 3, note that traced Vin_FILT is the actual value read directly on pin nr.45. This last value differs from the output voltage of power supply (Vin_Filt_PWR_set) due to the presence on the test board of an 800 Ohm resistor.

The measured parameters and the pass/fail criteria are listed in tables 3a and 3b. Table 3a lists pass/fail criteria obtained from detailed specification while table 3b lists pass/fail criteria based on Worst Case Analysis (WCA) values provided by ETCA in the WCA summary given in the User Manual (refer to PWM-PSU-ETCA-UM-0027, **issue 1.4**, paragraph 2.4). Both pass/fail criteria have been quoted and included in the results however, primarily pass/fail criteria based on the WCA were considered definitive.

Table 3.a Measured Parameters and Initial Min-Max Limits

N° (*)	Parameter	Note (measured at fig.3 points)	Min.	Max.	Unit
1.1	Primary Consumption	(8-13)	3.8	7	mA
1.4	Primary Consumption	(6-7)	220	290	uA
1.5	Consumption on 5V_DIG	Estimated value, (7-13, 15)	3.8	7	mA
1.6	Secondary Consumption	(7-13, 15-16)	5	9.5	mA
2.1	Vaux Supply voltage	(8-13)	9.3	10.24	V
3.1	2.5V output voltage	(7-13, 15-16)	2.493	2.507	V
4.1	5V reference voltage	(7-13, 15-16)	4.9	5.01	V
5.1	UVP Threshold Voltage	(16)	17.53	17.87	V
5.2	UVP Hysteresis	(16)	1.15	1.39	V
6.1	OVP Threshold Voltage	(16)	13.37	14	V
9.1	Clock Frequency	(16)	193'500	199'400	Hz
11.1	TP2 voltage	(15-16)	0	6	mV

(*) reference to parameter nr. in table 2 of ETCA 8090.0832-1 detail specification.

Pre-irradiation measurements performed at ESTEC of OVP Over-Voltage Protection (see table 13) resulted in values lower than the minimum limit stated in ETCA 8090.0832-1 detail specification, table 2. While pre-irradiation measurements performed at ETCA of the same parameter were within the specification. The reason of this discrepancy is not understood.

Table 3.b Min-Max Limits after Irradiation (**)

N° (*)	Parameter	Note (measurement points)	Min.	Max.	Unit
2.1	Vaux Supply voltage	(8-13)	8.57	10.80	V
3.1	2.5V output voltage	(7-13, 15-16)	2.486	2.514	V
4.1	5V reference voltage	(7-13, 15-16)	4.972	5.028	V
5.1	UVP Threshold Voltage	(16)	17.28	10.07	V
5.2	UVP Hysteresis	(16)	1.040	1.550	V
6.1	OVP Threshold Voltage	(16)	12.64	14.61	V
9.1	Clock Frequency	(16)	192'000	201'000	Hz

(*) reference to parameter nr. in table 2 of ETCA 8090.0832-1 detail specification.
(**) Worst Case Analysis limits as in paragraph 2.4 of ETCA PWM-PSU-ETCA-UM-0027 issue 1.4.

Note that for the parameter (4.1) 5V Reference Voltage, the initial and post irradiation limits (from detail specification and worst case analysis) are not consistent. The value for post irradiation limits in the worst case analysis is given with zero load while the detail specification parameter (4.1) is given with 2mA load.

4.2 Thermal conditions

All irradiations and measurements were performed at room temperature (20 ± 3 ^{o}C).

4.3 Dosimetry

A calibrated NE2571, 0.6cc air ionisation chamber read by a calibrated Farmer 2670 dosimeter was used to measure the Total Ionising Dose.

4.4 Test Results

Intermediate measurement results are reported in tables 4 to 15. The applied Total Dose is 49.51 krad(Si). At the end of the 49.51 krad step, electrical measurements were performed and the five samples shipped to ETCA for annealing and the full final electrical characterization.

The five devices were received by ETCA after five hours from the end of irradiation, and immediately tested with their proprietary automatic test setup (refer to ETCA nr.80900832 detail specification).

Devices were tested again the following day at 07:00 and at 16:00. During annealing the four irradiated devices were biased employing the burn-in test boards available at ETCA. The samples went through accelerated ageing for 168 hrs at 100°C, under bias conditions.

Following the accelerated ageing tests, full parametric measurements were performed and device returned to ESA. ETCA Results are reported in ETCA document “Post-Irradiation test report”, ref. PWM-PSU-TR-0064.

When received at ESA-ESTEC, parts were re-tested by using the set-up for the intermediate measurements. Those last measurements have been appended in tables 4 to 15; the measurement data have also been plotted on the relevant graphs.

Electrical Measurement uncertainty values, reported in table 4-15 footnotes, were estimated by observing the variations in the reference device (s/n 11) parameters, during the entire test campaign. Uncertainty has been calculated by using [1] below, with a coverage factor of 3.

[1] $$u = \frac{s}{\sqrt{n}},$$

u = estimated overall uncertainty
s = standard deviation
n= number of observations

All data from tables have been plotted from figures 4 to 15.

Table 4 – 1.1 Primary Consumption [A] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0057952	0.0057434	0.0057765	0.0057137	0.0058285
9.0	0.0057881	0.0057137	0.0057564	0.0057046	0.0058003
12.5	0.0057947	0.0057042	0.0057425	0.0057035	0.0057864
19.1	0.0057938	0.0056662	0.0057117	0.0056992	0.0057495
25.7	0.0057959	0.0056290	0.0056788	0.0056995	0.0057151
31.4	0.0057926	0.0055982	0.0056520	0.0056904	0.0056859
38.1	0.0057978	0.0055680	0.0056227	0.0056674	0.0056547
45.0	0.0057966	0.0055413	0.0055953	0.0056433	0.0056244
49.5	0.0057928	0.0055184	0.0055746	0.0056209	0.0056013
		After Annealing			
=	0.0057946	0.0054672	0.0055217	0.0055416	0.0055432

Mean value (s/n 11): 5.7942 mA
Estimated uncertainty: ± 0,044% (± 2.6 µA)

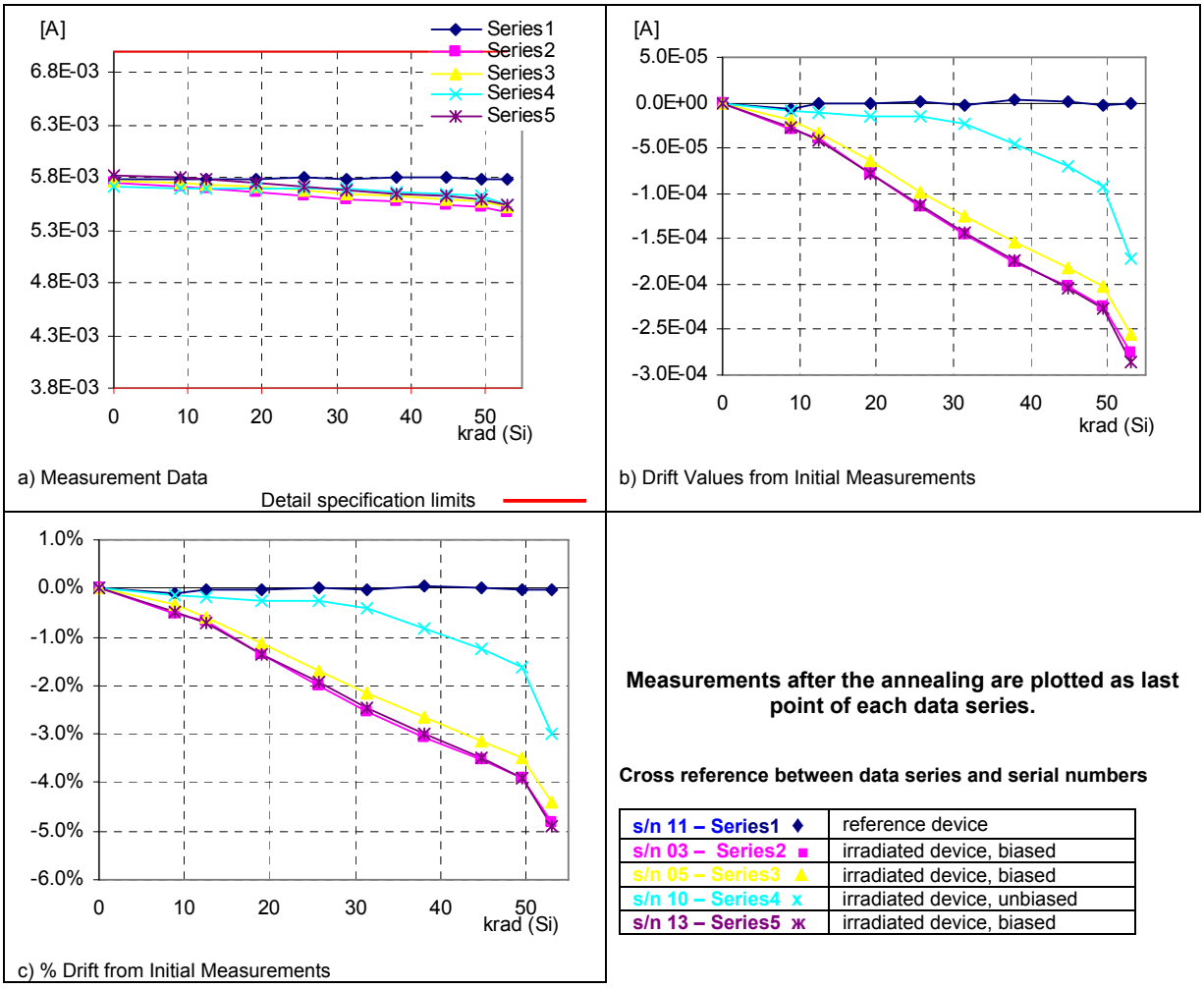
b) Drift Values from Initial Measurements [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
9.0	-0.0000071	-0.0000297	-0.0000201	-0.0000091	-0.0000282
12.5	-0.0000005	-0.0000392	-0.0000339	-0.0000101	-0.0000421
19.1	-0.0000014	-0.0000773	-0.0000648	-0.0000145	-0.0000791
25.7	0.0000007	-0.0001144	-0.0000977	-0.0000142	-0.0001134
31.4	-0.0000026	-0.0001452	-0.0001245	-0.0000233	-0.0001426
38.1	0.0000026	-0.0001754	-0.0001537	-0.0000462	-0.0001738
45.0	0.0000014	-0.0002021	-0.0001812	-0.0000704	-0.0002041
49.5	-0.0000024	-0.0002250	-0.0002019	-0.0000927	-0.0002273
		After Annealing			
=	-0.0000006	-0.0002762	-0.0002548	-0.0001721	-0.0002853

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.122%	-0.517%	-0.348%	-0.159%	-0.484%
12.5	-0.009%	-0.682%	-0.588%	-0.177%	-0.722%
19.1	-0.024%	-1.345%	-1.121%	-0.254%	-1.357%
25.7	0.012%	-1.993%	-1.692%	-0.248%	-1.946%
31.4	-0.045%	-2.527%	-2.154%	-0.407%	-2.447%
38.1	0.045%	-3.053%	-2.661%	-0.809%	-2.982%
45.0	0.024%	-3.518%	-3.137%	-1.232%	-3.502%
49.5	-0.042%	-3.917%	-3.495%	-1.623%	-3.899%
		After Annealing			
=	-0.010%	-4.809%	-4.411%	-3.012%	-4.895%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det.Spec.	0.0038	0.0070	[A]



Measurements after the annealing are plotted as last point of each data series.

Cross reference between data series and serial numbers

s/n 11 – Series1 ♦	reference device
s/n 03 – Series2 ■	irradiated device, biased
s/n 05 – Series3 ▲	irradiated device, biased
s/n 10 – Series4 x	irradiated device, unbiased
s/n 13 – Series5 ж	irradiated device, biased

Fig. 4 Primary Consumption vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 5 – 1.4 Primary Consumption [A] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0002381	0.0002347	0.0002368	0.0002396	0.0002388
9.0	0.0002382	0.0002377	0.0002396	0.0002374	0.0002402
12.5	0.0002408	0.0002396	0.0002421	0.0002381	0.0002417
19.1	0.0002375	0.0002376	0.0002399	0.0002377	0.0002401
25.7	0.0002407	0.0002409	0.0002433	0.0002374	0.0002404
31.4	0.0002384	0.0002402	0.0002423	0.0002389	0.0002409
38.1	0.0002401	0.0002414	0.0002415	0.0002394	0.0002425
45.0	0.0002391	0.0002398	0.0002424	0.0002400	0.0002409
49.5	0.0002399	0.0002420	0.0002427	0.0002388	0.0002410
		After Annealing			
=	0.0002382	0.0002396	0.0002446	0.0002424	0.0002400

Mean value (s/n 11): 239.09 µA
Estimated uncertainty: ± 0,47% (± 1.1 µA)

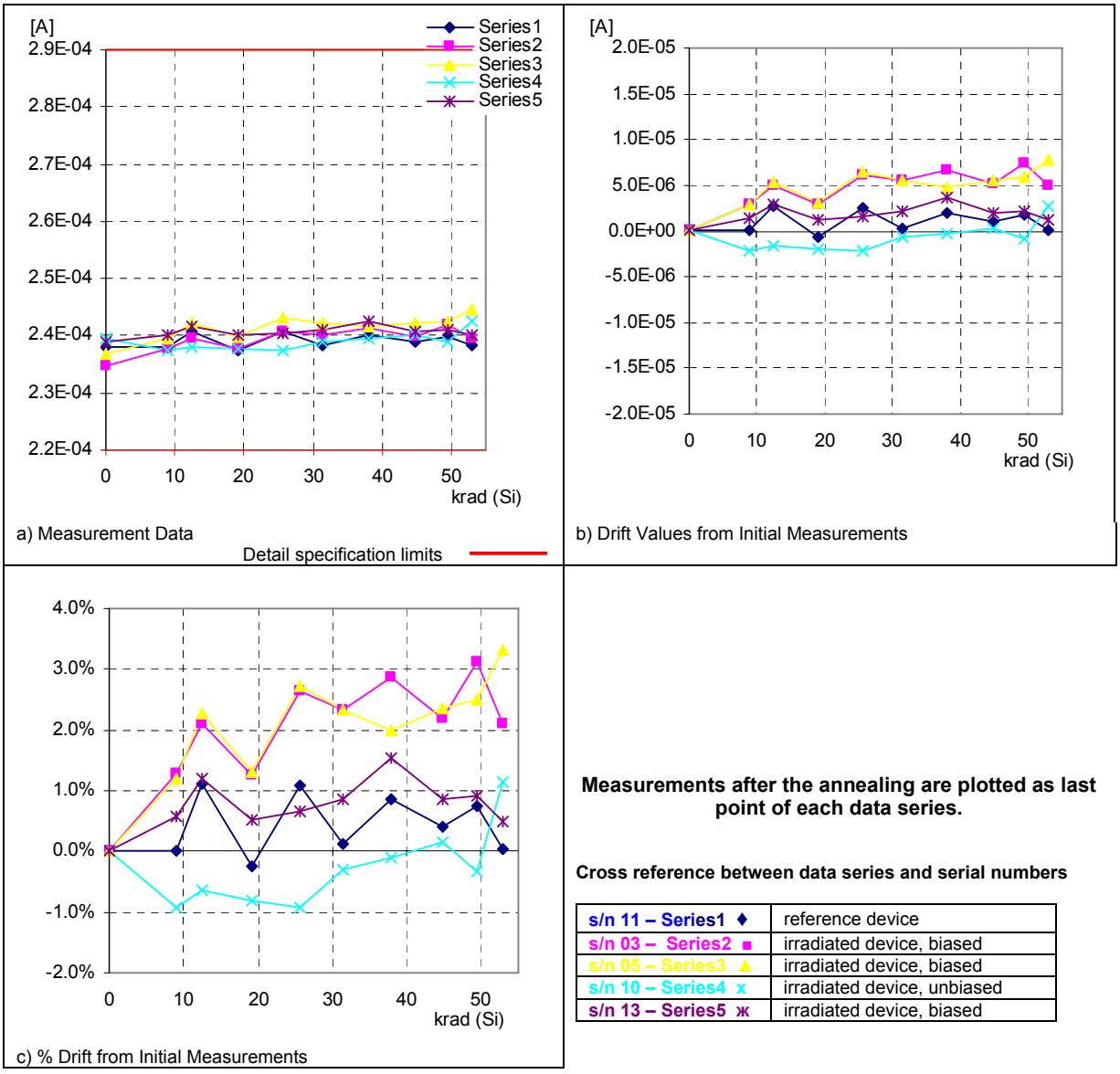
b) Drift Values from Initial Measurements [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9.0	5.50E-08	2.98E-06	2.87E-06	-2.23E-06	1.38E-06
12.5	2.66E-06	4.95E-06	5.37E-06	-1.55E-06	2.87E-06
19.1	-5.85E-07	2.93E-06	3.14E-06	-1.97E-06	1.22E-06
25.7	2.61E-06	6.17E-06	6.48E-06	-2.24E-06	1.59E-06
31.4	3.20E-07	5.48E-06	5.53E-06	-7.50E-07	2.07E-06
38.1	2.02E-06	6.70E-06	4.73E-06	-2.15E-07	3.67E-06
45.0	9.60E-07	5.11E-06	5.58E-06	3.70E-07	2.02E-06
49.5	1.76E-06	7.34E-06	5.90E-06	-8.00E-07	2.18E-06
		After Annealing			
=	1.05E-07	4.95E-06	7.86E-06	2.76E-06	1.16E-06

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	0.023%	1.270%	1.212%	-0.933%	0.578%
12.5	1.115%	2.109%	2.266%	-0.645%	1.202%
19.1	-0.246%	1.248%	1.324%	-0.822%	0.513%
25.7	1.094%	2.629%	2.737%	-0.933%	0.668%
31.4	0.134%	2.333%	2.333%	-0.313%	0.867%
38.1	0.848%	2.855%	1.996%	-0.090%	1.534%
45.0	0.403%	2.177%	2.357%	0.154%	0.846%
49.5	0.737%	3.127%	2.492%	-0.334%	0.913%
		After Annealing			
=	0.044%	2.107%	3.320%	1.152%	0.488%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det.Spec.	**0.000220**	**0.000290**	**[A]**



Measurements after the annealing are plotted as last point of each data series.

Cross reference between data series and serial numbers

s/n 11 – Series1 ♦	reference device
s/n 03 – Series2 ■	irradiated device, biased
s/n 05 – Series3 ▲	irradiated device, biased
s/n 10 – Series4 x	irradiated device, unbiased
s/n 13 – Series5 ж	irradiated device, biased

Fig. 5 Primary Consumption vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 6 – Consumption on 5V_DIG (estimated) vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.005159	0.005076	0.005006	0.005037	0.005056
9.0	0.005268	0.005292	0.005412	0.005450	0.005458
12.5	0.005453	0.005382	0.005431	0.005394	0.005436
19.1	0.005438	0.005314	0.005342	0.005385	0.005349
25.7	0.005620	0.005581	0.005585	0.005594	0.005611
31.4	0.005409	0.005328	0.005379	0.005430	0.005380
38.1	0.005338	0.005364	0.005401	0.005427	0.005426
45.0	0.005692	0.005646	0.005604	0.005620	0.005588
49.5	0.005654	0.005600	0.005593	0.005616	0.005585
		After Annealing			
=	0.005654	0.005607	0.005637	0.005633	0.005630

Mean value (s/n 11): 5.469 mA
Estimated uncertainty: ± 3,16% (± 173 µA)

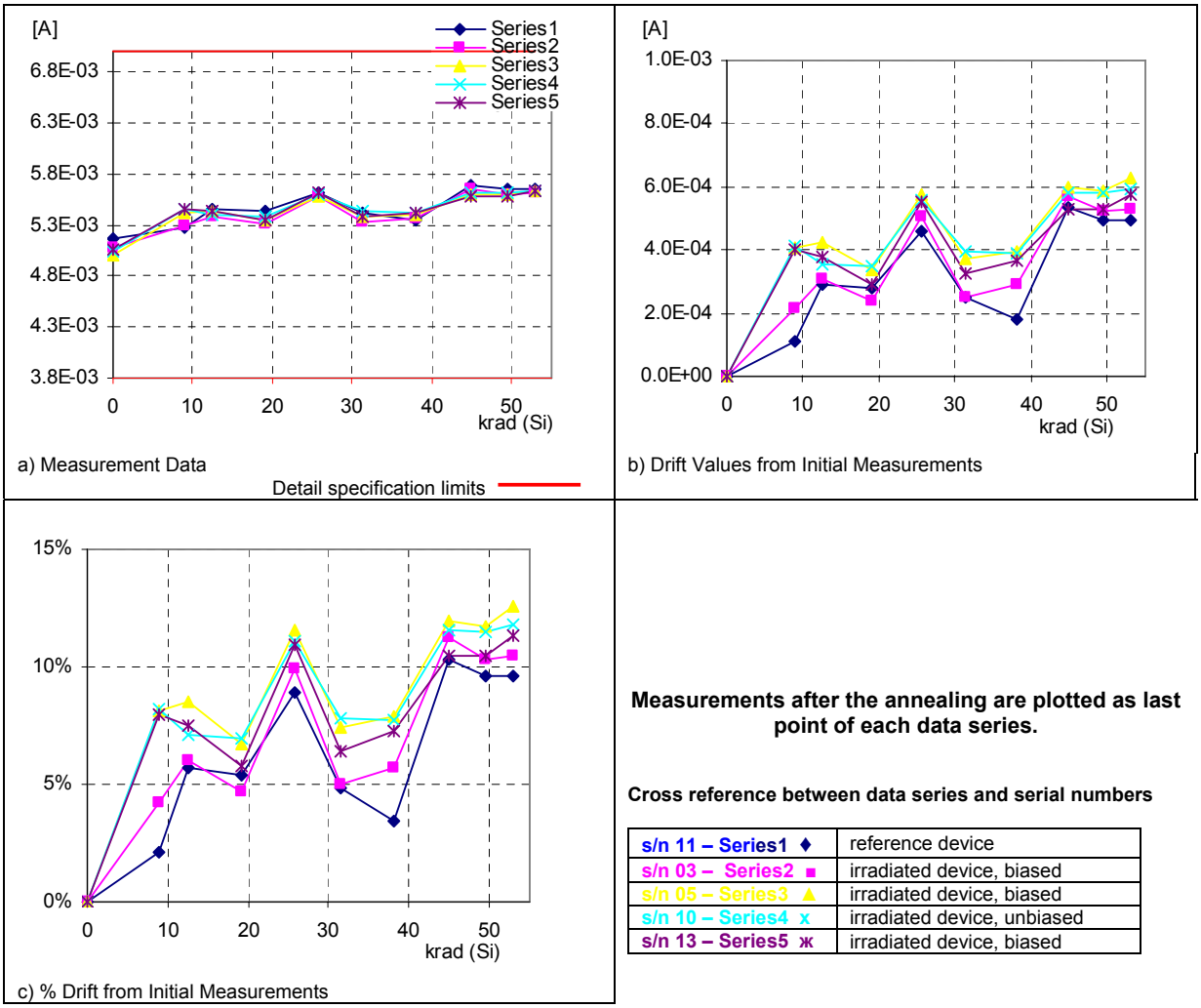
b) Drift Values from Initial Measurements [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000000	0.000000	0.000000	0.000000	0.000000
9.0	0.000109	0.000215	0.000406	0.000413	0.000401
12.5	0.000293	0.000305	0.000425	0.000356	0.000380
19.1	0.000279	0.000238	0.000336	0.000348	0.000293
25.7	0.000461	0.000505	0.000578	0.000557	0.000554
31.4	0.000250	0.000252	0.000372	0.000393	0.000324
38.1	0.000179	0.000288	0.000394	0.000390	0.000369
45.0	0.000533	0.000570	0.000597	0.000583	0.000531
49.5	0.000495	0.000524	0.000587	0.000579	0.000529
		After Annealing			
=	0.000495	0.000531	0.000630	0.000596	0.000573

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.00%	0.00%	0.00%	0.00%	0.00%
9.0	2.12%	4.24%	8.10%	8.19%	7.94%
12.5	5.69%	6.01%	8.48%	7.07%	7.51%
19.1	5.40%	4.69%	6.71%	6.91%	5.79%
25.7	8.94%	9.95%	11.55%	11.06%	10.96%
31.4	4.85%	4.97%	7.44%	7.80%	6.40%
38.1	3.47%	5.67%	7.88%	7.73%	7.30%
45.0	10.33%	11.23%	11.93%	11.58%	10.50%
49.5	9.59%	10.33%	11.72%	11.48%	10.45%
		After Annealing			
=	9.59%	10.46%	12.59%	11.83%	11.34%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det.Spec.	0.0038	0.007	[A]



Measurements after the annealing are plotted as last point of each data series.

Cross reference between data series and serial numbers

s/n 11 – Series1 ♦	reference device
s/n 03 – Series2 ■	irradiated device, biased
s/n 05 – Series3 ▲	irradiated device, biased
s/n 10 – Series4 x	irradiated device, unbiased
s/n 13 – Series5 ж	irradiated device, biased

Fig. 6 Consumption on 5V_DIG vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 7 – Secondary Consumption [A] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.007427	0.007621	0.008029	0.008110	0.007932
9.0	0.007356	0.008069	0.008619	0.008165	0.008478
12.5	0.007404	0.008158	0.008666	0.008202	0.008518
19.1	0.007399	0.008148	0.008696	0.008285	0.008555
25.7	0.007413	0.008115	0.008676	0.008343	0.008586
31.4	0.007399	0.008100	0.008715	0.008510	0.008562
38.1	0.007432	0.008089	0.008733	0.008683	0.008565
45.0	0.007428	0.008144	0.008728	0.008756	0.008590
49.5	0.007404	0.008076	0.008688	0.008716	0.008524
		After Annealing			
=	0.007404	0.008060	0.008585	0.008599	0.008525

Mean value (s/n 11): 7.407 mA
Estimated uncertainty: ± 0.28% (± 21 µA)

b) Drift Values from Initial Measurements [A]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000000	0.000000	0.000000	0.000000	0.000000
9.0	-0.000071	0.000448	0.000590	0.000055	0.000545
12.5	-0.000023	0.000537	0.000637	0.000091	0.000585
19.1	-0.000028	0.000527	0.000667	0.000175	0.000623
25.7	-0.000014	0.000494	0.000647	0.000232	0.000654
31.4	-0.000028	0.000479	0.000685	0.000400	0.000629
38.1	0.000005	0.000468	0.000704	0.000573	0.000632
45.0	0.000001	0.000523	0.000699	0.000646	0.000658
49.5	-0.000023	0.000454	0.000659	0.000605	0.000592
		After Annealing			
=	-0.000023	0.000439	0.000556	0.000489	0.000593

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.950%	5.879%	7.344%	0.673%	6.875%
12.5	-0.308%	7.050%	7.930%	1.125%	7.380%
19.1	-0.374%	6.916%	8.309%	2.155%	7.854%
25.7	-0.188%	6.476%	8.057%	2.865%	8.243%
31.4	-0.382%	6.279%	8.537%	4.931%	7.933%
38.1	0.066%	6.139%	8.769%	7.066%	7.973%
45.0	0.007%	6.861%	8.703%	7.961%	8.296%
49.5	-0.315%	5.963%	8.205%	7.462%	7.461%
		After Annealing			
=	-0.310%	5.760%	6.926%	6.026%	7.475%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det.Spec.	0.005	0.0095	[A]

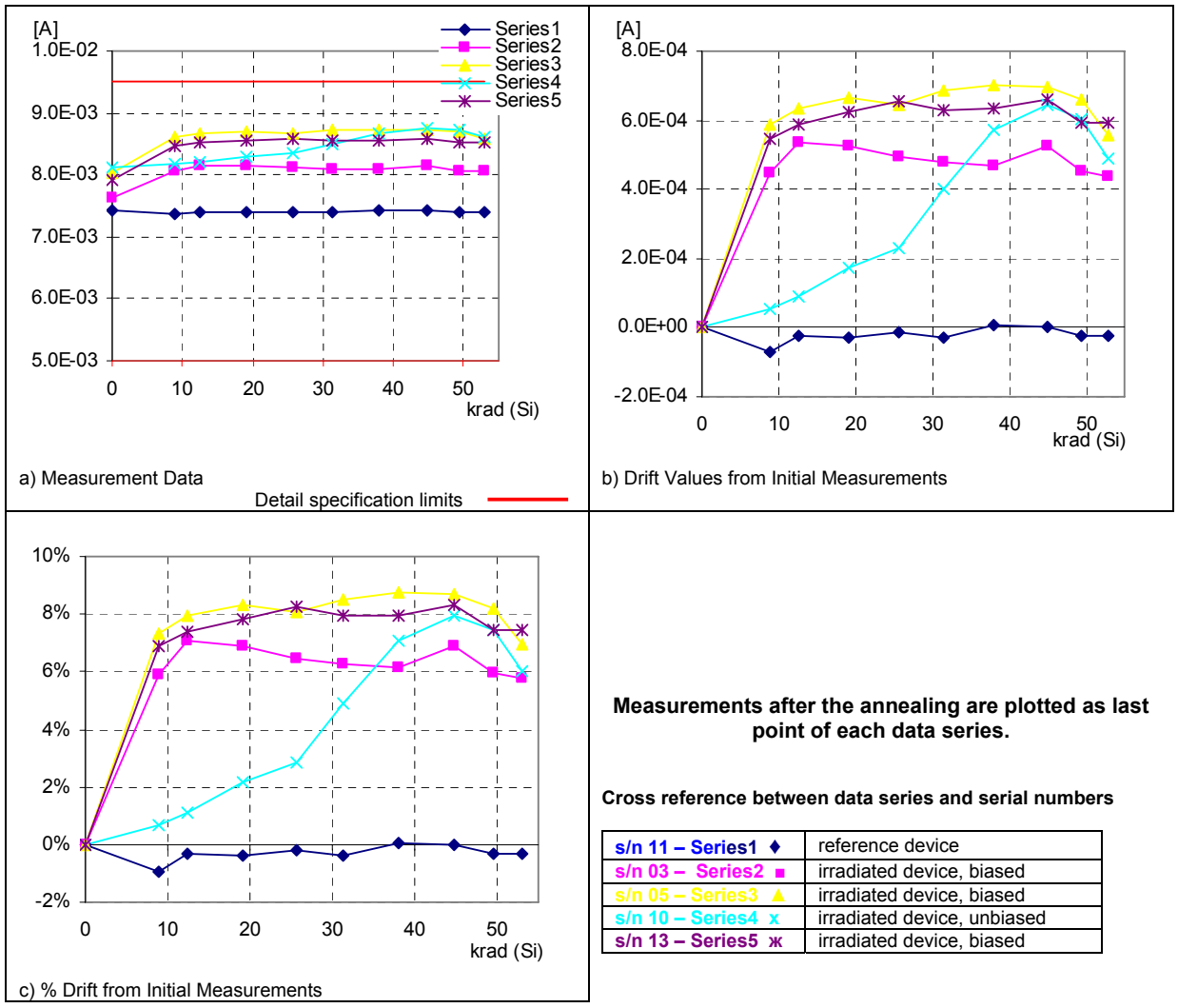


Fig.7 Secondary Consumption vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 8 – V_{AUX} supply Voltage [V] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	9.8874	9.9105	9.9589	9.9897	9.9485
9.0	9.8785	9.8935	9.9443	9.9835	9.9337
12.5	9.8835	9.8977	9.9400	9.9820	9.9305
19.1	9.8837	9.8895	9.9357	9.9810	9.9263
25.7	9.8870	9.8829	9.9296	9.9840	9.9268
31.4	9.8843	9.8790	9.9294	9.9785	9.9216
38.1	9.8905	9.8759	9.9292	9.9745	9.9197
45.0	9.8905	9.8822	9.9278	9.9746	9.9214
49.5	9.8846	9.8722	9.9224	9.9681	9.9146
		After Annealing			
=	9.8847	9.8924	9.9362	9.9808	9.9297

Mean value (s/n 11): 9.885 Volt
Estimated uncertainty: ± 0.03% (± 3.4 mV)

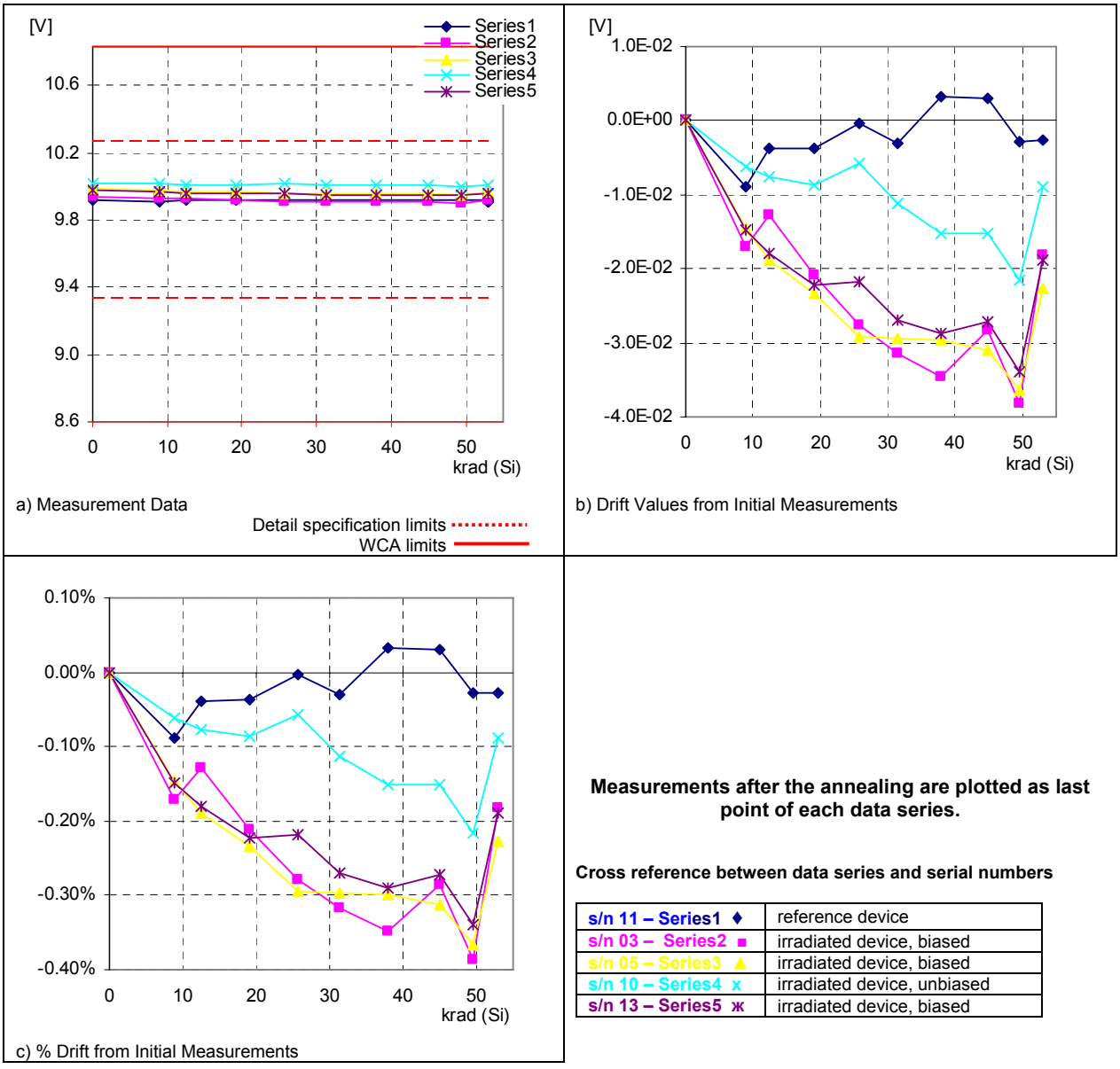
b) Drift Values from Initial Measurements [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0000	0.0000	0.0000	0.0000	0.0000
9.0	-0.0088	-0.0170	-0.0145	-0.0062	-0.0148
12.5	-0.0038	-0.0128	-0.0189	-0.0077	-0.0180
19.1	-0.0037	-0.0210	-0.0232	-0.0087	-0.0222
25.7	-0.0003	-0.0276	-0.0293	-0.0057	-0.0217
31.4	-0.0031	-0.0315	-0.0295	-0.0112	-0.0269
38.1	0.0031	-0.0346	-0.0297	-0.0152	-0.0288
45.0	0.0031	-0.0283	-0.0311	-0.0151	-0.0271
49.5	-0.0028	-0.0383	-0.0365	-0.0216	-0.0339
		After Annealing			
=	-0.0027	-0.0181	-0.0227	-0.0088	-0.0188

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.089%	-0.172%	-0.146%	-0.062%	-0.149%
12.5	-0.039%	-0.129%	-0.190%	-0.077%	-0.181%
19.1	-0.037%	-0.212%	-0.233%	-0.087%	-0.223%
25.7	-0.003%	-0.279%	-0.294%	-0.057%	-0.218%
31.4	-0.031%	-0.318%	-0.296%	-0.112%	-0.270%
38.1	0.032%	-0.349%	-0.298%	-0.152%	-0.290%
45.0	0.032%	-0.286%	-0.312%	-0.152%	-0.273%
49.5	-0.028%	-0.386%	-0.366%	-0.216%	-0.340%
		After Annealing			
=	-0.027%	-0.183%	-0.228%	-0.089%	-0.189%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	9.30	10.24	[V]
WCA After 50 krad	8.57	10.80	[V]



Measurements after the annealing are plotted as last point of each data series.

Cross reference between data series and serial numbers

s/n 11 – Series1 ♦	reference device
s/n 03 – Series2 ■	irradiated device, biased
s/n 05 – Series3 ▲	irradiated device, biased
s/n 10 – Series4 x	irradiated device, unbiased
s/n 13 – Series5 ✱	irradiated device, biased

Fig.8 V_{AUX} supply Voltage vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 9 – 2.5V Output Voltage [V] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	2.501024	2.500836	2.502927	2.501613	2.502123
9.0	2.501109	2.502417	2.504084	2.501863	2.503328
12.5	2.501096	2.502631	2.504629	2.501888	2.503528
19.1	2.501026	2.503271	2.505160	2.502088	2.504061
25.7	2.501049	2.503764	2.505657	2.502006	2.504614
31.4	2.501084	2.504120	2.505974	2.502360	2.504817
38.1	2.501012	2.504510	2.506391	2.502924	2.505207
45.0	2.501049	2.504700	2.506861	2.503517	2.505514
49.5	2.501109	2.505018	**2.507003**	2.503694	2.505750
			After Annealing		
=	2.501084	2.502488	2.504874	2.503187	2.503458

Blue Values: ***outside detail specification limit (still within WCA limits).***
Borderline value(+ 3 µV, within measurement uncertainty).

Mean value (s/n 11): 2.501064 V
Estimated uncertainty: ± 0.002% (± 40 µV)

b) Drift Values from Initial Measurements [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000000	0.000000	0.000000	0.000000	0.000000
9.0	0.000084	0.001581	0.001158	0.000250	0.001204
12.5	0.000071	0.001796	0.001702	0.000274	0.001404
19.1	0.000001	0.002436	0.002233	0.000474	0.001938
25.7	0.000024	0.002929	0.002730	0.000392	0.002491
31.4	0.000060	0.003284	0.003048	0.000747	0.002693
38.1	-0.000012	0.003674	0.003464	0.001311	0.003083
45.0	0.000024	0.003864	0.003934	0.001903	0.003391
49.5	0.000084	0.004182	0.004077	0.002081	0.003627
			After Annealing		
=	0.000060	0.001652	0.001948	0.001573	0.001334

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	0.003%	0.063%	0.046%	0.010%	0.048%
12.5	0.003%	0.072%	0.068%	0.011%	0.056%
19.1	0.000%	0.097%	0.089%	0.019%	0.077%
25.7	0.001%	0.117%	0.109%	0.016%	0.100%
31.4	0.002%	0.131%	0.122%	0.030%	0.108%
38.1	0.000%	0.147%	0.138%	0.052%	0.123%
45.0	0.001%	0.155%	0.157%	0.076%	0.136%
49.5	0.003%	0.167%	0.163%	0.083%	0.145%
			After Annealing		
=	0.002%	0.066%	0.078%	0.063%	0.053%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	2.493	2.507	[V]
WCA After 50 krad	2.486	2.514	[V]

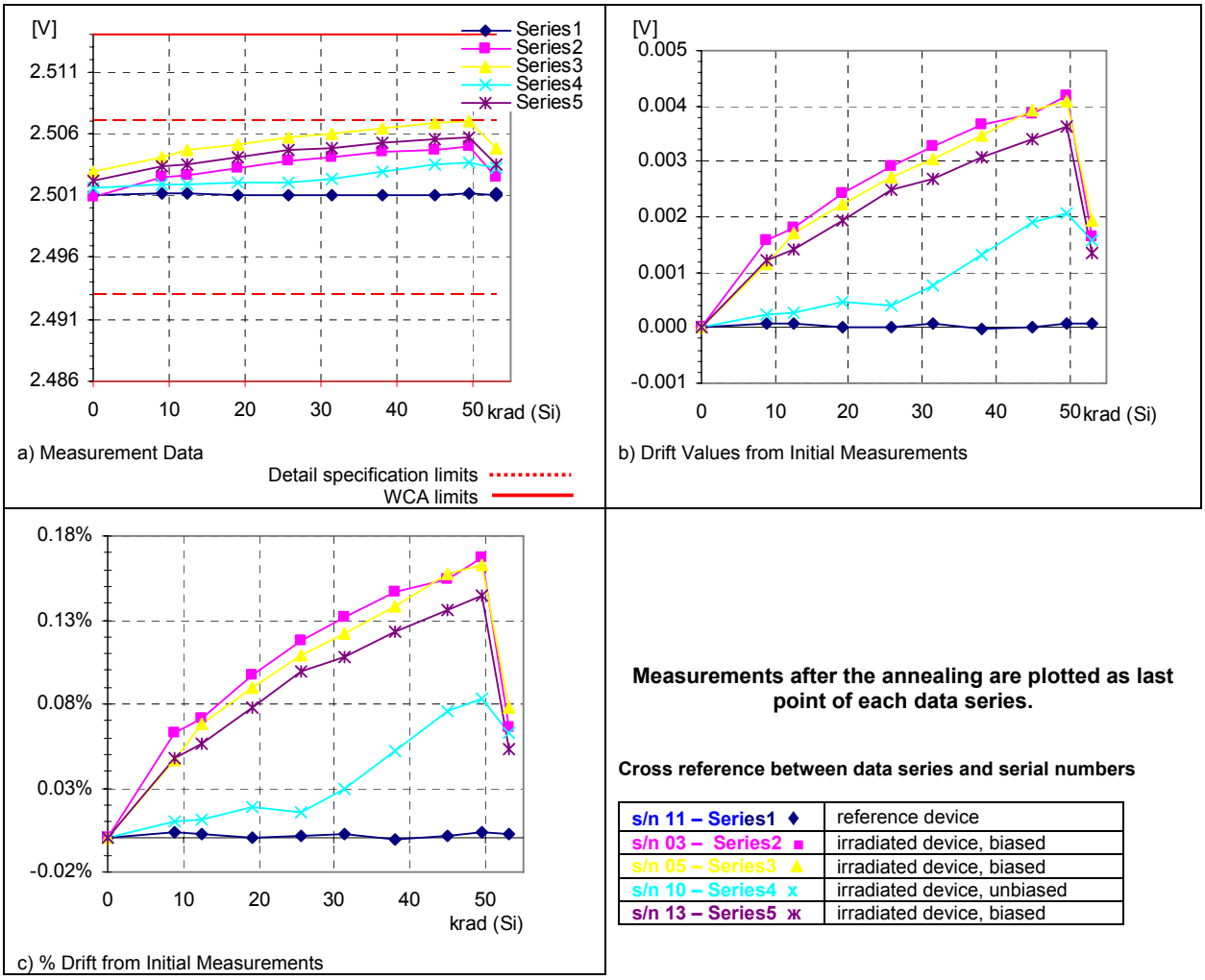


Fig. 9 - 2.5V Output Voltage vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 10 – 5V Reference Voltage [V] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	4.945992	4.946586	4.947257	4.945933	4.946724
9.0	4.946266	4.952150	4.952291	4.946464	4.951783
12.5	4.946087	4.953946	4.954229	4.946786	4.953661
19.1	4.946074	4.957264	4.957562	4.947554	4.957111
25.7	4.946051	4.960442	4.960740	4.948072	4.960230
31.4	4.946111	4.963044	4.963422	4.949397	4.962522
38.1	4.945911	4.965418	4.966244	4.952349	4.965217
45.0	4.946029	4.967888	4.969034	4.955317	4.967796
49.5	4.946158	4.969423	4.970772	4.957158	4.969458
		After Annealing			
=	4.946076	4.959618	4.961342	4.957741	4.960290

Mean value (s/n 11): 4.946075 V
Estimated uncertainty: ± 0.0018% (± 91 µV)

b) Drift Values from Initial Measurements [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000000	0.000000	0.000000	0.000000	0.000000
9.0	0.000273	0.005564	0.005034	0.000531	0.005059
12.5	0.000094	0.007360	0.006972	0.000852	0.006937
19.1	0.000082	0.010679	0.010306	0.001621	0.010387
25.7	0.000059	0.013857	0.013483	0.002139	0.013506
31.4	0.000119	0.016459	0.016166	0.003463	0.015798
38.1	-0.000081	0.018832	0.018988	0.006416	0.018492
45.0	0.000037	0.021302	0.021778	0.009383	0.021071
49.5	0.000166	0.022838	0.023516	0.011224	0.022733
		After Annealing			
=	0.000083	0.013032	0.014086	0.011808	0.013566

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	0.006%	0.112%	0.102%	0.011%	0.102%
12.5	0.002%	0.149%	0.141%	0.017%	0.140%
19.1	0.002%	0.216%	0.208%	0.033%	0.210%
25.7	0.001%	0.280%	0.273%	0.043%	0.273%
31.4	0.002%	0.333%	0.327%	0.070%	0.319%
38.1	-0.002%	0.381%	0.384%	0.130%	0.374%
45.0	0.001%	0.431%	0.440%	0.190%	0.426%
49.5	0.003%	0.462%	0.475%	0.227%	0.460%
		After Annealing			
=	0.002%	0.263%	0.285%	0.239%	0.274%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	4.900	5.010	[V]
WCA After 50 krad	4.972	5.028	[V]

Note that the initial and post irradiation limits (from detail specification and worst case analysis) are not consistent, as can be seen by comparing the limits line in fig.10a. The applicable limits are represented with a dotted (Detailed Specification) or continuous (WCA) red lines. The discrepancy is explained by the fact that the worst case analysis assumes a zero load while the parameter (4.1) according to detail specification shall be measured with 2mA load (which also have been done here).

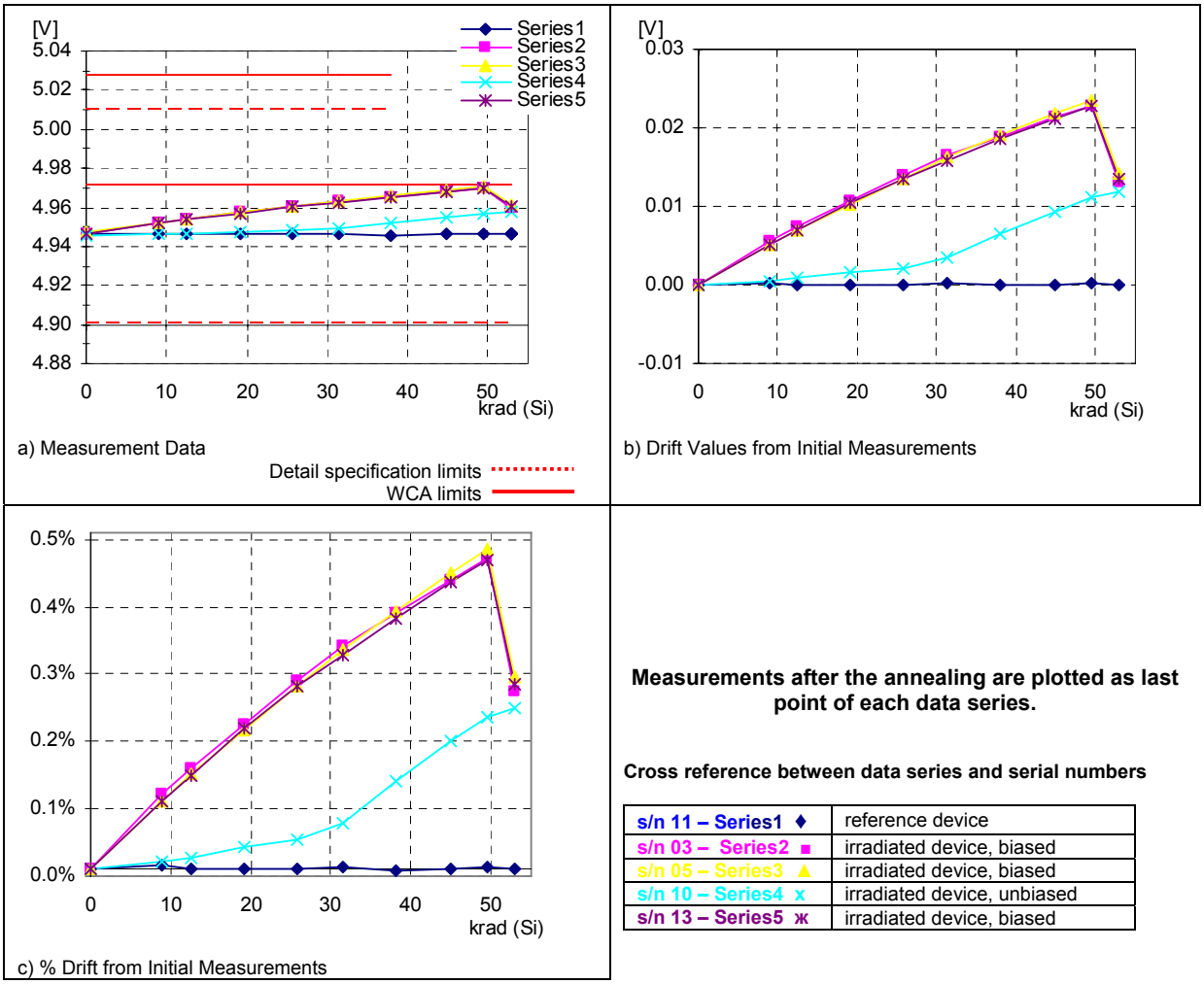


Fig. 10 - 5V Reference Voltage vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 11 – Under Voltage Protection (UVP) Voltage vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	17.8378	17.8054	17.8121	17.7991	17.8378
9.0	17.8345	17.8218	17.8280	17.7960	17.8504
12.5	17.8375	17.8279	17.8343	17.7991	17.8567
19.1	17.8377	17.8345	17.8439	17.7992	17.8663
25.7	17.8375	17.8408	17.8505	17.8024	***17.8761***
31.4	17.8378	17.8470	17.8599	17.8055	***17.8791***
38.1	17.8410	17.8567	17.8665	17.8152	***17.8855***
45.0	17.8406	17.8597	***17.8726***	17.8247	***17.8952***
49.5	17.8377	17.8631	***17.8760***	17.8249	***17.8952***
			After Annealing		
=	17.8406	17.8409	17.8537	17.8341	17.8759

Blue Values: outside detail specification limit (still within WCA limits)

Mean value (s/n 11): 17.8383 V
Estimated uncertainty: ± 0.010% (± 1.9 mV)

b) Drift Values from Initial Measurements [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0000	0.0000	0.0000	0.0000	0.0000
9.0	-0.0033	0.0164	0.0160	-0.0031	0.0125
12.5	-0.0003	0.0225	0.0222	0.0000	0.0189
19.1	-0.0001	0.0291	0.0318	0.0001	0.0285
25.7	-0.0003	0.0354	0.0384	0.0033	0.0383
31.4	0.0000	0.0416	0.0479	0.0064	0.0413
38.1	0.0032	0.0514	0.0545	0.0161	0.0476
45.0	0.0028	0.0543	0.0605	0.0256	0.0574
49.5	-0.0001	0.0577	0.0639	0.0258	0.0574
			After Annealing		
=	0.0028	0.0355	0.0416	0.0350	0.0381

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.019%	0.092%	0.090%	-0.017%	0.070%
12.5	-0.002%	0.127%	0.125%	0.000%	0.106%
19.1	-0.001%	0.164%	0.179%	0.001%	0.160%
25.7	-0.002%	0.199%	0.216%	0.019%	0.215%
31.4	0.000%	0.234%	0.269%	0.036%	0.231%
38.1	0.018%	0.289%	0.306%	0.090%	0.267%
45.0	0.015%	0.305%	0.340%	0.144%	0.322%
49.5	-0.001%	0.324%	0.359%	0.145%	0.322%
			After Annealing		
=	0.015%	0.199%	0.233%	0.197%	0.213%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	17.53	17.87	[V]
WCA After 50 krad	17.28	18.07	[V]

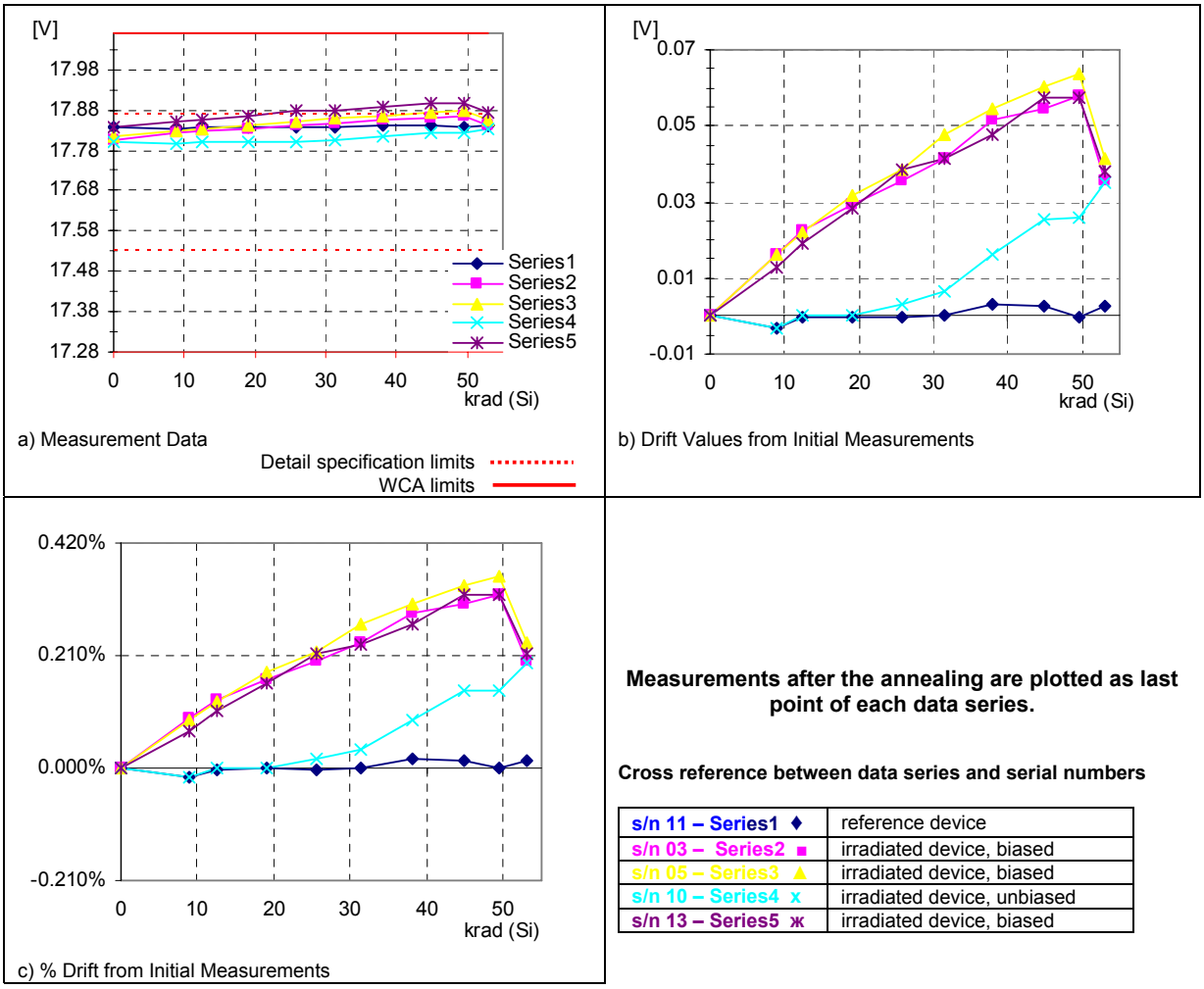


Fig. 11 Under Voltage Protection (UVP) Voltage vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 12 Under Voltage Protection (UVP) Hysteresis vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	1.2058	1.2248	1.2025	1.2183	1.2056
9.0	1.2055	1.2182	1.1961	1.2151	1.1961
12.5	1.2087	1.2150	1.1956	1.2152	1.1959
19.1	1.2056	1.2058	1.1894	1.2121	1.1896
25.7	1.2053	1.2026	1.1832	1.2119	1.1833
31.4	1.2058	1.1955	1.1800	1.2088	1.1799
38.1	1.2058	1.1957	1.1738	1.2023	1.1737
45.0	1.2055	1.1895	1.1670	1.1895	1.1735
49.5	1.2057	1.1862	1.1672	1.1770	1.1676
		After Annealing			
=	1.2055	1.2313	1.2121	1.2215	1.2119

Mean value (s/n 11): 1.2059 V
Estimated uncertainty: ± 0.08% (± 1.0 mV)

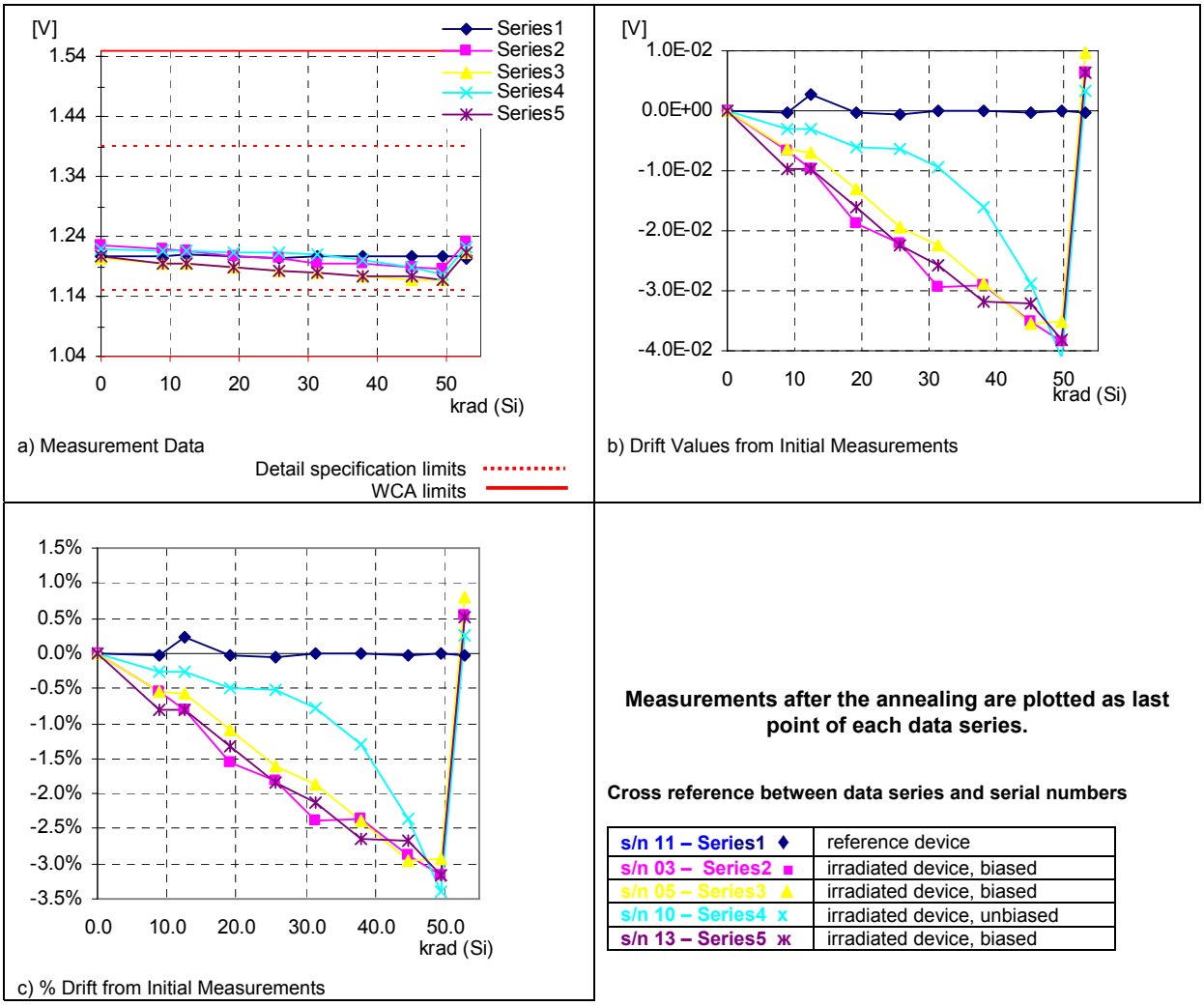
b) Drift Values from Initial Measurements [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0000	0.0000	0.0000	0.0000	0.0000
9.0	-0.0003	-0.0066	-0.0065	-0.0032	-0.0096
12.5	0.0029	-0.0098	-0.0069	-0.0031	-0.0098
19.1	-0.0002	-0.0189	-0.0132	-0.0062	-0.0161
25.7	-0.0005	-0.0222	-0.0194	-0.0064	-0.0223
31.4	0.0000	-0.0293	-0.0225	-0.0095	-0.0257
38.1	0.0000	-0.0290	-0.0287	-0.0160	-0.0319
45.0	-0.0003	-0.0353	-0.0355	-0.0288	-0.0321
49.5	-0.0001	-0.0386	-0.0353	-0.0413	-0.0381
		After Annealing			
=	-0.0003	0.0065	0.0096	0.0032	0.0063

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.027%	-0.538%	-0.539%	-0.261%	-0.794%
12.5	0.238%	-0.799%	-0.575%	-0.253%	-0.811%
19.1	-0.017%	-1.546%	-1.096%	-0.506%	-1.332%
25.7	-0.044%	-1.814%	-1.609%	-0.523%	-1.853%
31.4	0.000%	-2.388%	-1.874%	-0.777%	-2.135%
38.1	0.000%	-2.370%	-2.387%	-1.309%	-2.647%
45.0	-0.027%	-2.882%	-2.954%	-2.365%	-2.663%
49.5	-0.009%	-3.152%	-2.935%	-3.387%	-3.158%
		After Annealing			
=	-0.027%	0.529%	0.796%	0.263%	0.520%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	1.150	1.390	[V]
WCA After 50 krad	1.040	1.550	[V]



Measurements after the annealing are plotted as last point of each data series.

Cross reference between data series and serial numbers

s/n 11 – Series1 ♦	reference device
s/n 03 – Series2 ■	irradiated device, biased
s/n 05 – Series3 ▲	irradiated device, biased
s/n 10 – Series4 x	irradiated device, unbiased
s/n 13 – Series5 ж	irradiated device, biased

Fig. 12 Under Voltage Protection (UVP) Hysteresis vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 13 - Over Voltage Protection (OVP) Treshold vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	12.6789	12.6004	12.6838	12.6684	12.7101
9.0	12.6685	12.6265	12.7097	12.6685	12.7306
12.5	12.6734	12.6420	12.7307	12.6685	12.7464
19.1	12.6737	12.6687	12.7570	12.6685	12.7732
25.7	12.6794	12.6945	12.7838	12.6788	12.8044
31.4	12.6741	12.7156	12.8096	12.6842	12.8202
38.1	12.6793	12.7470	12.8466	12.7002	12.8467
45.0	12.6790	12.7730	12.8678	12.7207	12.8781
49.5	12.6743	12.7889	12.8832	12.7311	12.8889
		After Annealing			
=	12.6796	12.6685	12.7684	12.7106	12.7788

Blue Values: outside detail specification limits (since the initial measurements)
Red Values: outside WCA limits (since the initial measurements)

Mean value (s/n 11): 12.6760 V
Estimated uncertainty: ± 0.03% (± 4.0 mV)

b) Drift Values from Initial Measurements [V]

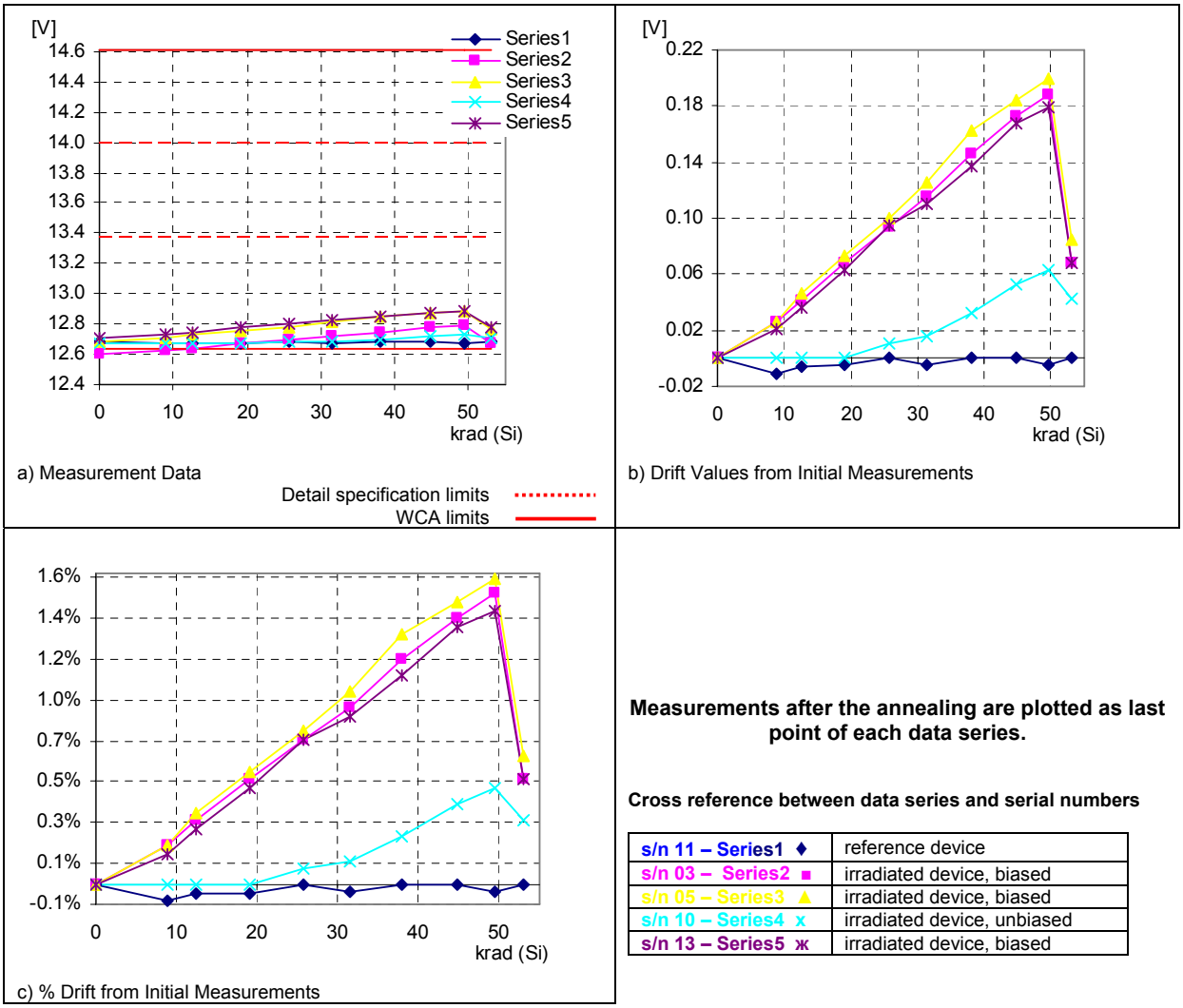
Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0000	0.0000	0.0000	0.0000	0.0000
9.0	-0.0104	0.0261	0.0258	0.0001	0.0205
12.5	-0.0055	0.0416	0.0469	0.0001	0.0363
19.1	-0.0052	0.0683	0.0732	0.0001	0.0631
25.7	0.0004	0.0940	0.1000	0.0104	0.0943
31.4	-0.0048	0.1152	0.1258	0.0158	0.1101
38.1	0.0003	0.1466	0.1628	0.0318	0.1367
45.0	0.0001	0.1726	0.1840	0.0523	0.1680
49.5	-0.0047	0.1885	0.1994	0.0627	0.1788
		After Annealing			
=	0.0006	0.0681	0.0845	0.0422	0.0687

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.082%	0.207%	0.204%	0.001%	0.161%
12.5	-0.044%	0.330%	0.370%	0.001%	0.285%
19.1	-0.041%	0.542%	0.577%	0.001%	0.496%
25.7	0.003%	0.746%	0.788%	0.082%	0.742%
31.4	-0.038%	0.914%	0.992%	0.125%	0.866%
38.1	0.003%	1.163%	1.284%	0.251%	1.075%
45.0	0.001%	1.370%	1.450%	0.413%	1.322%
49.5	-0.037%	1.496%	1.572%	0.495%	1.406%
		After Annealing			
=	0.005%	0.540%	0.667%	0.333%	0.540%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	13.37	14.00	[V]
WCA After 50 krad	12.64	14.61	[V]

Pre-irradiation measurements performed at ESTEC of OVP Over-Voltage Protection (see table 13) resulted in values lower than the minimum limit stated in ETCA 8090.0832-1 detail specification, table 2.
The measured relative drift with TID has been confirmed in the measurements performed at ETCA (see PWM-PSU-TR-0064).



Measurements after the annealing are plotted as last point of each data series.

Cross reference between data series and serial numbers

s/n 11 – Series1 ♦	reference device
s/n 03 – Series2 ■	irradiated device, biased
s/n 05 – Series3 ▲	irradiated device, biased
s/n 10 – Series4 x	irradiated device, unbiased
s/n 13 – Series5 ✱	irradiated device, biased

Fig. 13 Over Voltage Protection (OVP) Treshold vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 14 Clock Frequency [Hz] vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [Hz]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	195,131.09	194,796.58	195,221.34	195,554.76	194,857.64
9.0	195,000.61	194,579.75	195,815.85	195,471.94	194,850.08
12.5	195,012.54	193,589.19	195,081.13	195,558.57	193,900.11
19.1	195,065.28	***191,335.08***	***193,275.28***	195,695.23	***191,683.83***
25.7	195,127.16	***188,975.86***	***191,341.30***	195,903.17	***189,406.71***
31.4	195,030.52	***186,758.09***	***189,371.42***	195,509.18	***187,410.98***
38.1	195,162.35	***184,511.12***	***187,372.11***	194,040.56	***185,081.79***
45.0	195,174.92	***182,318.41***	***185,401.45***	***192,154.69***	***182,843.04***
49.5	195,063.53	***180,796.49***	***184,027.83***	***190,547.88***	***181,306.58***
			After Annealing		
=	195,075.22	***182,035.46***	***185,762.18***	***191,098.10***	***186,517.12***

Blue Values: outside detail specification limit (still within WCA limits)
Red Values: outside WCA limits

Mean value (s/n 11): 195'084 Hz
Estimated uncertainty: ± 0.03% (± 60 Hz)

b) Drift Values from Initial Measurements [Hz]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.0	0.0	0.0	0.0	0.0
9.0	-130.5	-216.8	594.5	-82.8	-7.6
12.5	-118.6	-1,207.4	-140.2	3.8	-957.5
19.1	-65.8	-3,461.5	-1,946.1	140.5	-3,173.8
25.7	-3.9	-5,820.7	-3,880.0	348.4	-5,450.9
31.4	-100.6	-8,038.5	-5,849.9	-45.6	-7,446.7
38.1	31.3	-10,285.5	-7,849.2	-1,514.2	-9,775.9
45.0	43.8	-12,478.2	-9,819.9	-3,400.1	-12,014.6
49.5	-67.6	-14,000.1	-11,193.5	-5,006.9	-13,551.1
			After Annealing		
=	-55.9	-12,761.1	-9,459.2	-4,456.7	-8,340.5

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000%	0.000%	0.000%	0.000%	0.000%
9.0	-0.067%	-0.111%	0.305%	-0.042%	-0.004%
12.5	-0.061%	-0.620%	-0.072%	0.002%	-0.491%
19.1	-0.034%	-1.777%	-0.997%	0.072%	-1.629%
25.7	-0.002%	-2.988%	-1.988%	0.178%	-2.797%
31.4	-0.052%	-4.127%	-2.997%	-0.023%	-3.822%
38.1	0.016%	-5.280%	-4.021%	-0.774%	-5.017%
45.0	0.022%	-6.406%	-5.030%	-1.739%	-6.166%
49.5	-0.035%	-7.187%	-5.734%	-2.560%	-6.954%
			After Annealing		
=	-0.029%	-6.551%	-4.845%	-2.279%	-4.280%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det. Spec. (before irradiation)	193'500	199'400	[Hz]
WCA After 50 krad	192'000	201'000	[Hz]

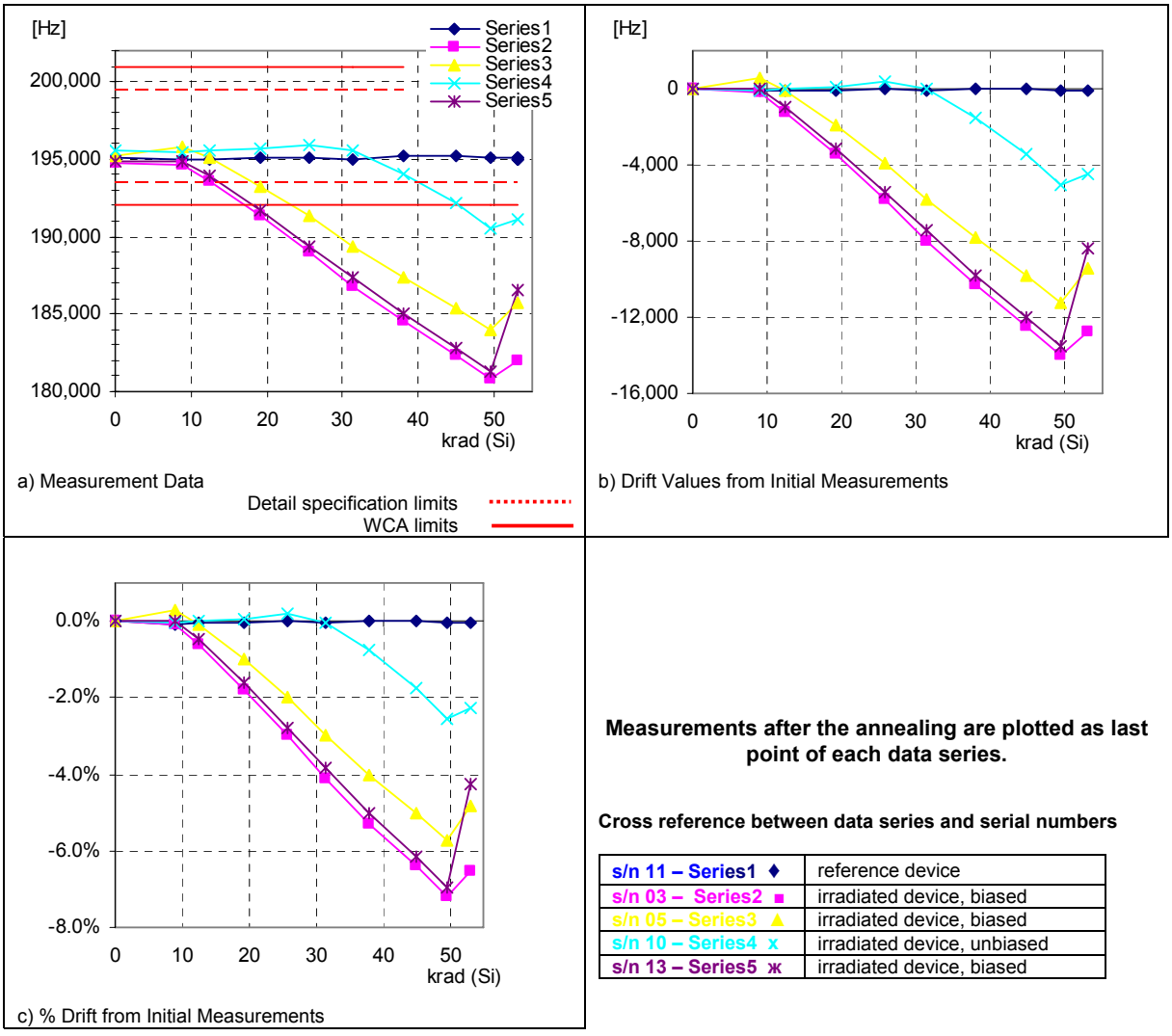


Fig. 14 Clock Frequency [Hz] vs ^{60}Co Irradiation Total Dose [krad (Si)]

Table 15 TP2 Voltage (Protection Flag) vs ^{60}Co Irradiation Total Dose [krad (Si)]

a) Measurement data [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000690	0.000690	0.000585	0.000530	0.000635
9.0	0.000795	0.001060	0.000955	0.000795	0.001010
12.5	0.000690	0.001225	0.001060	0.000640	0.001010
19.1	0.000905	0.001065	0.001225	0.000640	0.001330
25.7	0.000745	0.001380	0.001225	0.000690	0.000955
31.4	0.000690	0.001330	0.001220	0.000800	0.001010
38.1	0.000690	0.001435	0.001170	0.001010	0.001060
45.0	0.000740	0.001115	0.001170	0.001010	0.001065
49.5	0.000640	0.001065	0.001010	0.001120	0.001010
		After Annealing			
=	0.000850	0.000530	0.000425	0.000850	0.000535

Mean value (s/n 11): 743 µV
Estimated uncertainty: ± 10.6% (± 80 µV)

b) Drift Values from Initial Measurements [V]

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.000000	0.000000	0.000000	0.000000	0.000000
9.0	0.000105	0.000370	0.000370	0.000265	0.000375
12.5	0.000000	0.000535	0.000475	0.000110	0.000375
19.1	0.000215	0.000375	0.000640	0.000110	0.000695
25.7	0.000055	0.000690	0.000640	0.000160	0.000320
31.4	0.000000	0.000640	0.000635	0.000270	0.000375
38.1	0.000000	0.000745	0.000585	0.000480	0.000425
45.0	0.000050	0.000425	0.000585	0.000480	0.000430
49.5	-0.000050	0.000375	0.000425	0.000590	0.000375
		After Annealing			
=	0.000160	-0.000160	-0.000160	0.000320	-0.000100

c) % Drift from Initial Measurements

Total Dose krad (Si)	s/n 11	s/n 3	s/n 5	s/n 10	s/n 13
0.0	0.00%	0.00%	0.00%	0.00%	0.00%
9.0	15.22%	53.62%	63.25%	50.00%	59.06%
12.5	0.00%	77.54%	81.20%	20.75%	59.06%
19.1	31.16%	54.35%	109.40%	20.75%	109.45%
25.7	7.97%	100.00%	109.40%	30.19%	50.39%
31.4	0.00%	92.75%	108.55%	50.94%	59.06%
38.1	0.00%	107.97%	100.00%	90.57%	66.93%
45.0	7.2%	61.6%	100.0%	90.6%	67.7%
49.5	-7.2%	54.3%	72.6%	111.3%	59.1%
		After Annealing			
=	23.2%	-23.2%	-27.4%	60.4%	-15.7%

Applicable limits:	*Min.*	*Max.*	*Unit*
Det.Spec.	0	0.006	[V]

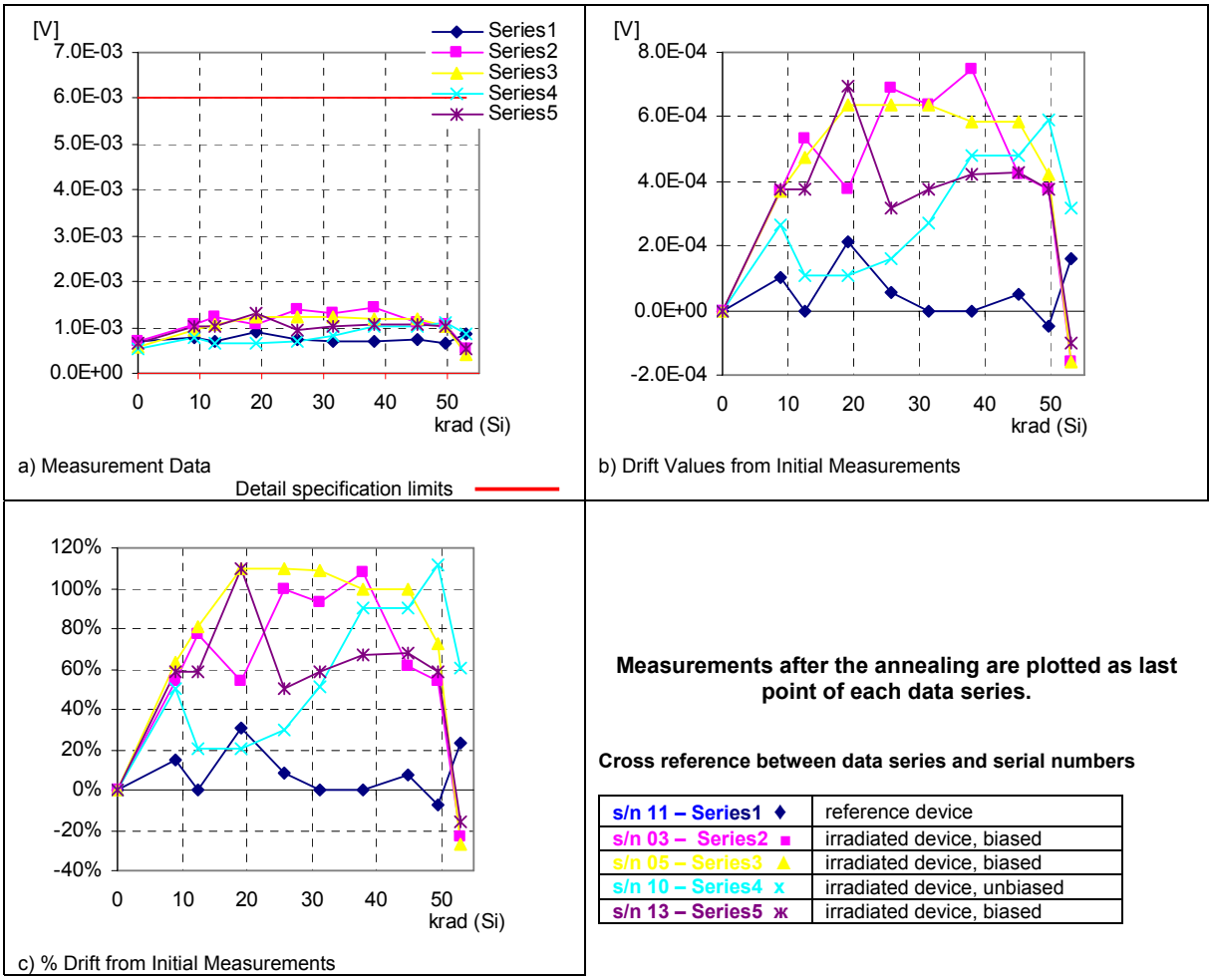


Fig. 15 TP2 Voltage (Protection Flag) vs ^{60}Co Irradiation Total Dose [krad (Si)]

5 CONCLUSION

Four devices (sn's 03, 05, 13 and s/n 10) were irradiated (three biased + one unbiased) up to 49.5(± 5%) krad(Si). After the irradiation, all devices were annealed for 24 hrs at room temperature followed by 168hrs at 100°C; during annealing all devices under test were biased. One more device (s/n 11) was used as control sample during the intermediate measurements. Table 16 summarises the irradiation test history.

Table 16 Irradiation Test History

Step	Location	Total Dose krad (Si)	Dose Rate (Si)Rad/min	Measured Parameters
Full init. measurements	ETCA[1]	-	-	Table 2 D.S.
init. measurements	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 1	ESTEC	9.0	0.65	Bias Voltages
Intermediate meas..	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 2	ESTEC	12.5	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 3	ESTEC	19.1	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 4	ESTEC	25.7	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 5	ESTEC	31.4	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 6	ESTEC	38.0	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 7	ESTEC	45.0	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Irradiation step 8	ESTEC	49.5	0.65	Bias Voltages
Intermediate meas.	ESTEC	-	-	Table 2 D.S. subset
Full measurements	ETCA[1]	-	-	Table 2 D.S.
24 hrs annealing R.T.	ETCA[1]	-	-	-
Full measurements	ETCA[1]	-	-	Table 2 D.S.
168 hrs annealing 100°C	ETCA[1]	-	-	-
Full measurements	ETCA[1]	-	-	Table 2 D.S.
Final measurements	ESTEC	-	-	Table 2 D.S. subset

Note 1 - data reported, separately, in ThalesAleniaSpace ETCA "Post-irradiation test report " ref. PWM-PSU-TR-0064.

No catastrophic failures were observed up to 49.51 krad(Si). The parametric degradation induced by gamma radiation has been summarized in table 17.
The only parameter outside specified limits, after 49.51 krad(Si), was (9.1) Clock frequency for all devices. As a consequence of this TID test the detail specification and the WCA analysis has been updated with new TID drift limits for the clock frequency. Also the limits for the 5V reference voltage and the UVP Voltage Threshold parameters have been updated.

Pre-irradiation measurements performed at ESTEC of OVP Over-Voltage Protection (see table 13) resulted in values lower than the minimum limit stated in detail specification, table 2. However, the measured relative drift with TID has been confirmed to be satisfying in the measurements performed at ETCA (see PWM-PSU-TR-0064).

Table 17 Summary of TID test results at ESTEC (D.S. Table 2 subset)

N° (*)	Parameter	Table	Fig.	Remarks
1.1	Primary Consumption	4a-4c	4a-4c	Still within limits for all devices; max drift ≈ –4%
1.4	Primary Consumption	5a-5c	5a-5c	Still within limits for all devices; max drift ≈ +3%
1.5	Consumption on 5V_DIG	6a-6c	6a-6c	Still within limits for all devices. No clear indication of TID dependency.
1.6	Secondary Consumption	7a-7c	7a-7c	Still within limits for all devices; max drift ≈ +8%
2.1	Vaux Supply voltage	8a-8c	8a-8c	Still within limits for all devices; max drift ≈ –0.4%
3.1	2.5V output voltage	9a-9c	9a-9c	Still within limits for all devices; max drift ≈ +0.2%
4.1	5V reference voltage	10a-10c	10a-10c	Specified limits not consistent (see tables 3.a 3.b and fig.10a). Max drift ≈ +0.4%
5.1	UVP Threshold Voltage	11a-11c	11a-11c	Still within WCA limits for all devices; max drift ≈ +0.4%. S/n 13 outside initial max limit after 25.6 krad(Si) S/n 10 outside initial max limit after 45.0 krad(Si)
5.2	UVP Hysteresis	12a-12c	12a-12c	Still within limits for all devices; max drift ≈ -3.5 %
6.1	OVP Threshold Voltage	13a-13c	13a-13c	All devices out of spec. limits since the initial measurements. Max drift ≈ +1.6% *NB This discrepancy is addressed to be an affect by different measurement set-ups.*
9.1	Clock Frequency	14a-14c	14a-14c	On all biased devices, below the min.limit after 19.1 krad(Si); on the unbiased device, after 45.0 krad(Si). *NB: After update of applicable documents, TID drift are within specified limits.*
11.1	TP2 voltage	15a-15c	15a-15c	Still within limits for all devices. No clear indication of TID dependency.

(*) reference to parameter nr. in table 2 of ETCA 8090.0832-1 detail specification.

All biased devices failed parameter 9.1 (clock frequency) after total dose of 19.1 krad(Si) as shown in table 14. The unbiased device (s/n 10) failed the same parameter after a total dose of 45 krad(Si). The TID drift for this parameter has been updated in later revisions of the detail specification and worst case analysis.

Devices s/n 13 and s/n 5 show marginal out of spec. values (det.spec. limits) in UVP (Under Voltage Protection) Threshold Voltage after a total dose of 25.6 krad(Si) and 45 krad(Si) respectively. However, both devices are still within the WCA limits, see table 11.

After the annealing, the device status can be summarized as in the following table 18.

Table 18 Summary of test results after the annealing (24 hrs at room temperature plus 168 hrs at 100°C)

N° (*)	Parameter	Table	Fig.	Remarks
1.1	Primary Consumption	4a-4c	4a-4c	Degradation not recovered by the annealing; max drift after annealing ≈ – 5 %
1.4	Primary Consumption	5a-5c	5a-5c	Degradation not recovered by the annealing; max drift after annealing ≈ + 3 %
1.5	Consumption on 5V_DIG	6a-6c	6a-6c	Degradation not recovered by the annealing
1.6	Secondary Consumption	7a-7c	7a-7c	Degradation slightly recovered by the annealing, max drift after annealing ≈ + 7.5%
2.1	Vaux Supply voltage	8a-8c	8a-8c	Degradation slightly recovered by the annealing, max drift after annealing ≈ – 0.22%
3.1	2.5V output voltage	9a-9c	9a-9c	Degradation partially recovered by the annealing, max drift after annealing ≈ + 0.078 %
4.1	5V reference voltage	10a-10c	10a-10c	Degradation partially recovered by the annealing, max drift after annealing ≈ + 0.28 %
5.1	UVP Threshold Voltage	11a-11c	11a-11c	Degradation partially recovered by the annealing with final measurements within the initial limits for all devices (s/n 13 still marginally outside initial max limit). Max drift after annealing ≈ +0.23%.
5.2	UVP Hysteresis	12a-12c	12a-12c	Degradation fully recovered by the annealing; max drift after annealing ≈ + 0.8 %
6.1	OVP Threshold Voltage	13a-13c	13a-13c	Degradation partially recovered by the annealing, max drift after annealing ≈ + 0.67 %
9.1	Clock Frequency	14a-14c	14a-14c	Degradation partially recovered by the annealing, max drift after annealing ≈ - 6.55 % On all devices, meas.values still below the minimum limits. *NB: After update of applicable documents, TID drift are within specified limits.*
11.1	TP2 voltage	15a-15c	15a-15c	Always within limits for all devices. No clear indication of TID/Annealing dependency.

(*) reference to parameter nr. in table 2 of ETCA 8090.0832-1 detail specification.

6 APPENDIX A MEASUREMENTS FROM ETCA

Manufacturer full electrical measurements results are reported in the document nr. **PWM-PSU-TR-0064.**