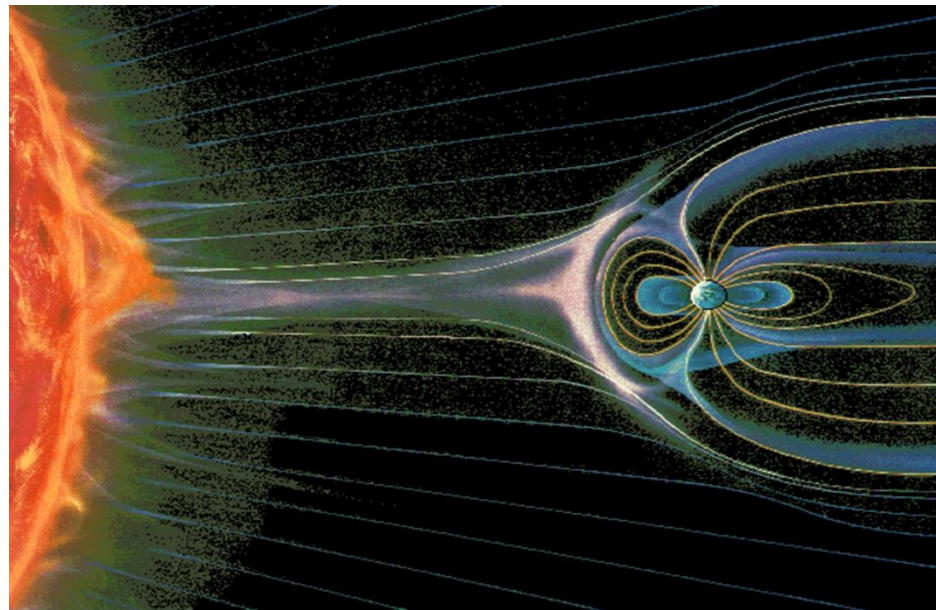


Total Ionizing Dose (TID) testing, update on ESCC22900 and discussion on TID response variability (part to part and lot to lot) and impact on sampling size and test requirements

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Nikkei Science, Inc. of Japan, by K. Endo

1. ESCC22900 issue 5
2. TID variability, part to part and lot to lot
3. Conclusion

ESCC22900 issue 5

Section 4 Equipment and General Procedures



1. Section 4.2 radiation levels (ESCC qualification or procurement LAT)

Letter	Rad(Si)	Gy(Si)	Minimum exposure levels in Rad(Si)*
D	10K	100	5K/10K/15K
P	30K	300	15K/30K/45K
F	50K	500	25K/50K/75K
R	100K	1000	50K/100K/150K
A	300K	3000	150K/300K/450K
G	500K	5000	250K/500K/750K
H	1000K	10K	500K/1000K/1500K

** Issue 4: 1/3, 1, 3 times radiation level*

1. Section 4.3: Radiation dose rates
 - a. Window 1 ("standard rate"):
 - 0.36 to 180 Krad(Si)/h (3.6 to 1800 Gy(Si)/h) (Issue 4: 3.6 to 36 Krad(Si)/h)
 - b. Window 2 ("low Rate"):
 - 36 to 360 rad(Si)/h (0.36 to 3.6 Gy(Si)/h)
2. Section 4.4: Temperature requirements
 - a. The room temperature annealing of the devices shall not differ by more than 5°C from the irradiation environment but shall not exceed 30°C to minimize annealing (new)

1. Section 5: Procedures for evaluation testing
 - a. ELDRS shall be studied for devices that contain bipolar transistors and optoelectronics, by comparing at a given dose level, low dose rate test results (within the low dose rate window for discrete devices and ≤ 36 rad/h for Integrated Circuits) with high dose rate test results (at least 2 orders of magnitude higher than low dose rate) on parts from the same wafer lot. A part is considered as ELDRS sensitive if the enhancement factor observed at the lower dose rate is greater than 1.5 on the median value of the most sensitive measured parameter (new)
 - b. Devices containing bipolar transistors and MOS elements (e.g. BiCMOS) shall be evaluated for both ELDRS and MOS specific effects. (new)

ESCC22900 issue 5

section 5 Procedures for Evaluation Testing



1. Section 5.2 sample selection
 - a. Minimum of 10 samples selected at random **from different wafers and wafer locations** from a minimum of 2 different lots
 - b. For each wafer lot , the sample size of each unique set of test condition shall be at least 5 (new)
 - c. As a minimum the test conditions shall include biased and unbiased testing (new)

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section 5 Procedures for Evaluation Testing



1. Section 5.4 radiation exposure and test sequence
 - a. Irradiation up to failure (up to a maximum of 1.5 Mrad(Si) or up to the targeted ESCC RHA qualification level)
 - b. Post irradiation electrical characterization should start within 1 hour of completion of exposure and the time between 2 irradiation steps shall be less than 2 hours
 - c. Room temperature anneal under bias, unless otherwise specified parts shall be measured again after 24, 48 and 168 hours
 - d. Accelerated ageing under bias. Devices shall be baked at $+100 \pm 5$ °C

1. Section 6.2 Test Plan

- a. For devices identified as ELDRS sensitive during evaluation phase, the dose rate shall be ≤ 36 rad(Si)/h for Integrated Circuits and be within low dose rate window for discrete bipolar devices

2. Section 6.3 Sample Selection

- a. A minimum of 10 samples shall be selected at random from one diffusion lot. Each wafer shall contribute at least 1 test sample from the irradiated group
- b. The sample for each unique set of test condition shall be at least 5. At least 5 samples shall be irradiated unbiased

3. Section 6.5 Radiation exposure and test sequence

- a. **At least three exposures are required**

1. Section 7.1 General

- a. Evaluation tests are performed when the TIDS of a part is unknown
- b. RVTs or RADLATs are performed to ensure that, within statistical limits, the procured lot meets the applicable procurement specification requirements or the requirements of a specific application
- c. NOTE: Any part type tested according to section 7 is not compliant with the ESCC evaluation and ESCC qualification test requirements and cannot be considered as ESCC evaluated or qualified.

1. Section 7.2 Test Plan

- a. The test devices shall be irradiated in accordance with the Test Plan. All electrical parameters to be tested and biasing conditions shall be clearly described. As a minimum, the Test Plan should contain all information according to the Test Plan Notes provided in the ESCC forms section of <https://ESCIES.org>
- b. The Dose rate shall be
 - Within the standard or low dose rate window for MOS and CMOS devices
 - Within low dose rate window for devices containing bipolar transistors

1. Section 7.3 Sample Selection

- a. A sample size of 5 devices per set of unique test conditions
- b. Smaller sample sizes if agreed by customer
- c. One additional sample shall be designated as unirradiated control

2. Section 7.4 Sample Serialization

- a. Immediately after selection, each individual sample device shall be serialised to facilitate pre- and post-irradiation data identification and comparison. The system of marking shall be such as to ensure that the samples are clearly identified as to:
 - Date-code
 - Individual serial number

1. Section 7.5 Radiation exposure and test sequence

- a. Initial room temperature electrical tests
- b. Irradiation of devices to the exposure level specified
- c. Post radiation electrical test on exposed devices and control device
- d. A **minimum of 5 exposures** should be aimed for, however fewer exposure levels can be used if agreed upon by the customer.
 - Repetition of steps (b), (c), and until total dose value specified in test plan is reached.
 - A maximum of 2 hours between consecutive irradiation exposures is allowed
- e. 24 hour room temperature anneal under bias
- f. Accelerated ageing under bias at $100\pm 5^{\circ}\text{C}$ for 168 hours
 - Alternative conditions are allowed

1. Test Plan
2. Test Report
 - a. Part traceability information
 - Full part type number, Serial number, Date code, Package type and marking, Die picture, Part technology/process
 - Wafer lot number (if known), Manufacturing facility (if known)
 - b. Irradiation Conditions
 - Test date, Irradiation facility, source type, dose rate, accuracy on dose levels
 - Irradiation test sequence
 - c. Bias conditions during irradiation
 - d. Electrical measurements conditions and acceptable limits
 - e. Test Results (tabulated and figures) for each electrical parameter measured for each part after each step
 - f. Description of anomalies (if any) that occurred during test

1. ESCC 22900
 - a. ESCC evaluation: **22** (20 +2) samples, minimum of 11 (10+1) samples from a minimum of 2 different diffusion lots
 - b. ESCC qualification or procurement LAT: minimum of 11 (10+1) samples from the qualification or procurement lot, and a minimum of **5 samples** per test condition
 - c. Outside ESCC context: **6** (5 + 1) samples per test condition (issue 5)
2. MIL_PRF-38535: **2 (0)** devices per wafer or **22 (0)** devices per wafer lot
3. ASTM F1892: At least **5 samples** for each set of test condition and preferably larger

1. ESA / TRAD study
 - a. Test of 3 types of linear bipolar devices
 - AD584, AD
 - LM124, TI
 - TL1431, STM
 - b. 3 lots per device type
 - c. 30 parts per device type per lot
2. NASA GSFC study (R. Ladbury, IEEE Trans Nuc Sci, Vol. 56, 2009)
 - a. Analysis of historical data on 5 types of linear bipolar devices
 - b. > 7 lots per device type

TID Variability Within One Lot

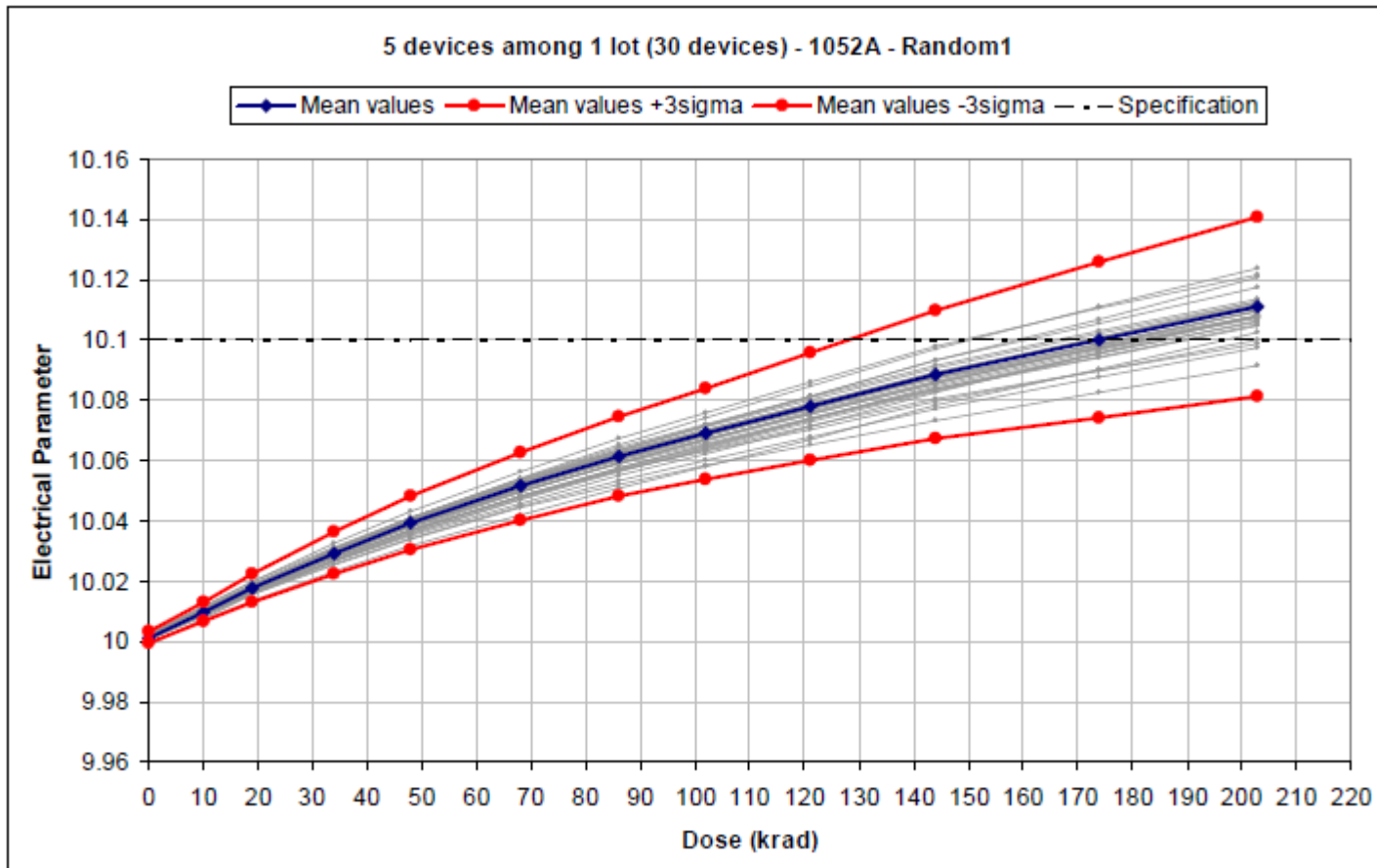


Figure 14: 5 devices among 1 lot (30 devices) – 1052A – Random1 - (AD584 - Vout1 - V)

TID Variability Within One Lot

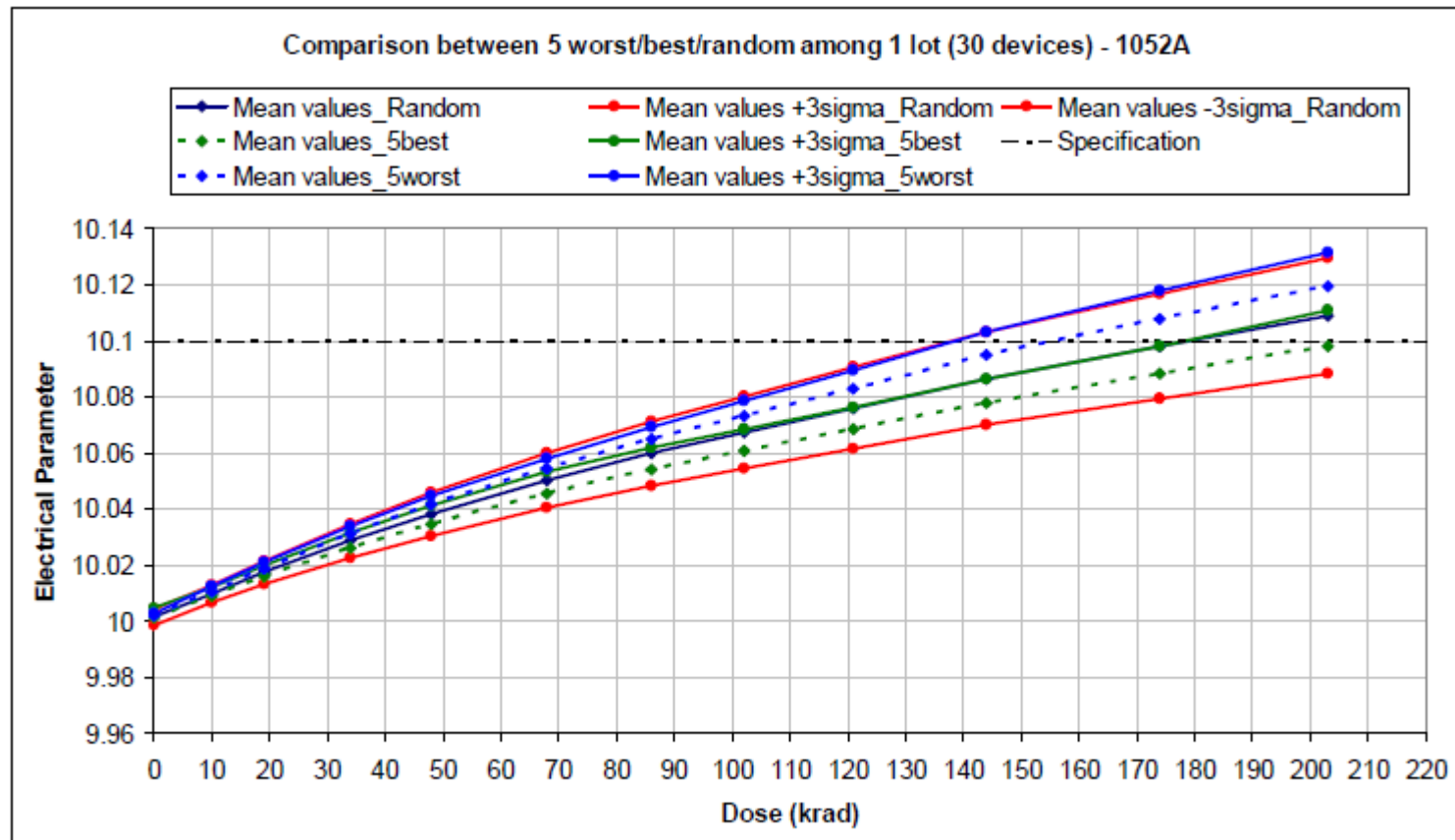


Figure 17: Comparison between 5 worst/best/random among 1 lot (30 devices) – 1052A – (AD584 - Vout1 - V)

TID Variability Within One Lot, Atypical Devices / Mavericks

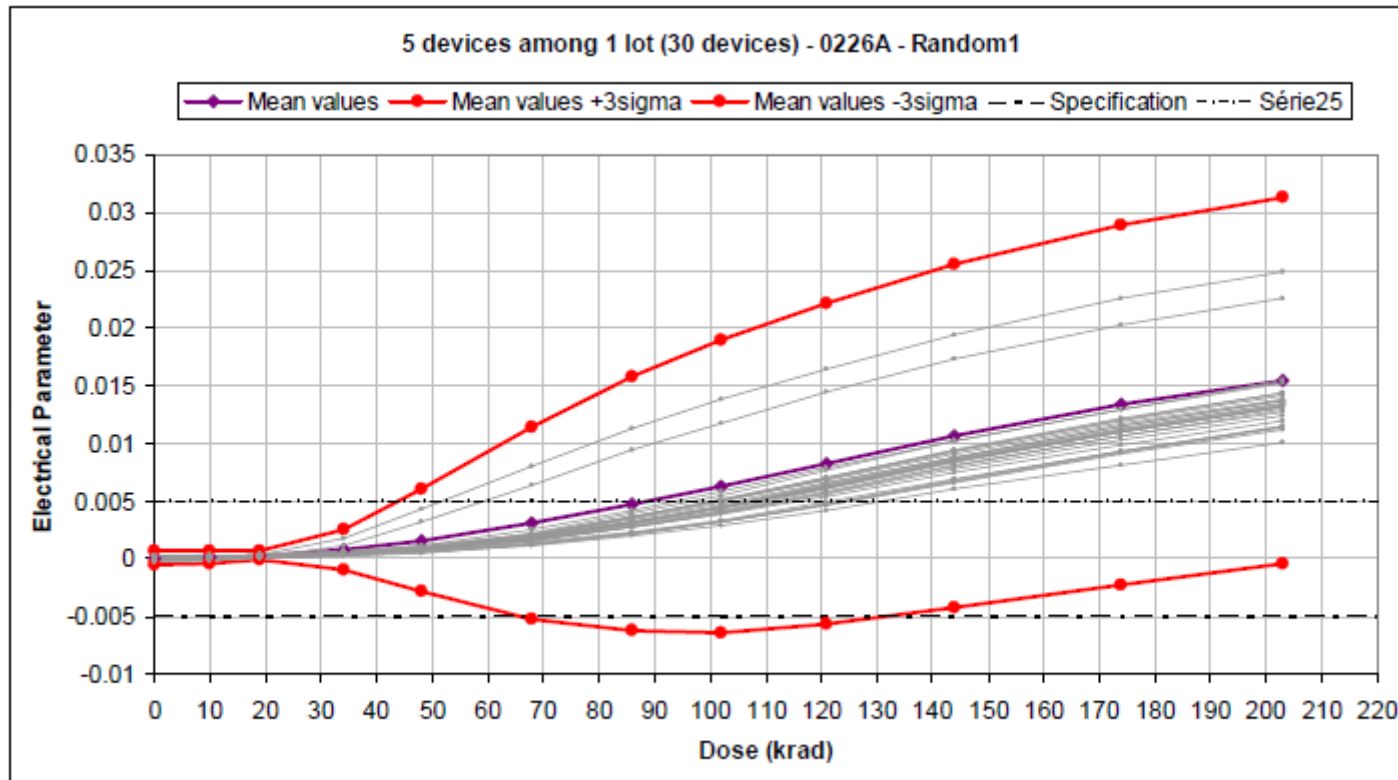


Figure 43: 5 devices among 1 lot (30 devices) - 0226A - Random1 (AD584 - VrLine1 - %/V)

TID Variability Within One Lot, Atypical Devices / Mavericks

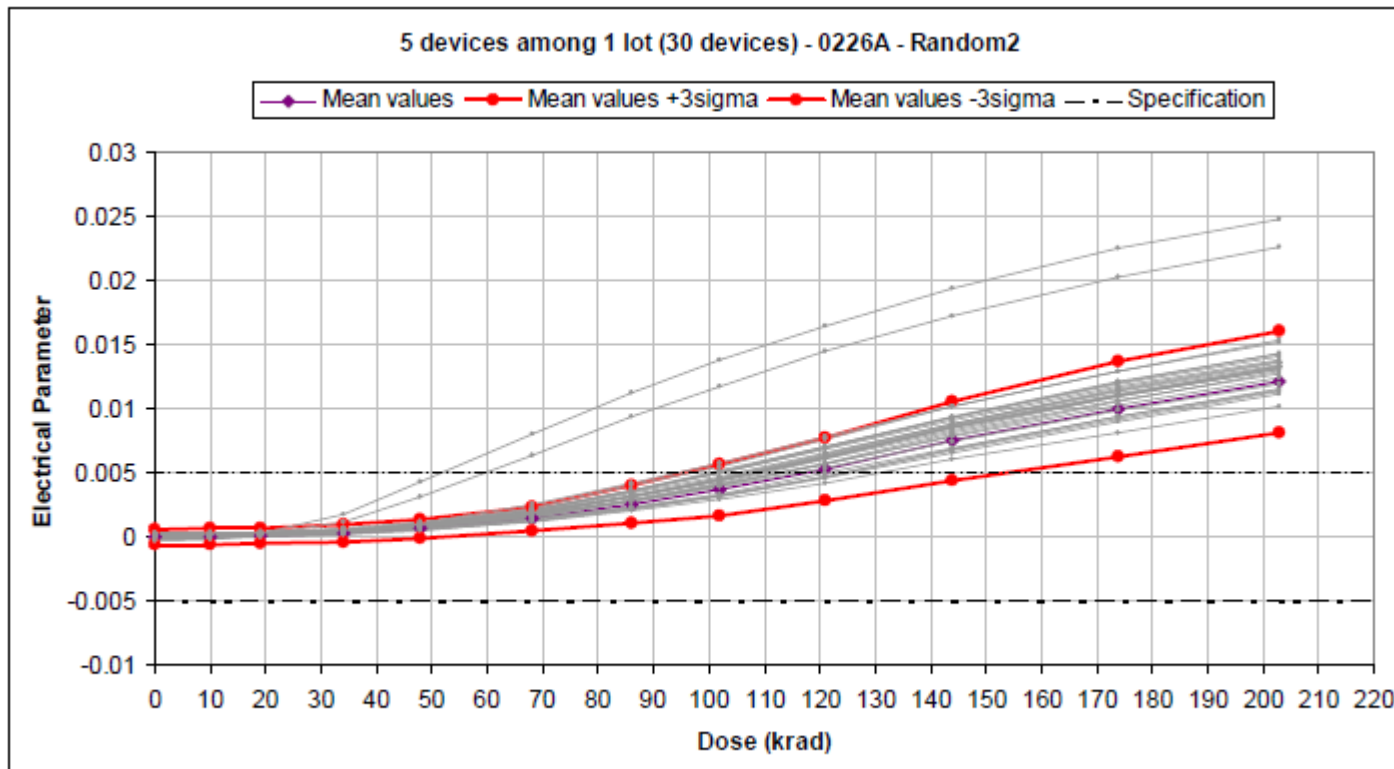


Figure 44: 5 devices among 1 lot (30 devices) – 0226A – Random2 (AD584 - VrLine1 - %/V)

TID Variability Within One Lot, High Variability Within One Lot

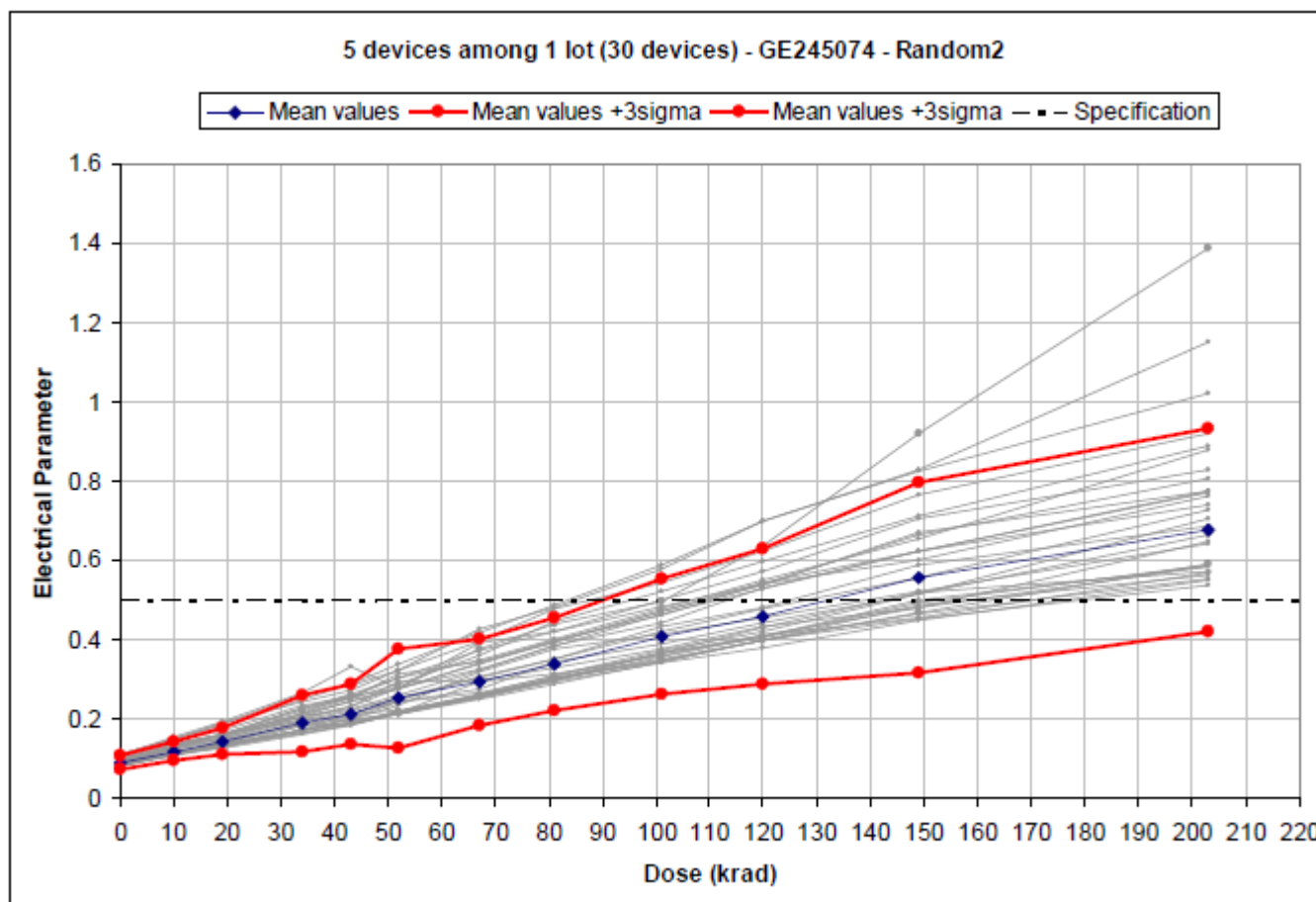


Figure 57: 5 devices among 1 lot (30 devices) – GE245074 – Random2 (TL1431 – Zka - Ohm)

TID Variability Lot to Lot

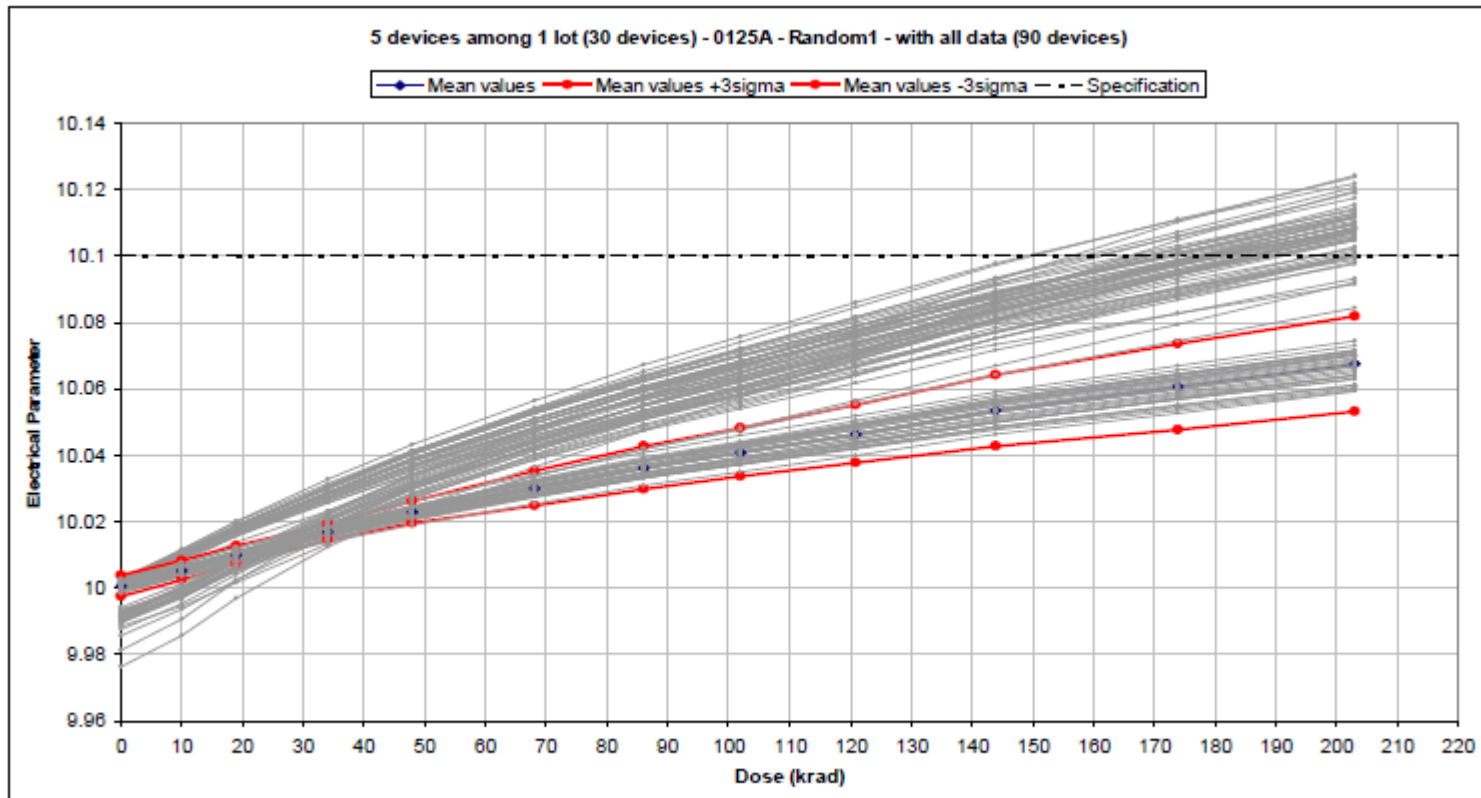


Figure 18: 5 devices among 1 lot (30 devices) – 0125A – Random1 – with all data (90 devices) - (AD584 - Vout1 - V)

TID variability Lot to Lot

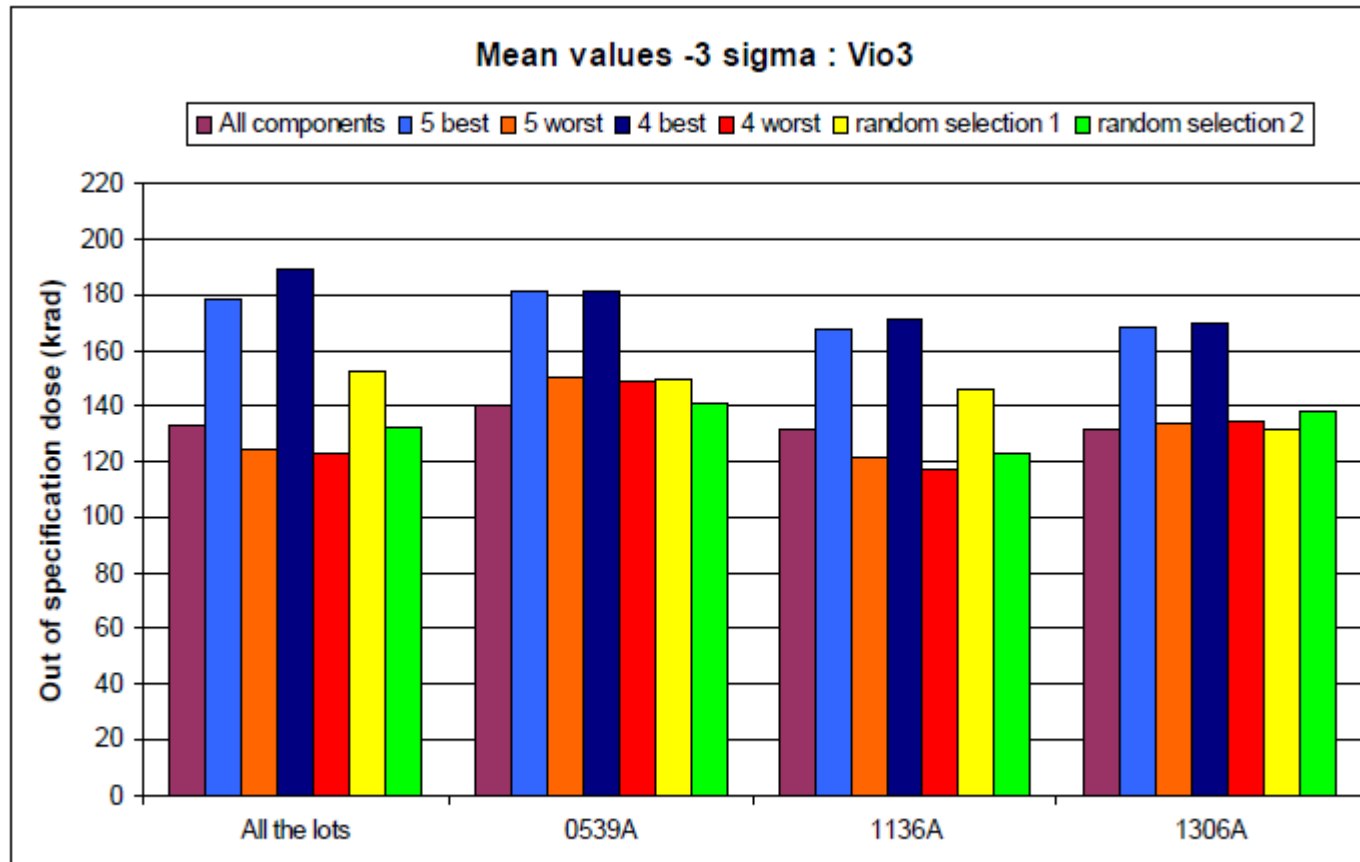


Figure 32: Mean values -3 sigma (LM124 – Vio3 - mV)

TID Variability Lot to Lot

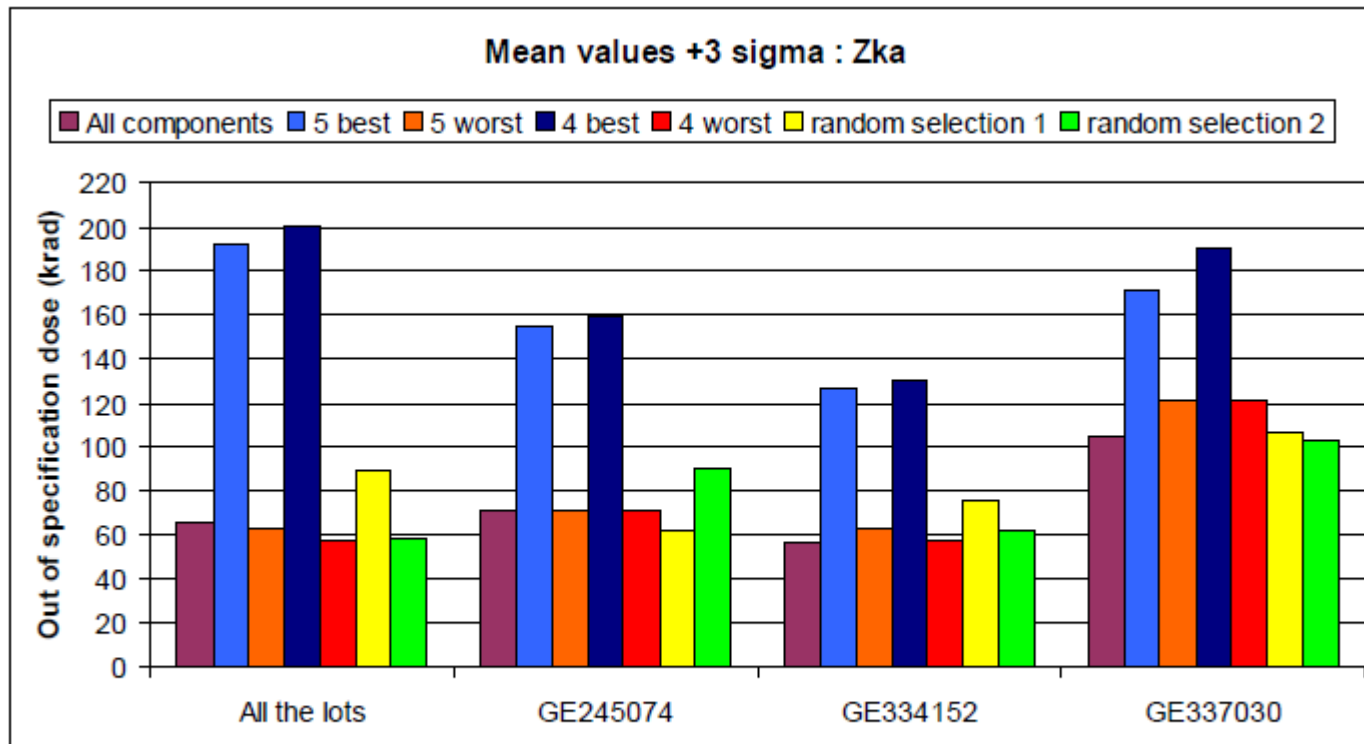


Figure 34: Mean values +3 sigma (TL1431 – Zka - Ohm)

TID variability lot to lot – summary



Reference	Parameter	Lot ratio	Mean value							Mean value +/- 3 sigma						
			m							m+/-3s						
			5 best	5 worst	4 best	4 worst	Random1	Random2	Worst-case	5 best	5 worst	4 best	4worst	Random1	Random2	
AD584	IOS	0125A/0226A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		0125A/1052A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		0226A/1052A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Vout1	0125A/0226A	1.00	1.24	1.00	1.24	1.13	1.07	1.30	1.08	1.36	1.04	1.37	1.42	1.25	
		0125A/1052A	1.00	1.30	1.00	1.32	1.17	1.09	1.36	1.14	1.46	1.13	1.46	1.59	1.49	
		0226A/1052A	1.00	1.05	1.00	1.06	1.03	1.01	1.05	1.05	1.08	1.09	1.06	1.12	1.19	
	VRload1	0125A/0226A	1.52	2.42	1.51	2.54	1.98	1.70	3.07	1.73	3.88	1.74	4.00	3.70	2.03	
		0125A/1052A	1.15	1.57	1.15	1.59	1.34	1.32	1.66	1.28	1.86	1.29	1.89	1.76	1.49	
		1052A/0226A	1.32	1.54	1.31	1.60	1.48	1.28	1.85	1.35	2.09	1.35	2.12	2.10	1.36	
	VrLine1	0125A/0226A	1.62	2.86	1.61	3.05	2.29	1.73	3.92	1.71	4.77	1.71	4.86	4.64	2.13	
		0125A/1052A	1.30	1.79	1.28	1.81	1.51	1.50	1.89	1.57	2.05	1.57	2.05	2.11	1.82	
		1052A/0226A	1.24	1.60	1.26	1.68	1.52	1.16	2.07	1.09	2.33	1.09	2.37	2.20	1.17	
LM124	Vio3	0539A/1136A	1.02	1.05	1.01	1.06	1.02	1.04	1.15	1.08	1.23	1.06	1.26	1.03	1.15	
		0539A/1306A	1.13	1.10	1.13	1.10	1.12	1.10	1.09	1.08	1.12	1.07	1.10	1.14	1.03	
		1136A/1306A	1.10	1.04	1.11	1.04	1.10	1.06	0.95	1.00	0.91	1.01	0.87	1.11	0.89	
	CMRR	0539A/1136A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		0539A/1306A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		1136A/1306A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
	SR+	0539A/1136A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		0539A/1306A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		1136A/1306A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
	IIB1	0539A/1136A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		0539A/1306A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		1136A/1306A	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

TID Variability Lot to Lot – Summary



Reference	Parameter	Lot ratio	Mean value							Mean value +/- 3 sigma					
			m							m+/-3s					
			5 best	5 worst	4 best	4 worst	Random1	Random2	Worst-case	5 best	5 worst	4 best	4worst	Random1	Random2
TL1431	Iref	GE245074/GE334152	1.11	1.42	1.08	1.40	0.97	1.50	1.33	1.30	1.15	1.27	1.15	0.81	2.35
		GE337030/GE334152	1.44	2.54	1.41	2.58	1.56	1.69	2.67	1.51	2.89	1.41	2.84	1.63	3.17
		GE337030/GE245074	1.30	1.79	1.30	1.85	1.61	1.13	2.00	1.16	2.51	1.11	2.48	2.00	1.35
	Vref	GE334152/GE245074	1.18	1.02	1.17	0.98	1.24	1.09	1.06	1.15	0.70	1.03	1.10	0.62	1.18
		GE334152/GE337030	1.22	1.11	1.23	1.08	1.22	1.28	1.09	1.04	1.00	1.04	1.63	0.54	4.87
		GE245074/GE337030	1.03	1.09	1.05	1.10	0.98	1.17	1.03	0.91	1.42	1.01	1.48	0.87	4.11
	Zka	GE245074/GE334152	0.94	1.24	0.93	1.22	1.03	1.56	1.21	1.23	1.13	1.23	1.24	0.83	1.46
		GE337030/GE334152	1.12	1.77	1.08	1.77	1.39	1.76	1.81	1.36	1.93	1.46	2.10	1.41	1.68
		GE337030/GE245074	1.19	1.42	1.17	1.46	1.35	1.13	1.50	1.10	1.70	1.19	1.70	1.70	1.15
	Ioff	GE245074/GE334152	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		GE337030/GE334152	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		GE337030/GE245074	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6: Out-of-specification dose level ratio between different lots

1. ESCC22900 issue 5 will be issued this year
2. For TID sampling, size matters
 - a. 5 samples is adequate to bound the device TID response within one lot with good uniformity
 - b. It is not sufficient in cases with large variability of TID response within one lot or presence of mavericks.
 - A minimum sample size of 10 is recommended
3. For bipolar linear ICs, lot to lot variation can not be assured without testing