A Comparison of Board-Level Lot Acceptance Testing Method with Worst-Case Analysis Results

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Purpose

- To assess how testing at board level can replace testing at component level for ionizing dose
- Especially interesting for low cost COTS-based boards

Study plan

- To perform a complete Worst-Case Analysis of a given board based on component data
- To test the board
- To compare the results between analysis and measurement at multiple temperatures and several doses
- To provide recommendations for board level radiation testing

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Current validation method for high reliability space

Component radLAT at RT
ESCC22900, 5 samples min

X number of component types

Dose at room temperature
Evaluation data, specification for rad-hard, radLAT

1

Ageing at mission average T
Mostly generic data (ECSS-Q-TM-30-12A, ECSS-Q-60-11A)

2

T min/25°C/max in operation
Spec., datasheet, datapack for space-grade, eval. data

3

WCA
ECSS-Q-HB-30-01A

Simplification hypotheses at board level

Board
Engin. / Qual. Models

Electrical meas. at T min/25°C/max

Board
Flight Models

Electrical meas. at RT

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Proposed validation method

Board design phase

- **Unchanged**: use the most reliable available data, perform component evaluation if needed
  - Build WCA envelopes to cover the future lots with the desired coverage (probability of success) and confidence level
  - Do not necessarily irradiate all sensitive active components, but a subset considered as critical
  - Design taking care of future tests (design for test methodology), e.g. place measurement test points to access relevant electrical parameters

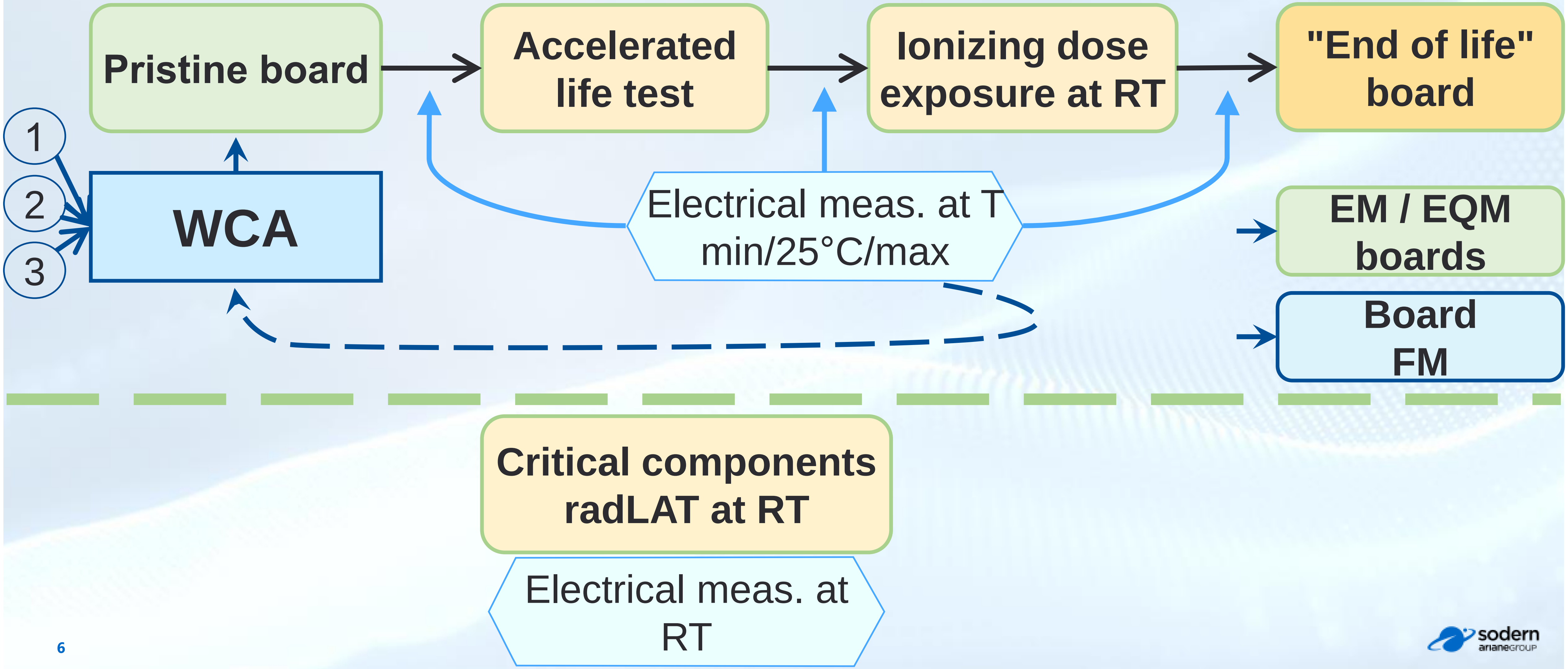
Proposed validation method

Board production phase

- Take fully functional boards equipped with flight electronic component lots. Single lot for every part reference:

  from capacitors/resistors to active integrated circuits
- Measure at 3 temperatures: min / Room Temperature / max
- Irradiate the boards (perform the radLAT)
- Apply ageing prior to irradiation if required/desired, e.g. only on first lot

Proposed validation method



Proposed validation method

Expected benefits

- Reduced recurrent costs with COTS-boards: only 1 test for several types of components
- Radiation effects measured at board level i.e. system specification level
- Validation of WCA by test
- Interactions between temperature and dose are covered

Proposed validation method

Counterparts

- Required definition of board lots, procurement & management of component lots for the manufacturing of board lots
- Potential difficulty to find the cause of a failure
  - →the whole lot of boards can be rejected instead of a single component lot
  - →definition of the board lot only validated after the test is complete
- High temperature measurement is limited to the last dose step if annealing effects have to be avoided

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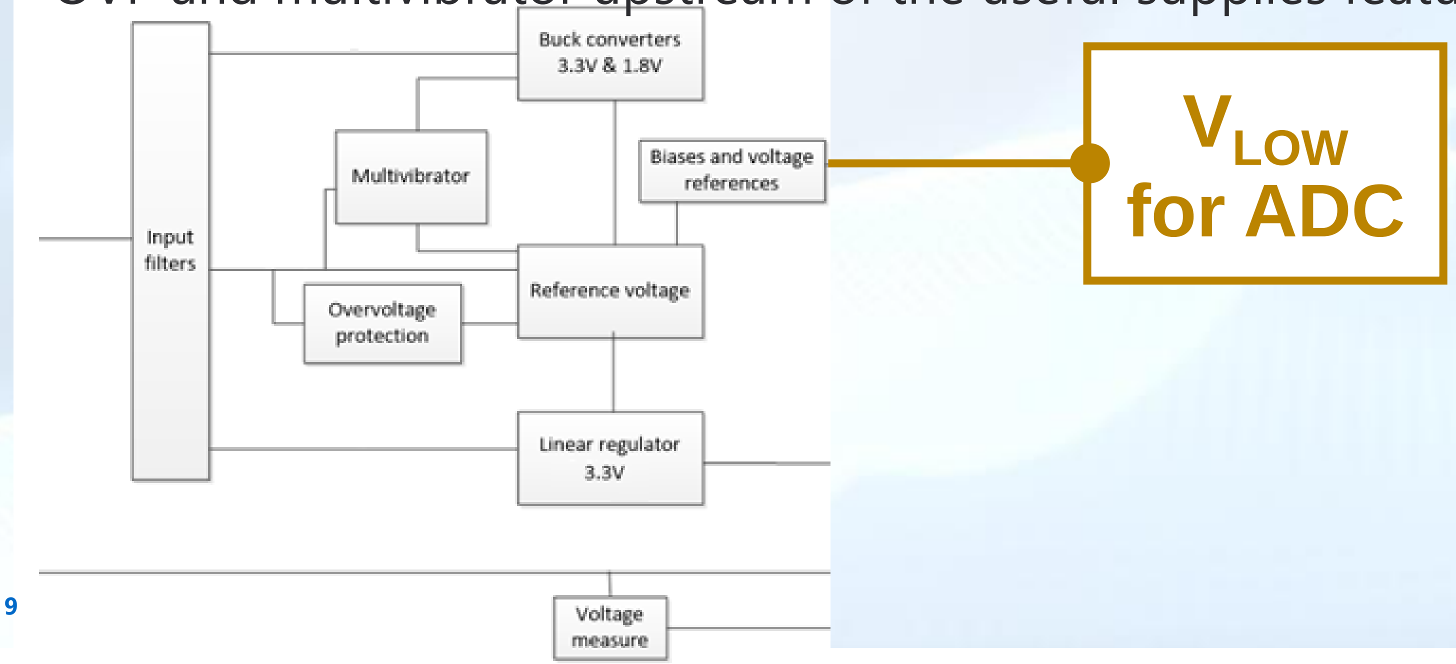
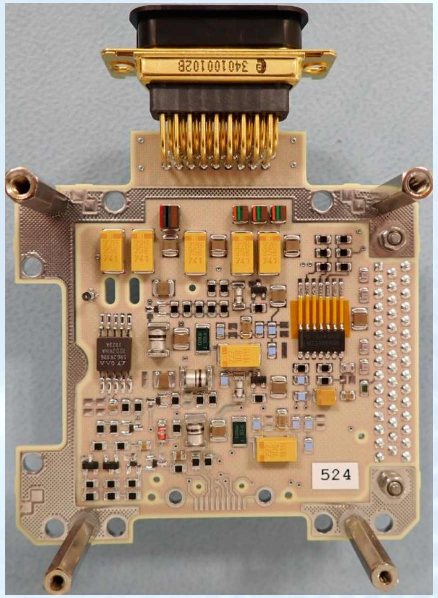
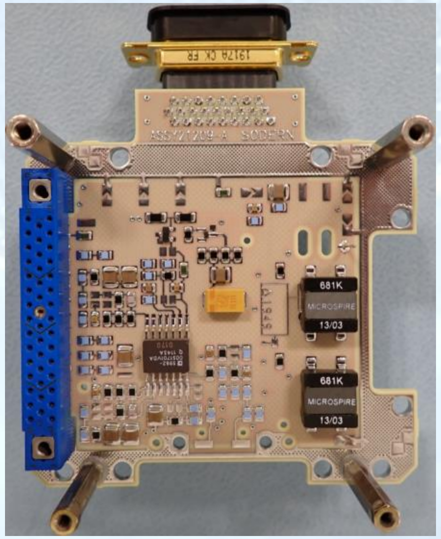
Tested board: Modified DC/DC converter board for enhanced TID sensitivity

- Stabilized +3.3V and +1.8V with buck converters (same architecture)
- LDO linear regulator at +3.3V
- Two accurate reference levels for an ADC: V_{HIGH}~2.042 V & V_{LOW}~872 mV
- Analogue measurement of an external voltage
- OVP and multivibrator upstream of the useful supplies feature



Tested board: Modified DC/DC converter board for enhanced TID sensitivity



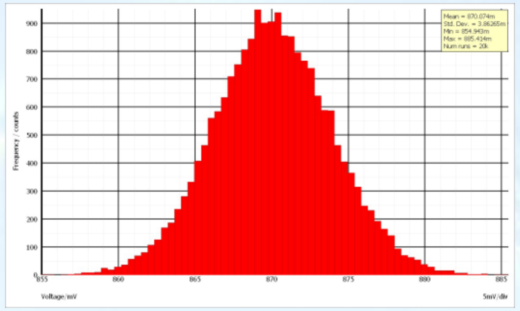


- 8 references of active components (bipolar technologies)
  - 3 diodes
  - 1 quad op-amp → known lot of a space-qualified alternative part very sensitive to ionizing dose
  - 1 quad comparator → COTS automotive-qualified alternative, tested to dose (low sensitivity)
  - 1 voltage reference (1 part, radiation-hardened bipolar) → no pin-to-pin compatible alternative
  - 2 transistors → COTS automotive-qualified alternative, tested to dose

Worst-Case Analysis

<u>WCA with component-level data specific to mounted lots per three methods</u>

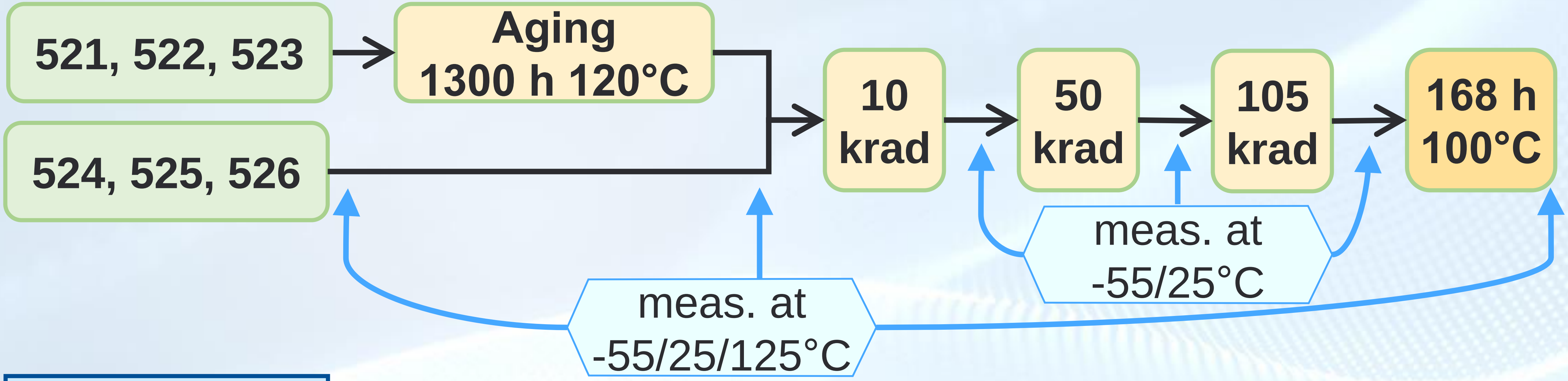
- Extreme Value Analysis (EVA) $|\Delta X| + |\Delta Y|$
- Root Sum Square analysis (RSS) $\sqrt{(\Delta X^2 + \Delta Y^2)}$
- Monte Carlo Analysis (MCA)



- Only dose-induced drifts inputs taken as lot-dependent

Test sequence

6 boards tested



EVA
RSS
MCA

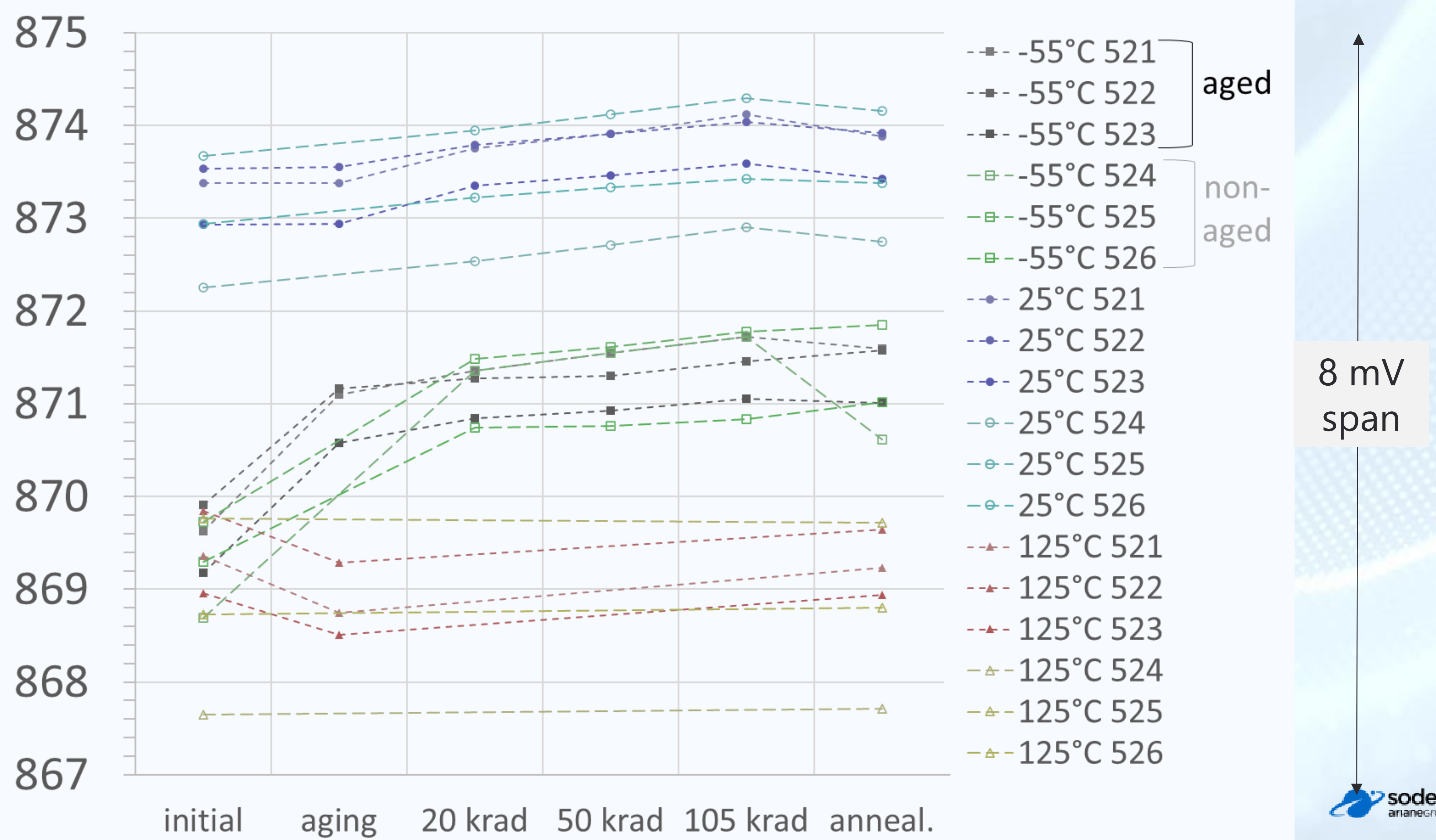
210 rad(Si)/h (^{60}Co source)
Same dose rate as component-level test results used for WCA
Unbiased as found by WCA

Reference level V_{LOW} [mV]

O meas. at 25°C

□ meas. at -55°C

Δ meas. at 125°C



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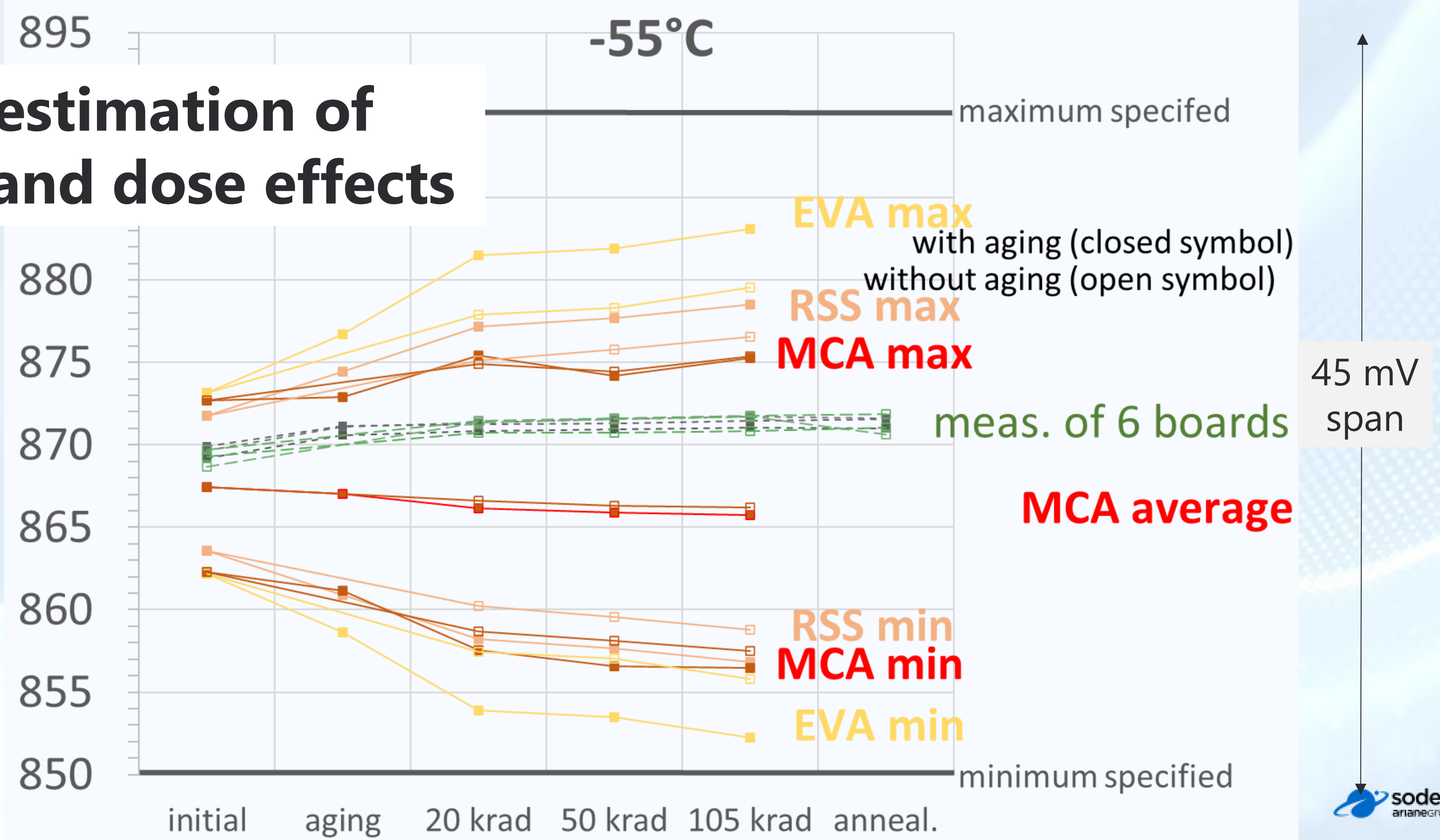
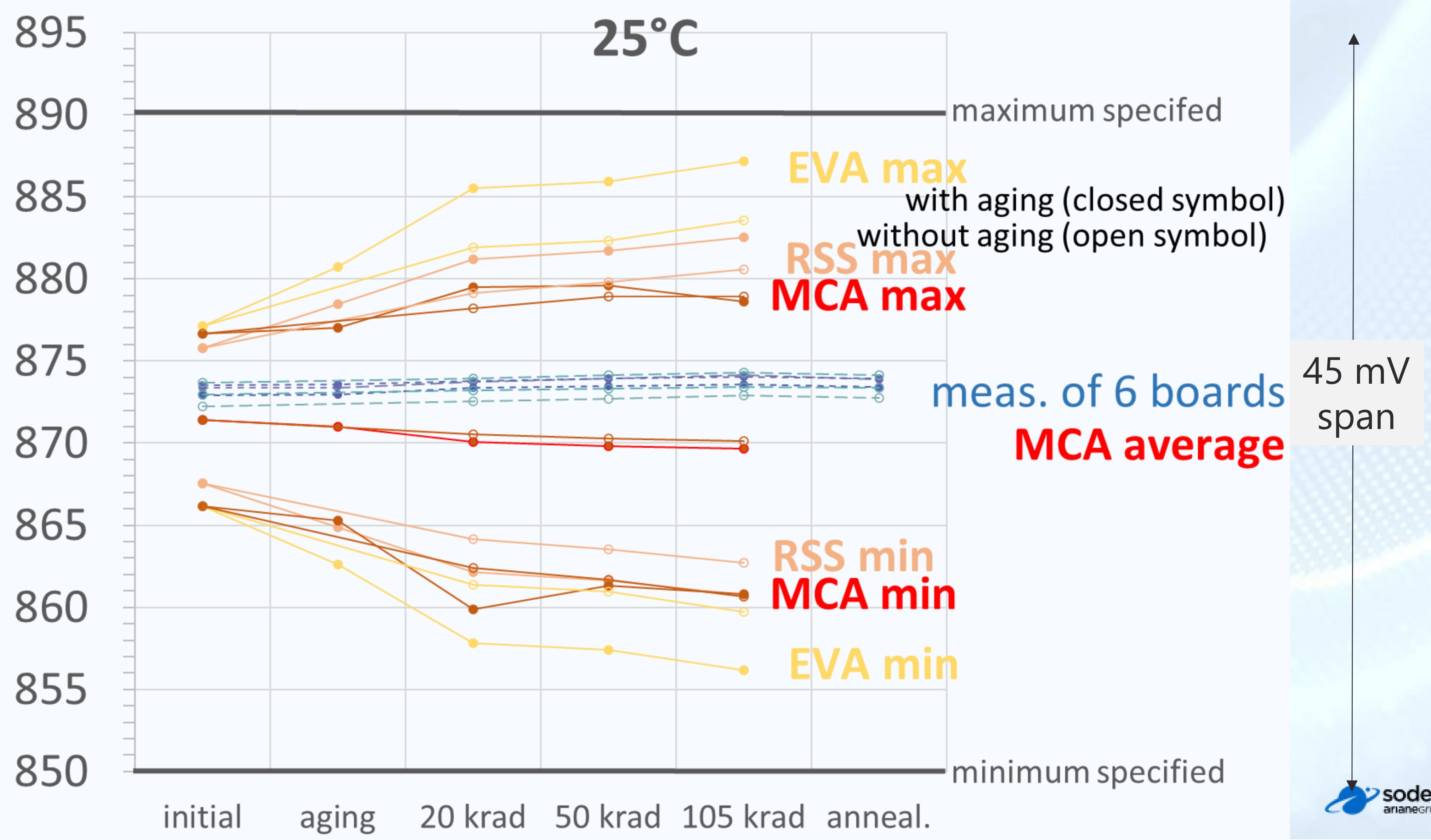
Reference level V_{LOW} [mV] at -55°C

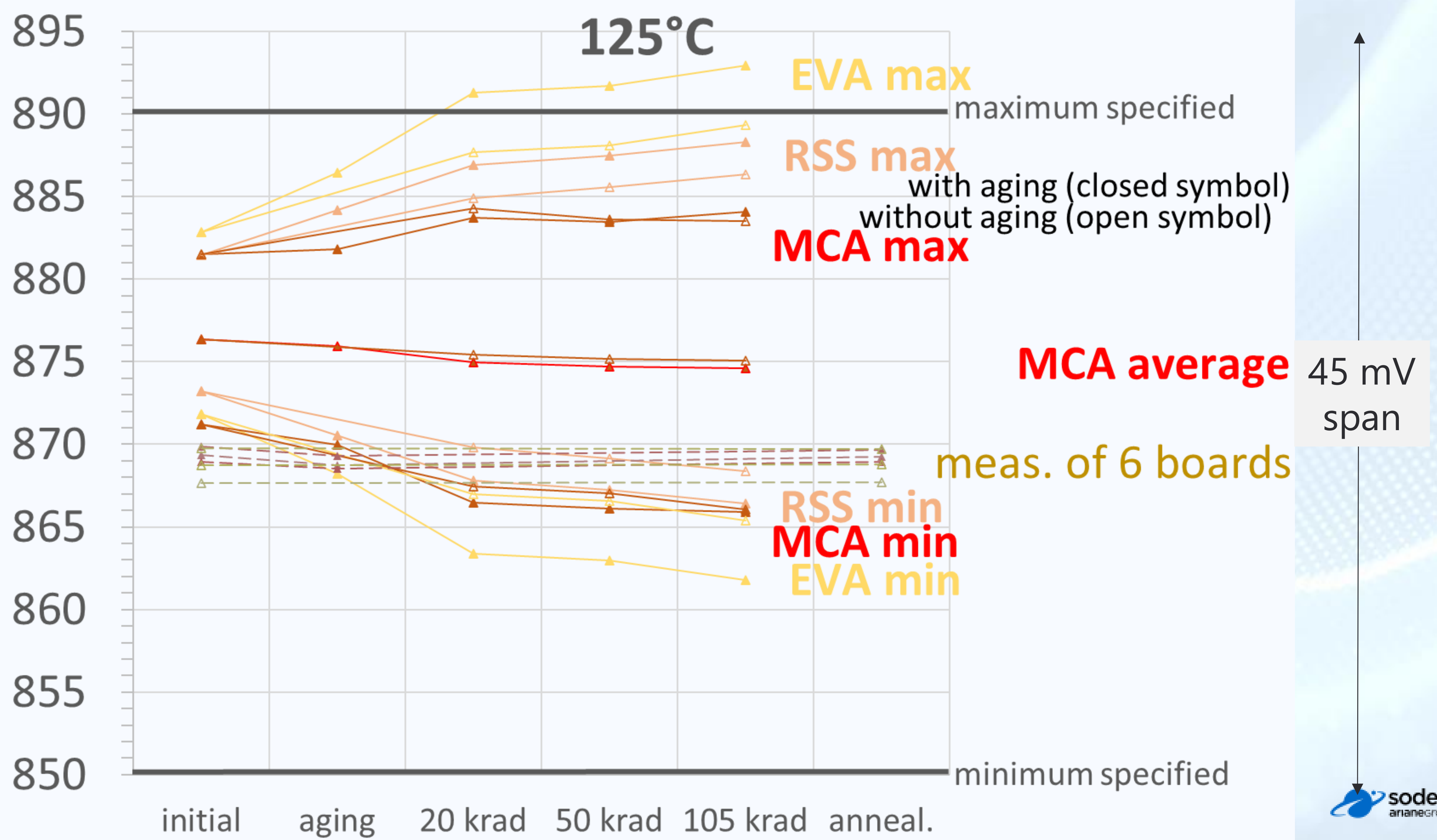
Overestimation of ageing and dose effects



Reference level V_{LOW} [mV] at 25°C



Reference level V_{LOW} [mV] at 125°C



General observations

WCA for the studied boards irradiated up to 105 krad

- Dose effects and ageing are overestimated by WCA budgets for all measured functions (V_{LOW}, V_{HIGH}, 3.3 & 1.8 V power supplies, 3.3 V LDO regulator, multivibrator, offset of external voltage measurement)
  - Dose effects: statistical extremes are summed up for all parameters and components in EVA and RSS methods (p= 0,9 with c=0,9 applied)
  - Ageing effects: generic end-of-life drifts are more conservative than experimental life test data

General observations

<u>WCA for the studied boards irradiated up to 105 krad</u>

- Low initial dispersion compared to WCA: potentially due to the low sample number (6) and the lot homogeneity
  - EVA and RSS methods sum up initial electrical specification limits for all parts, whereas parts close to specifications limits are rare and only on a few parameters
- Difficulties in modelling very non-linear functions like multivibrator
  - bias of results (measurements non-centered within the envelopes)
  - even wider initial dispersion according to WCA

Conclusions

<u>Board level testing is possible, how to perform it rigourously?</u>

- Proposed board level test method can capture all worst-case analysis contributors
- Radiation tolerance level measured through board level testing is much higher than by usual WCA methods due to:
  - The real lot parametric dispersion and ageing drift being taken into account
  - Favorable statistics (no combination of statistical extremes as in EVA and RSS)
- The radLAT can be designed and its results handled as usually done at component level

Conclusions

Board level testing is possible, how to perform it rigourously?

- The test plan should:
  - Rely more on the WCA results
  - Take especially into account what is known on the critical components since their evaluations (e.g. biasing influence on dose sensitivity, expected failure dose, dose-induced drift model)
  - Define the relevant measurements, e.g. in order to derive a drift model: to be considered by the board design

Conclusions

<u>Board level testing is possible, how to perform it rigourously?</u>

- Probabilities of success and confidence levels should be set according to the number of boards tested and the statistical parameters of the measured distributions
  - Targeting the same confidence levels as EVA and RSS methods in WCA would likely be cost-prohibitive
- Functional Go/No-Go approaches to board level testing radLAT ("it still works") must rely on a failure dose model likely difficult to establish with a high confidence level
- Further analysis and proposals to be studied: Mix between Radiation Design Margin and statistical knowledge?

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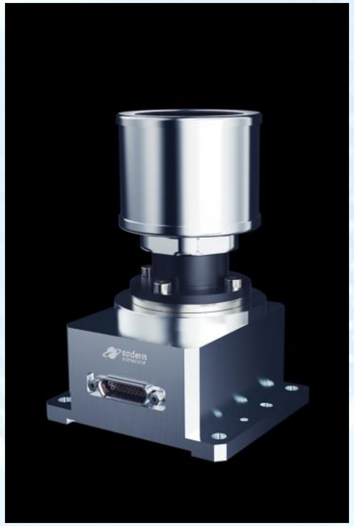
Available documentation

- Article *A Comparison of Board-Level Lot Acceptance Testing Method with Worst-Case Analysis Results*, in IEEE Transactions on Nuclear Science – 2024

Where is it already practiced?



- Methodology applied to SODERN Auriga star trackers based on COTS components

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