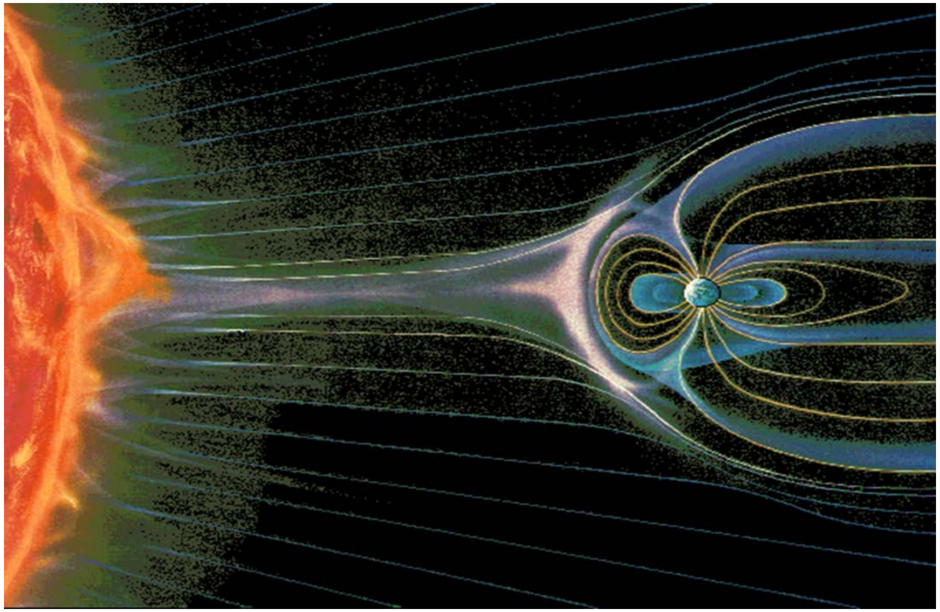
Radiation Hardness Assurance Update

Christian POIVEY



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

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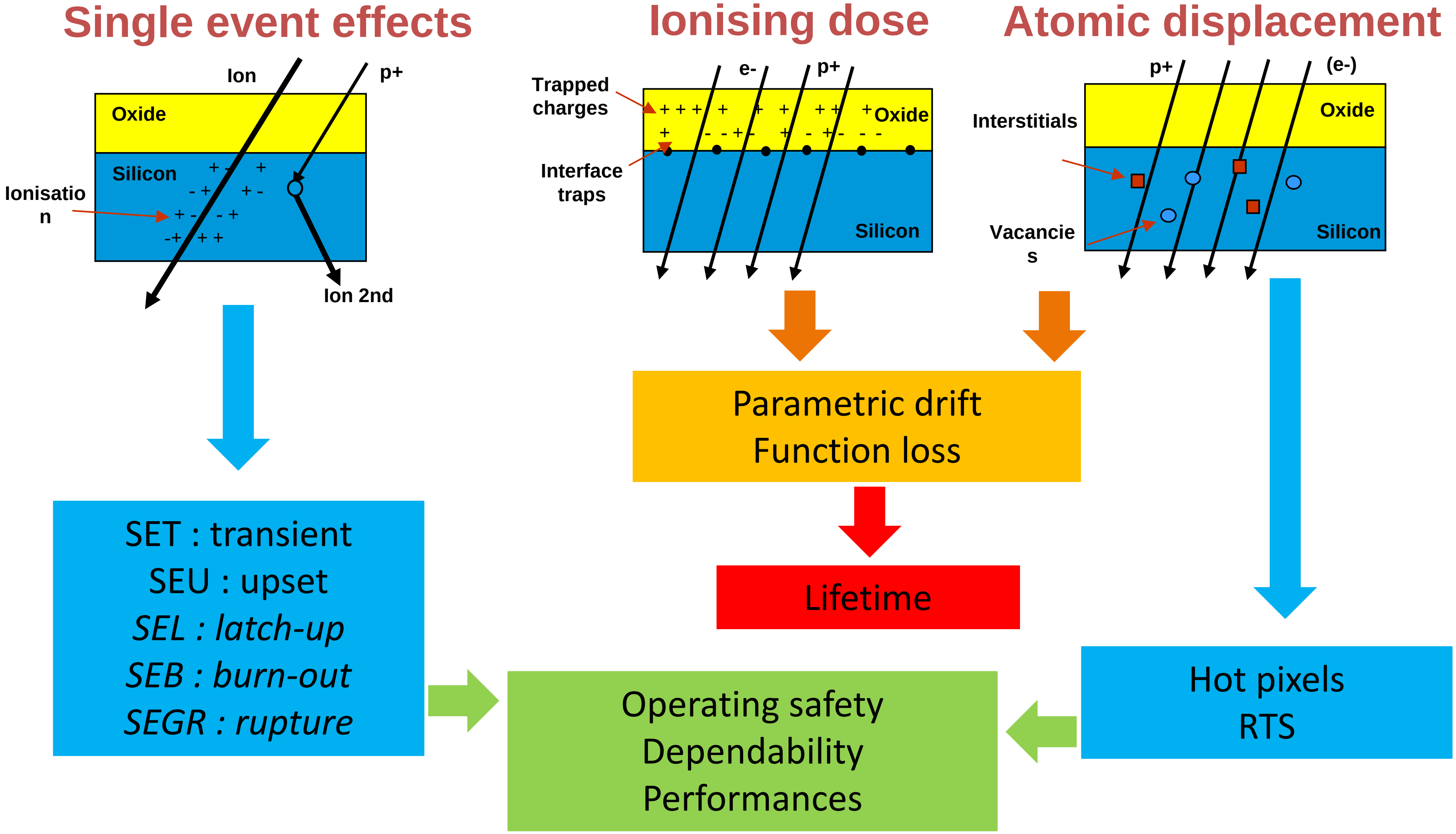
Radiation Effects in Electronic Parts



SET : transient
SEU : upset
SEL : latch-up
SEB : burn-out
SEGR : rupture

Parametric drift
Function loss

Lifetime

Hot pixels
RTS

Operating safety
Dependability
Performances

S. Gerardin, RADECS 2015 short course

Outline

1. RHA standard
2. TID RHA
3. **TID testing sampling size**
4. Conclusion

Radiation Related Standards

1. Radiation Hardness Assurance – EEE components: **ECSS-Q-ST-60-15C**
    a. ESA Adoption standard: **ESSB-AS-Q-008 issue 1 (2013)**
2. Space Environment: ECSS-E-10-04A (new issue in progress)
3. Methods for calculation of radiation received and its effects, and a policy for design margins:
    a. ECSS-E-ST-10-12C
    b. ECSS-E-HB-10-12
4. Techniques for radiation effects mitigation in ASIC and FPGA
    a. ECSS-Q-HB-60-02A (draft under review)
5. EEE components: ECSS-Q-ST-60
6. Dependability: ECSS-Q-ST-30
7. EEE components derating: ECSS-Q-ST-30-11

Radiation Test Standards

1. Total Ionizing Dose Test method:
    a. **ESCC 22900 issue 4** (issue 5 under review)
    b. MIL-STD-883 method 1019
    c. MIL-STD-750 method 1019
    d. ASTM F1892
2. Single Event Effect Test Method and Guidelines:
    a. **ESCC 25100 issue 2**
    b. MIL-STD-750 method 1080 (SEB/SEGR)
    c. ASTM F1192-11
    d. EIA/JEDEC JESD57
    e. EIA/JEDEC JESD234
3. Displacement Damage Test Guidelines (in progress)
    a. “Displacement Damage Test Guideline for 2D imagers,” SSTL report 0195162, December 2012

TID Hardness Assurance

1. TID Hardness assurance ensures that electronic piece parts in a space system perform to design specification after exposure to space environment
2. TID hardness assurance is based on Radiation Design Margin RDM
    a. $RDM = \frac{Radiation\ Failure\ Level}{Radiation\ Specification\ Level}$
        - Radiation Failure Level definition (aka TIDS) needs analysis of part TID test data and acceptable drifts in a given application
        - Radiation Specification Level (aka TIDL) definition needs analysis of mission environment and shielding

TID Hardness Assurance

1. ECSS-Q-ST-60-15C
    a. Component type TIDS shall be calculated either as
        - Total Dose level at which the worst case part of the worst case lot exceeds its limits, or
        - Total Dose level at which the one sided tolerance limit, as defined in MIL-HDBK-814, exceeds its limits (statistical approach).

TID Hardness Assurance

1. One sided tolerance limit
    a. limit that will not be exceeded with a probability P and a confidence level C, assuming that TID degradation of electrical parameters follow a normal distribution law
    b. If <delta x> is the mean shift among tested population of n samples, σ is the standard deviation of the shift, and K is the one sided tolerance limit factor, then:
        - Delta XL = <delta x > + K σ, for increasing total dose shift
        - Delta XL = <delta x > - K σ, for decreasing total dose shift
        - K depends on the number of tested samples n, the probability of success P and the confidence limit C.

TID Hardness Assurance

1. K values for P=0.9 and C=0.9 as a function of the number n of tested samples:

n	K
3	4.259
4	3.188
5	**2.742**
6	2.493
7	2.332
8	2.218
9	2.133
10	2.065

TID Hardness Assurance

1. Radiation Design Margin Requirements:
   a. **1** if statistical analysis is used to determine failure level and guarantee a probability of 90% of not exceeding the failure level with a confidence level of 90%
   b. **1.2** for GEO orbits
   c. **2** in any other case (ESA requirement)
2. Criteria for Flight Lot Testing:
   a. Tested part date code 4 years older than flight lot date code
   b. **RDM< 2** for GEO orbits
   c. **All lots** of bipolar ICs and optoelectronics parts (ESA requirement)

TID Sampling Size

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

TID Variability Within a Lot and Lot to Lot

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

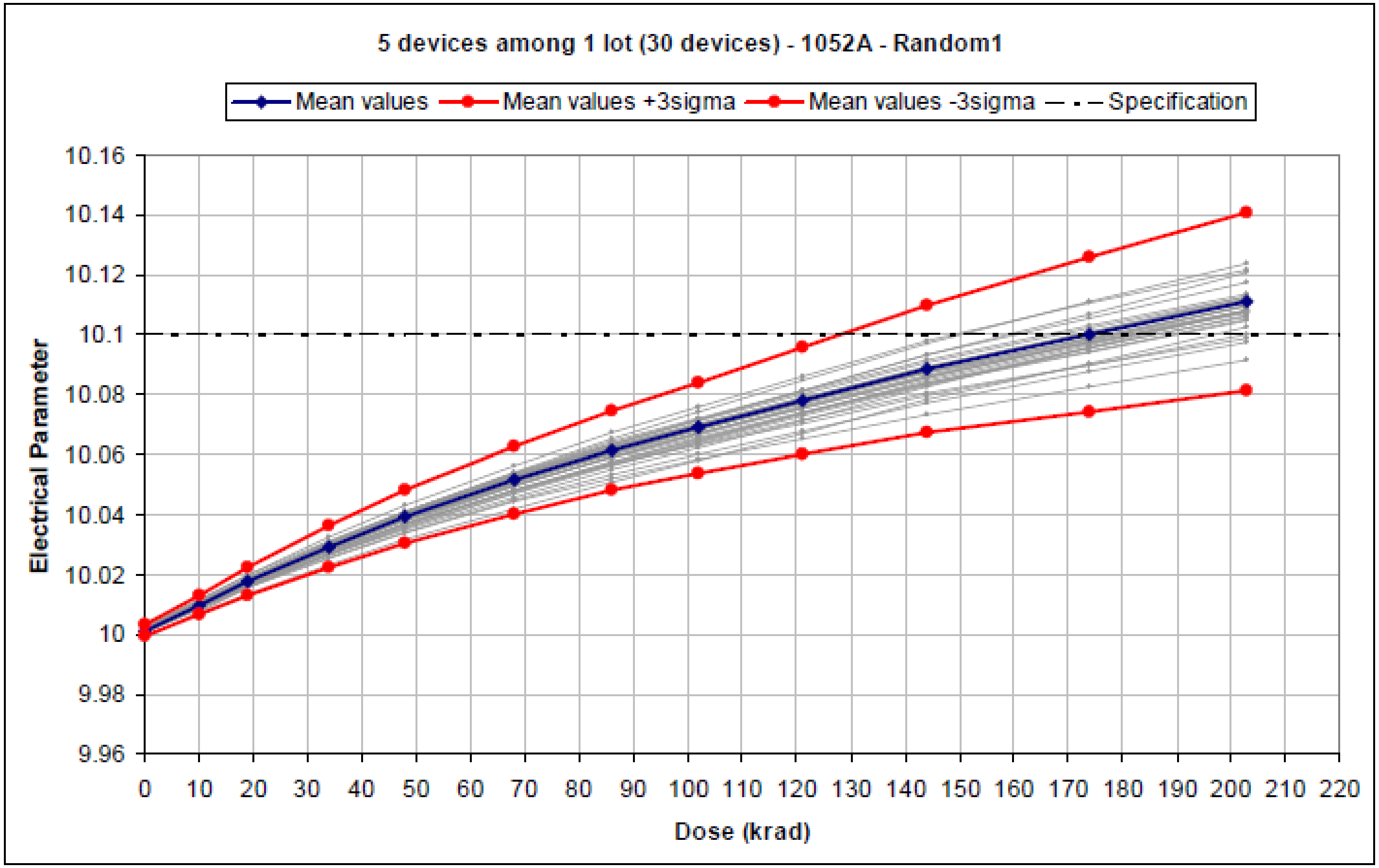


Figure 14: 5 devices among 1 lot (30 devices) – 1052A – Random1 - (AD584 - Vout1 - V)

TID Variability Within One Lot

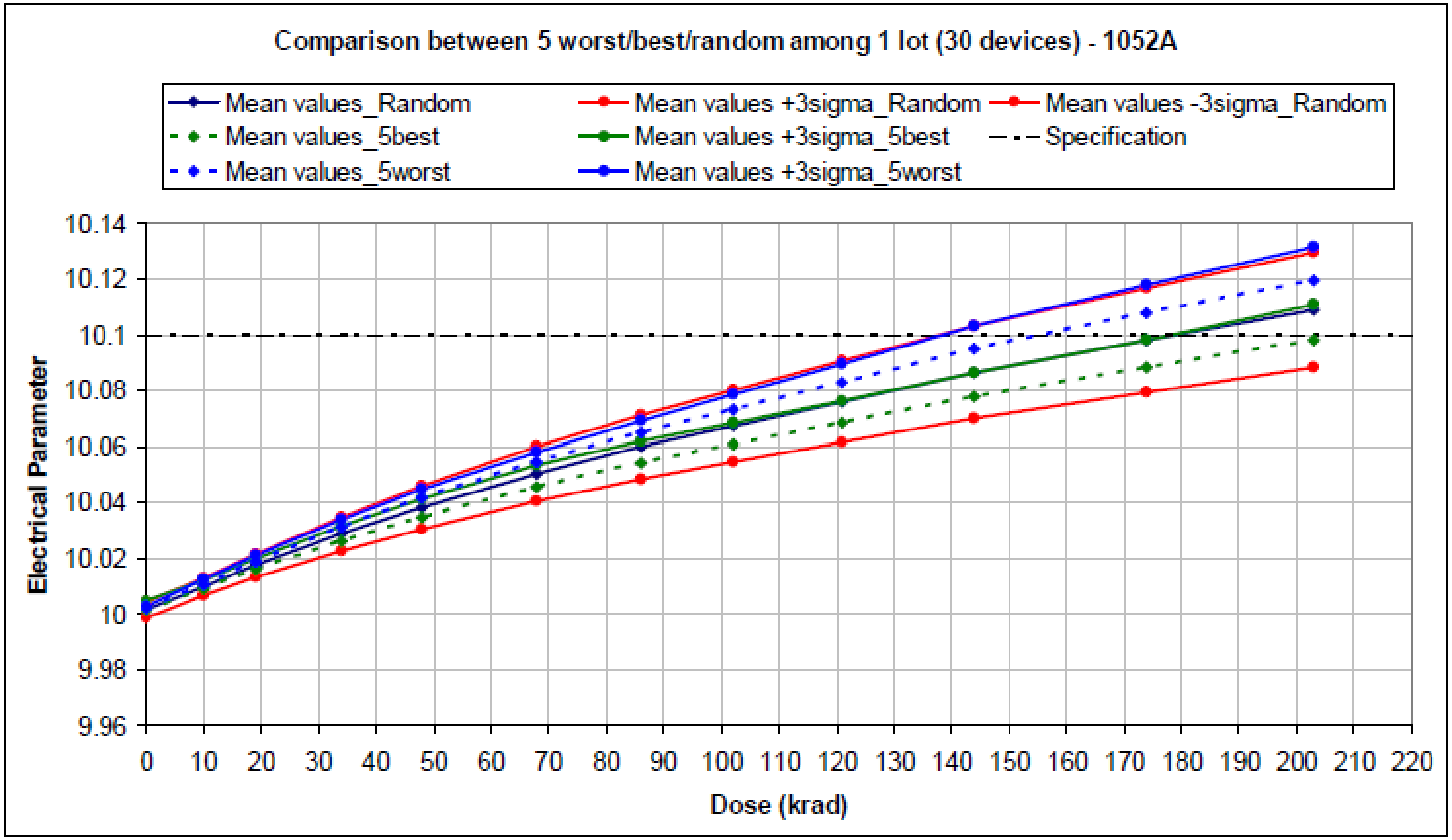


Figure 17: Comparison between 5 worst/best/random among 1 lot (30 devices) – 1052A – (AD584 - Vout1 - V)

TID Variability Within One Lot, Atypical Devices / Mavericks

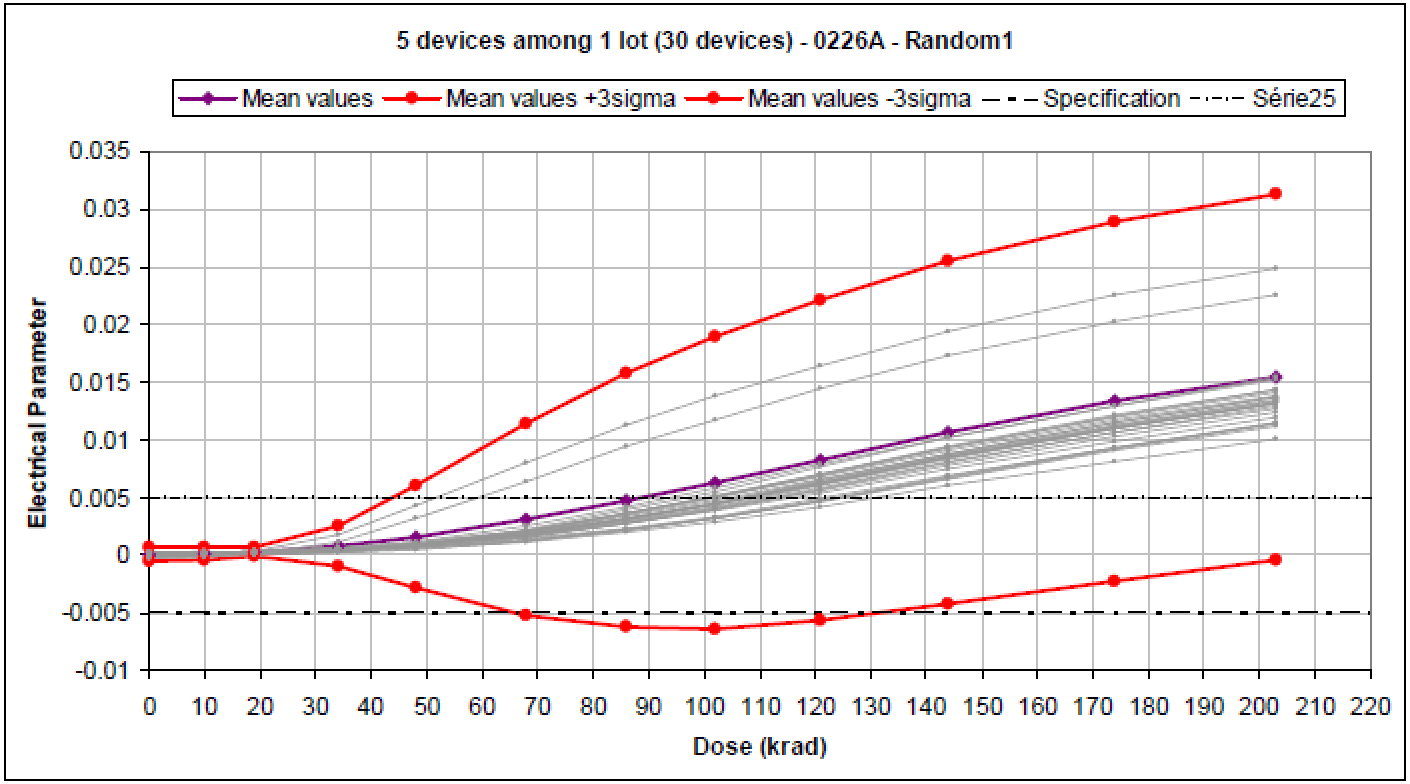


Figure 43: 5 devices among 1 lot (30devices) – 0226A – Random1 (AD584 - VrLine1 - %/V)

TID Variability Within One Lot, Atypical Devices / Mavericks

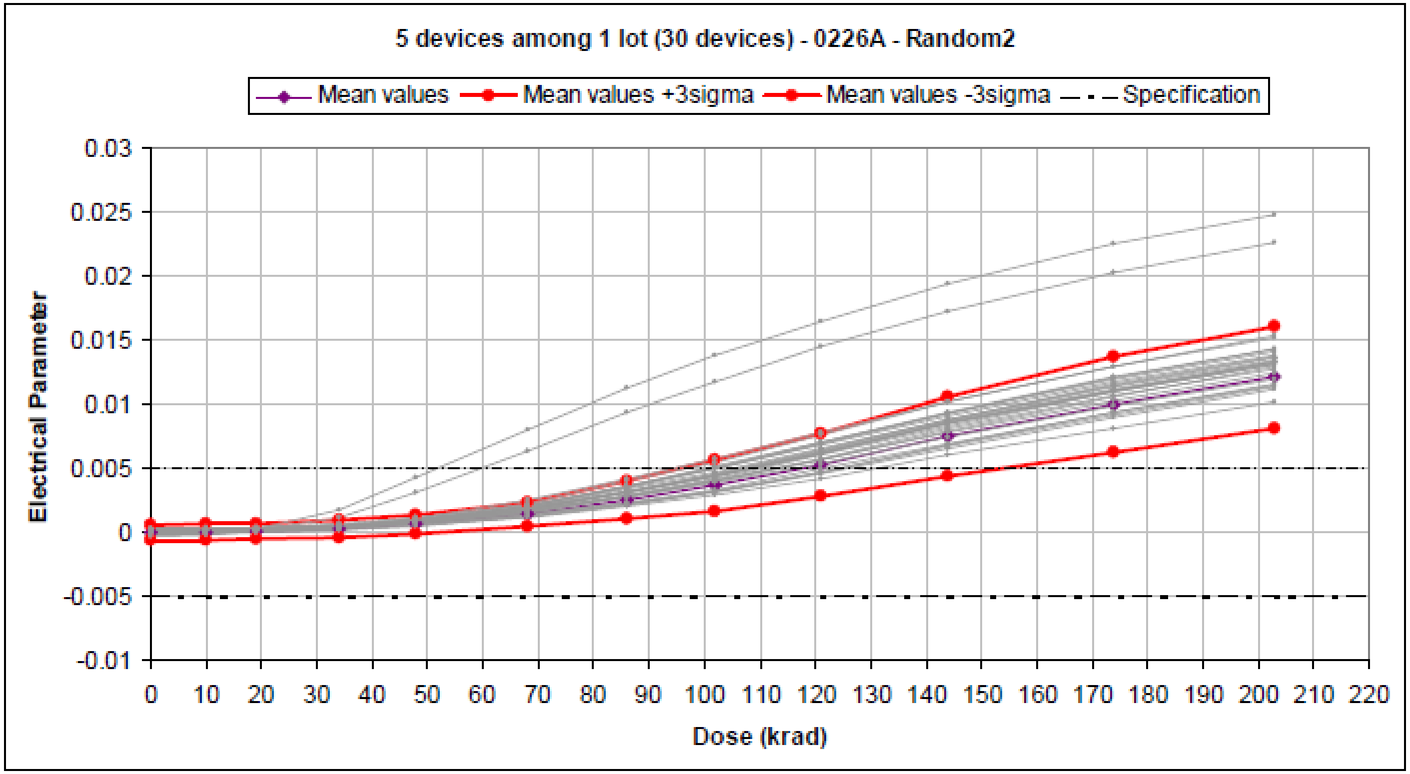


Figure 44: 5 devices among 1 lot (30devices) – 0226A – Random2 (AD584 - VrLine1 - %/V)

TID Variability Within One Lot, High Variability Within One Lot

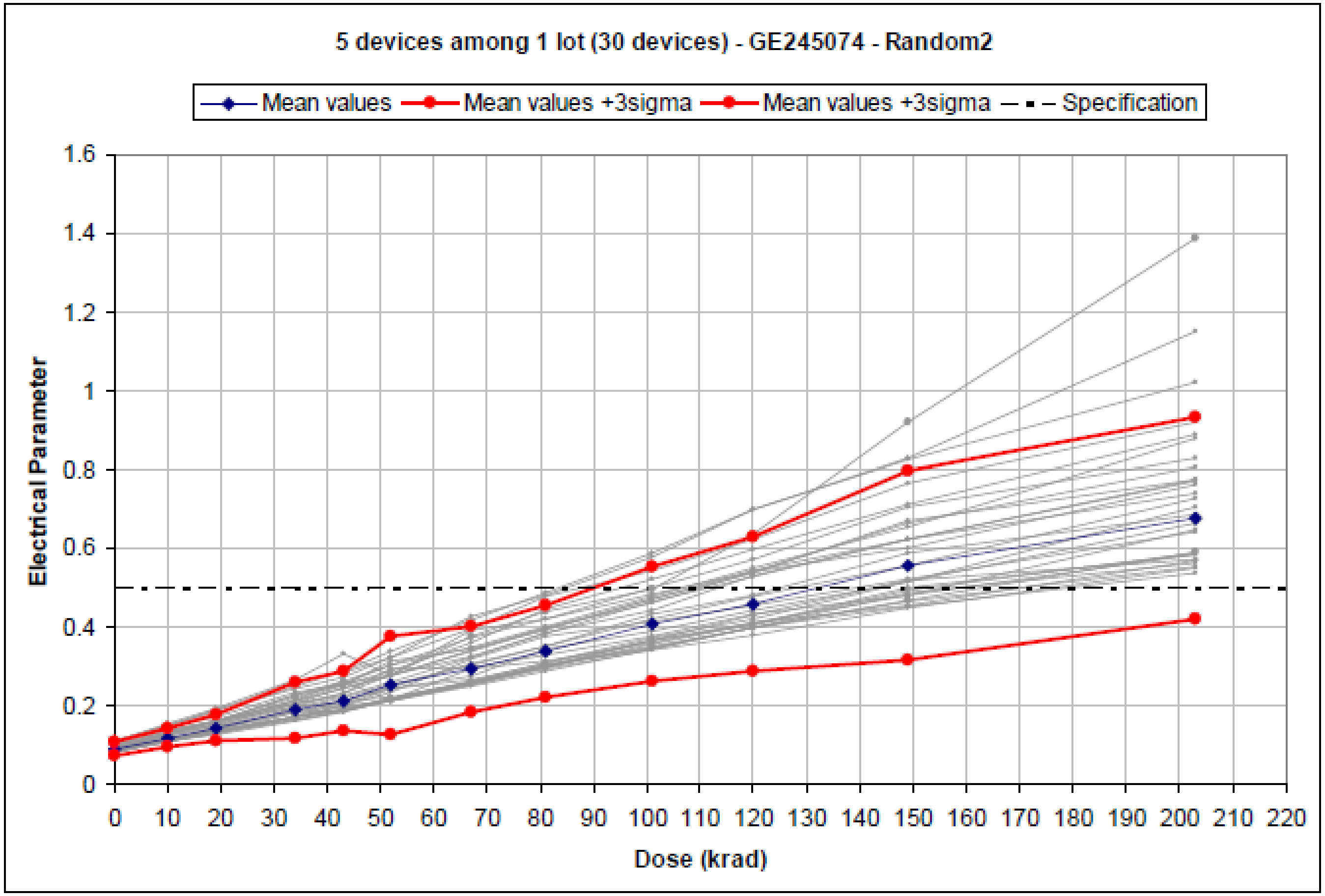


Figure 57: 5 devices among 1 lot (30devices) – GE245074 – Random2 (TL1431 – Zka - Ohm)

TID Variability Lot to Lot

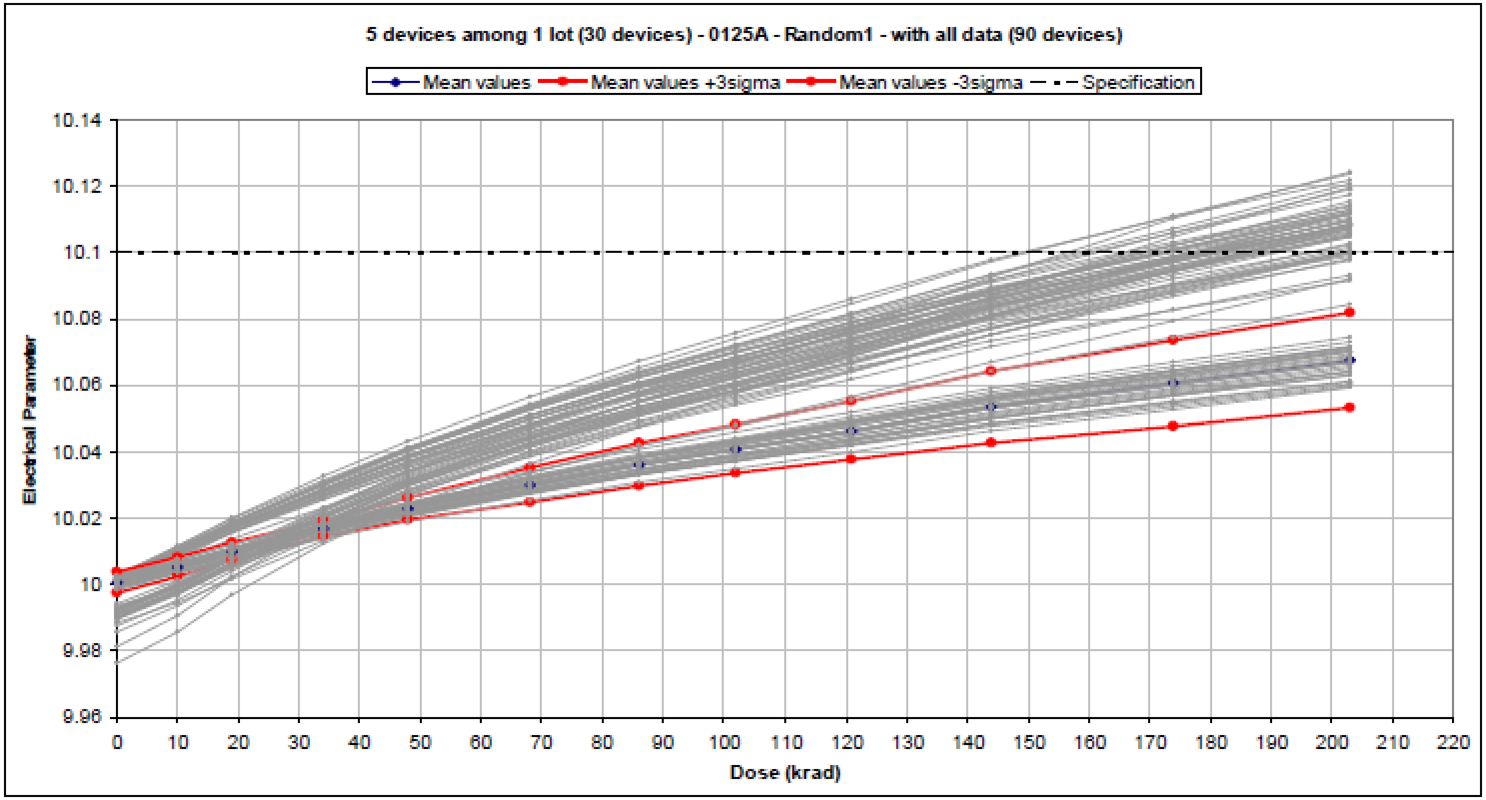


Figure 18: 5 devices among 1 lot (30 devices) – 0125A – Random1 – with all data (90 devices) - (AD584 - Vout1 - V)

TID variability Lot to Lot

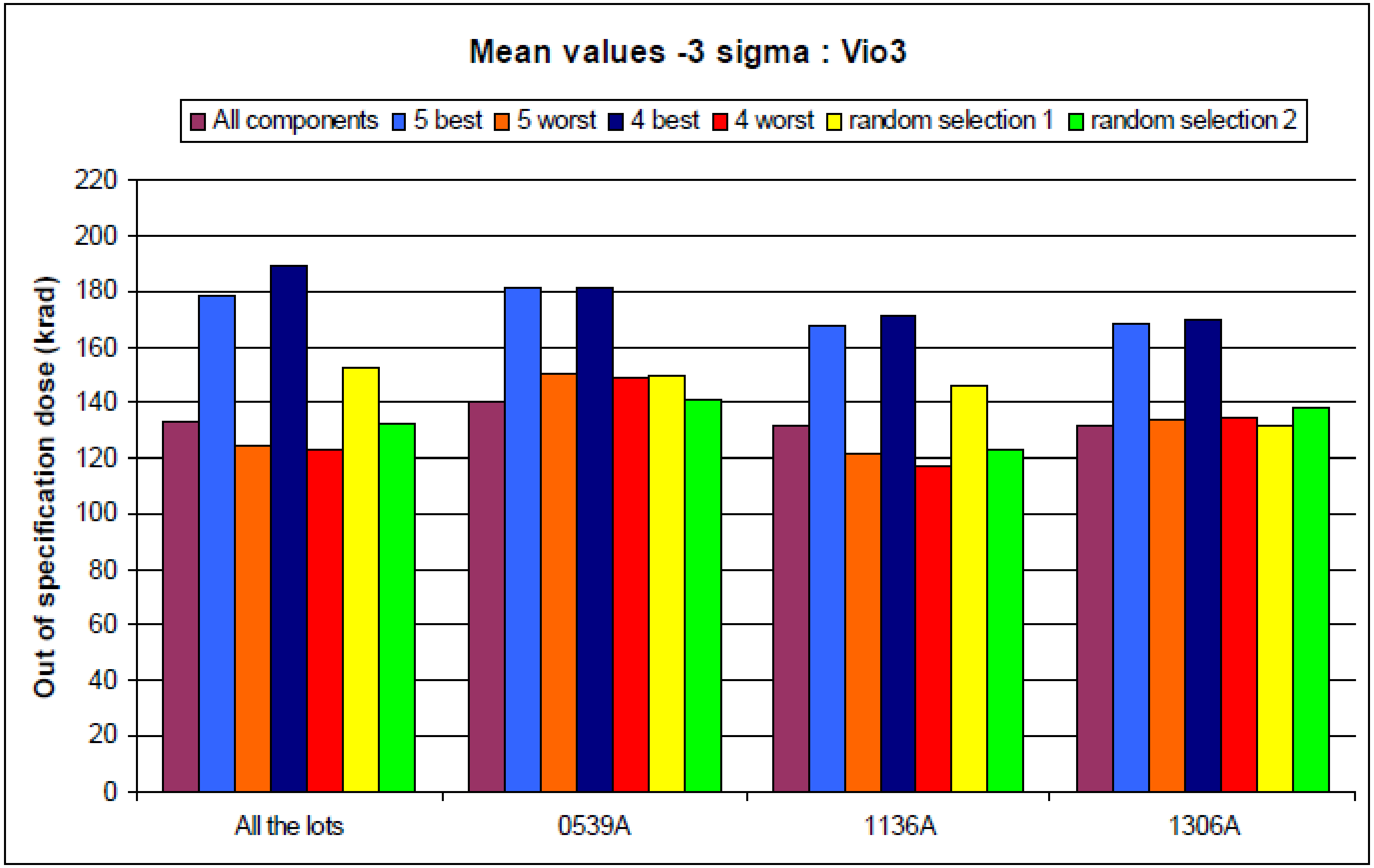


Figure 32: Mean values -3 sigma (LM124 – Vio3 - mV)

TID Variability Lot to Lot

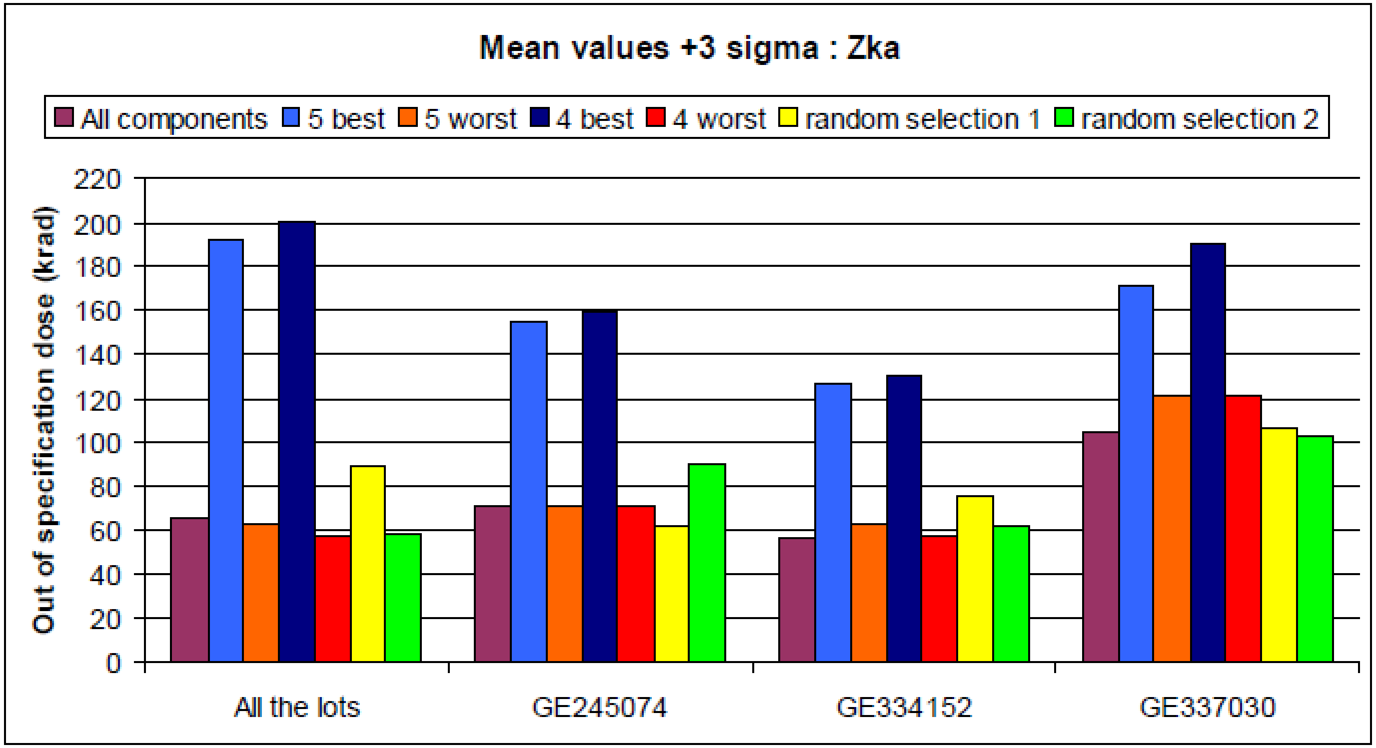
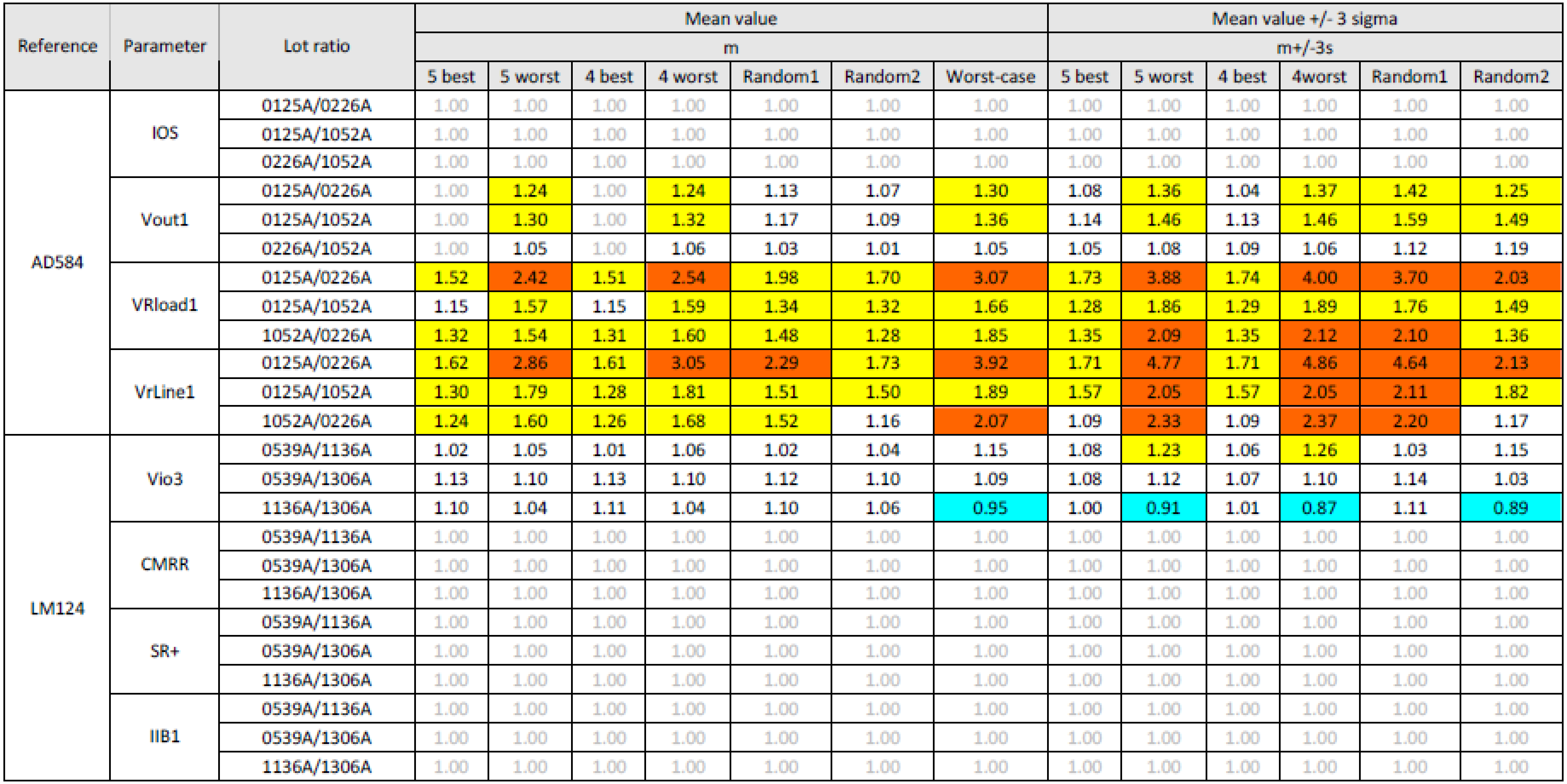


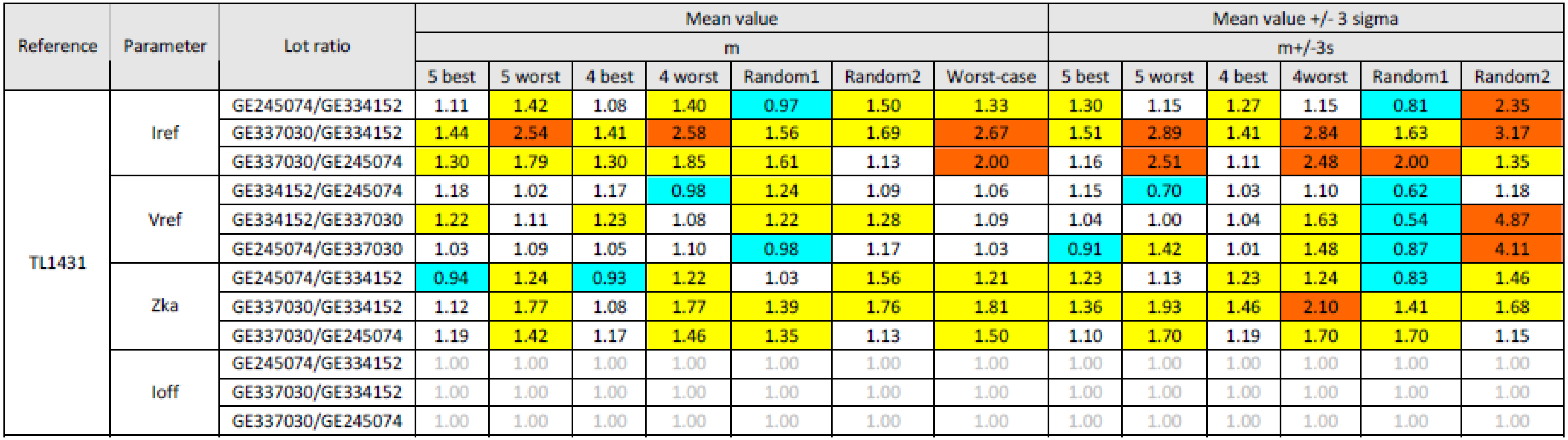
Figure 34: Mean values +3 sigma (TL1431 – Zka - Ohm)

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
		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
		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
	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

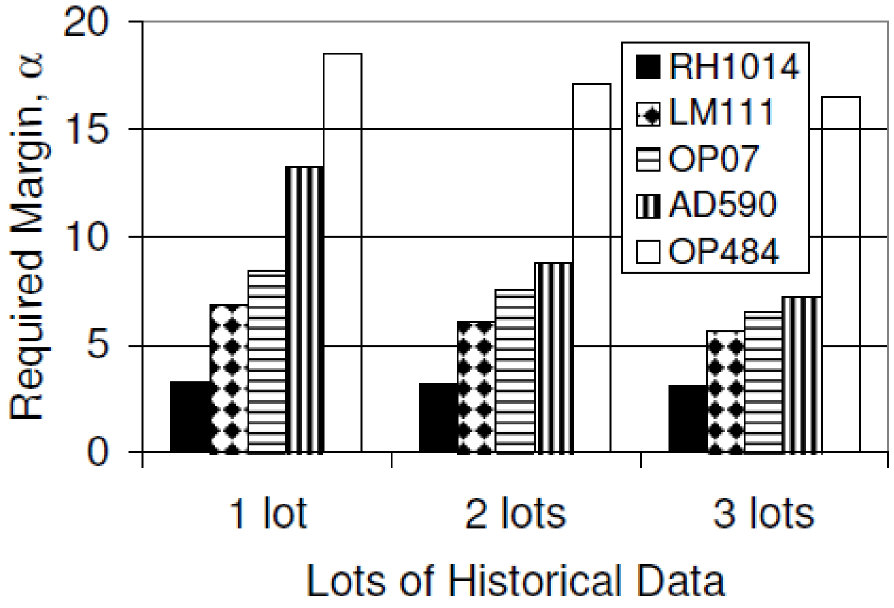


Reference	Parameter	Lot ratio	Mean value							Mean value +/- 3 sigma					
			m							m+/-3s					
			5 best	5 worst	4 best	4 worst	Random1	Random2	Worst-case	5 best	5 worst	4 best	4worst	Random1	Random2
TL1431	Iref	GE245074/GE334152	1.11	1.42	1.08	1.40	0.97	1.50	1.33	1.30	1.15	1.27	1.15	0.81	2.35
		GE337030/GE334152	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

TID Variability Lot to Lot

I. Part	II. # of Lots	III. Mean Parametric Δ Ratio: SL to HL	IV. Failure Criterion	V. Mean Failure Level Ratio: HL to SL	VI. WC Failure Level Ratio: HL to SL	VII. 99/90 PL ratio HL to SL
RH1014	38	~1.9 (@100 krad(Si))	ΔIbias>50 nA	1.6	1.7	3.2
OP484	7	~9 (@100 krad(Si))	ΔIin>2 μA	~9.3	29	424
AD590	10	~10 (@15 krad(Si))	Amb. Err> 5°C	10	N/A	N/A
LM111	8	~3.4 (@60 krad(Si))	ΔIb_{in+}>300 nA	3.4	3.8	5.6
OP07	11	~3.4 (@300 krad(Si))	ΔIin>40 nA	4.2	3.8	5.5



HL: Hardest Lot
SL: Softest Lot

After Ladbury, IEEE Trans Nuc Sci, Vol. 56, 2009

Conclusion

1. 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
        - A more advanced statistical model is needed
            - Maximum loglikelihood ratio
2. For bipolar linear ICs, lot to lot variation can not be assured without testing

Further Reading

1. R. Ladbury & al.,"Statistical Model Selection for TID Hardness Assurance," IEEE Trans Nuc Sci, Vol. 56, 2009
2. N. Sukhaseum, "Part to Part and Lot to Lot Variability Study of TID effect in bipolar linear devices," TRAD report TRAD/ESA/IR/VAR/NS/241115, 2015, https://escies.org
3. *TRAD/ESA paper to be presented at RADECS 2016*