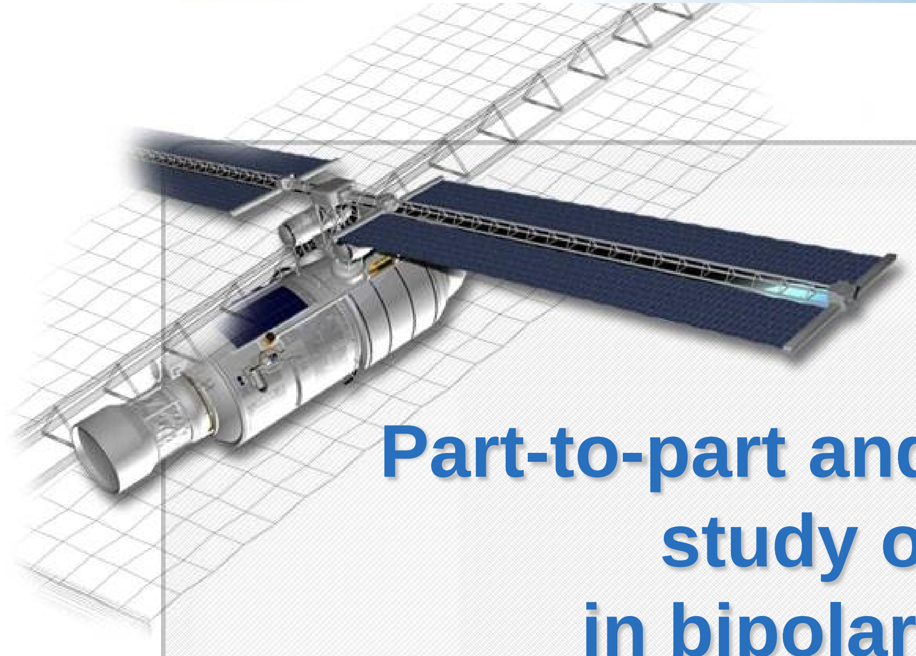


Part-to-part and lot-to-lot variability study of TID effects in bipolar linear devices

J. Guillermin, N. Sukhaseum, A. Varotsou,
P. Garcia and C. Poivey

Radecs 2016 Proceedings [PC-2]

Introduction

- **Definition of Radiation Design Margin (RDM) requirements for Radiation Verification Testing (RVT) on flight lots under Total Ionizing Dose (TID)**
- **Critical for linear bipolar devices**
  - **Likely to show part-to-part and lot-to-lot variation in TID sensitivity**
- **Investigation on the within-one-lot and inter-lot variability on three different references**
  - **Experimental characterizations**
  - **Data analysis**
- **One-sided tolerance limit (K_{TL}) method is usually considered for TID testing**
  - **Applied to our test data**
  - **Compared to a Maximum Likelihood Ratio (MLR) method which is investigated and provides an interesting accuracy**

Devices Under Test

- **Three different references were irradiated**
  - Three lots were tested for each reference
  - 30 devices were irradiated for each lot

- **Cobalt 60 TID test**
  - Dose rate 210 rad/h
  - GAMRAY facility (TRAD – Labège, France)

Device	Part number	Manufacturer	Lots
LM124AWG	**5962R9950401VZA**	**Texas Instruments**	**0539A** **1136A** **1306A**
AD584SH	**5962R3812801VGA**	**Analog Devices**	**0125A** **0226A**
AD584SH	**5962-3812801VGA**	**Analog Devices**	**1052A**
TL1431ACZ	**-**	**ST Microelectronics**	**GE245074** **GE334152** **GE337030**

Op. Amp.

Volt. Ref.

Study Framework

- **Radiation hardness assurance standards**
    - **Intra-lot variability taken into account with the 3-sigma approach**
        - Over a test sample, the electronic device parameter drift considered for the worst-case analysis is mean ± 3 sigma
    - **Inter-lot variability taken into account with periodic testing**
        - RVT periodicity depends on space project prime-contractor
- **In most of the cases, the 3-sigma approach is representative enough and well adpated (when the associated risk is accepted) to take into account the intra-lot variability for a space project**
    - **This study focuses on the few other cases…**
        - In this presentation, 3 worst-cases (1 per tested reference) are shown
    - **Investigate the application of another statistical methodology (MLR) that could be applied when a higher confidence level is required**

Statistical Analysis

- **First level analysis**
  - 3-sigma approach
  - $K_{TL} = 2.742$ for n = 5 (C=90, P=90) [1]

Experimental mean 'm'

$$m = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - m)^2}$$

Standard deviation 's'

- **Second level analysis**
  - Maximum Likelihood Ratio
  - Test data fitted to a normal law

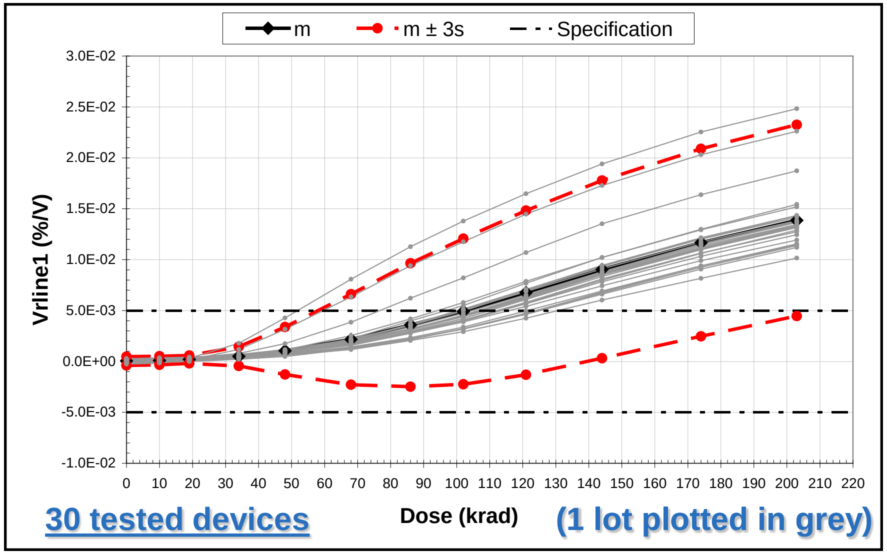
$$f_{nm}(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

Normal law (2 parameters μ and σ)

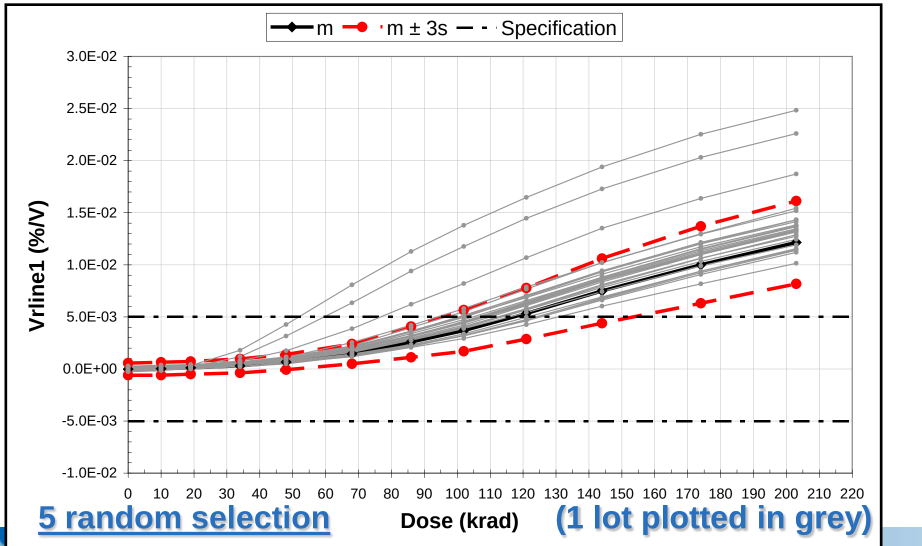
- **2-level analysis based on the use of experimental parameters 'm' and 's' as defined above, as well as statistical parameters 'μ' and 'σ'**

AD584SH (AD)

AD584SH Vrline1 (%/V) lot 0226A

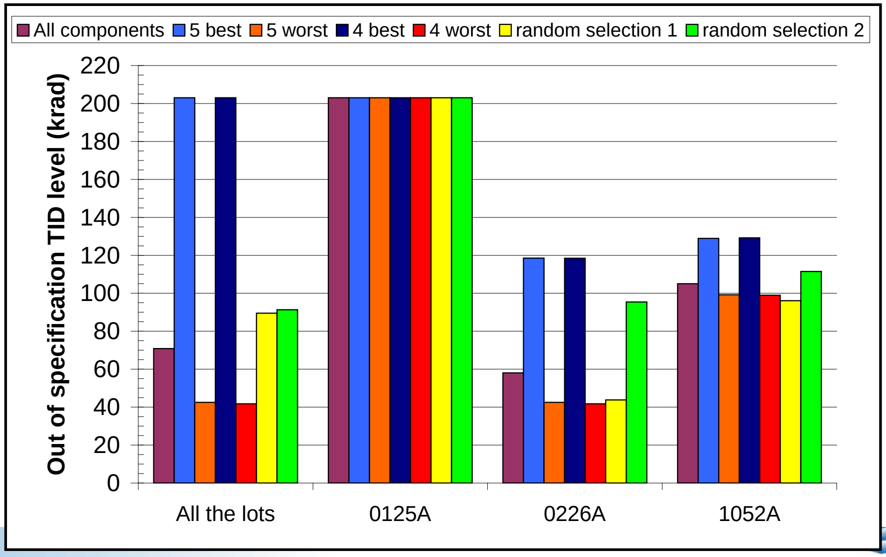


30 tested devices (1 lot plotted in grey)



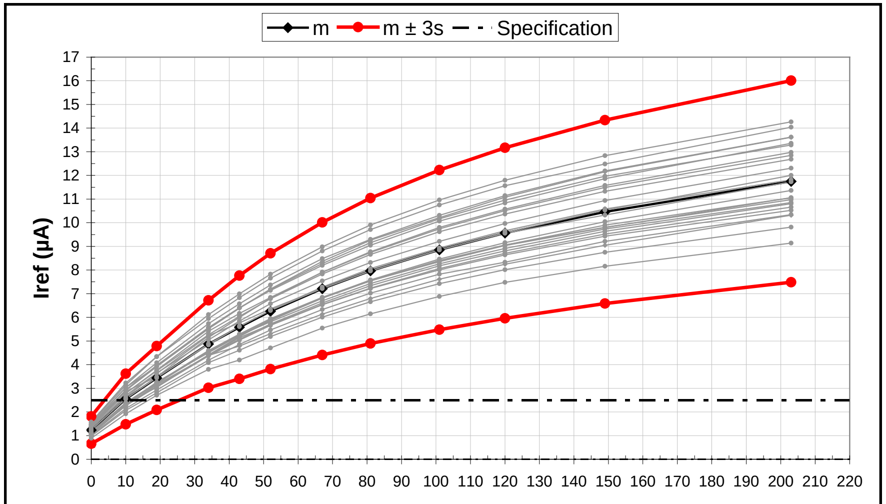
5 random selection (1 lot plotted in grey)

- **Mean ± 3 sigma calculated over the 30 tested devices**
- **Mean ± 3 sigma calculated over 5 randomly selected devices**
- **Estimated lot behaviour for different subgroups**
  - Out-of-specification TID level based on m+3s limit
  - All devices, 5 best or worst, 4 best or worst, random selections



TL1431ACZ (STM)

TL1431ACZ Iref (µA) lot GE334152



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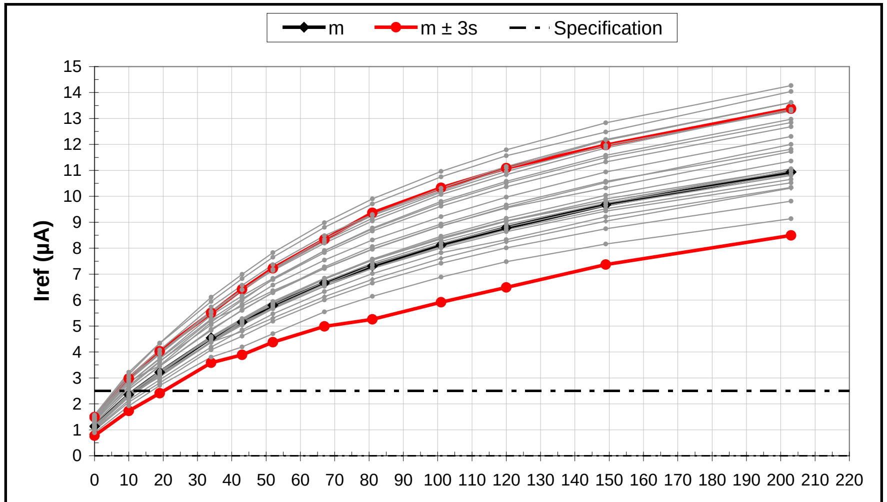

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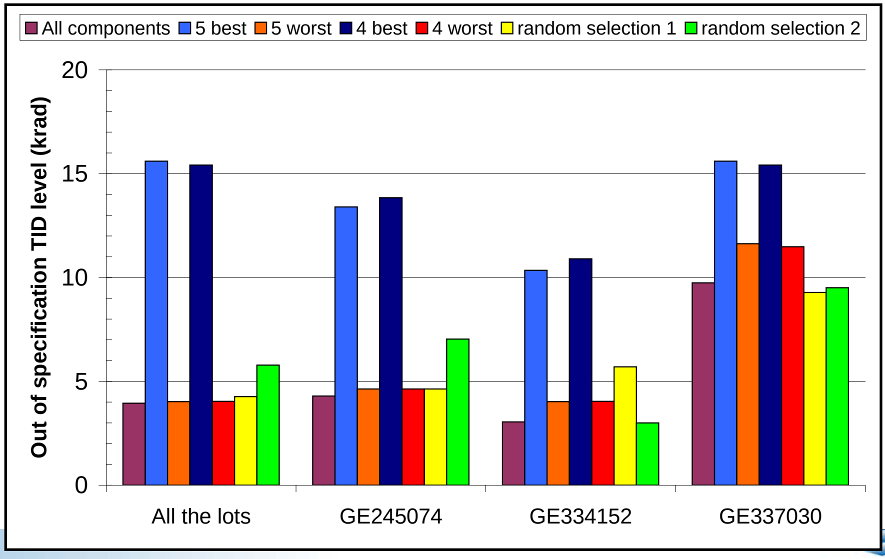
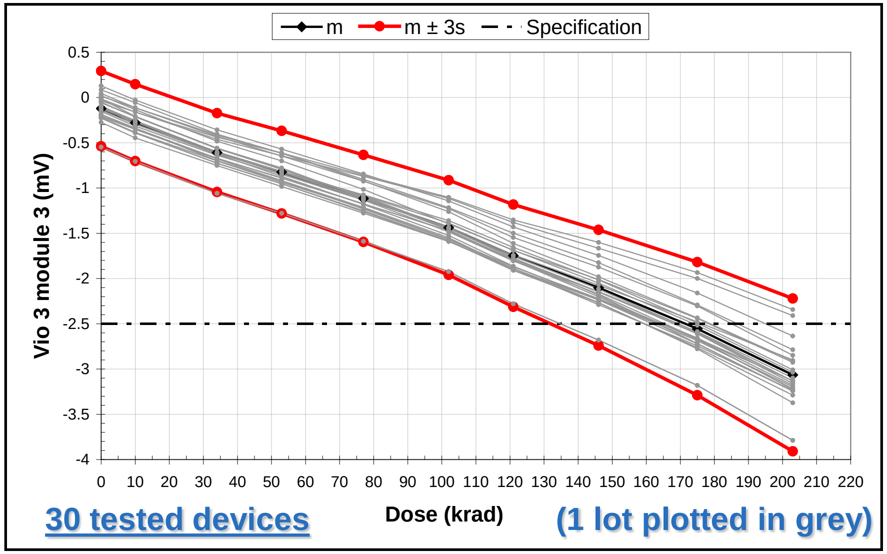
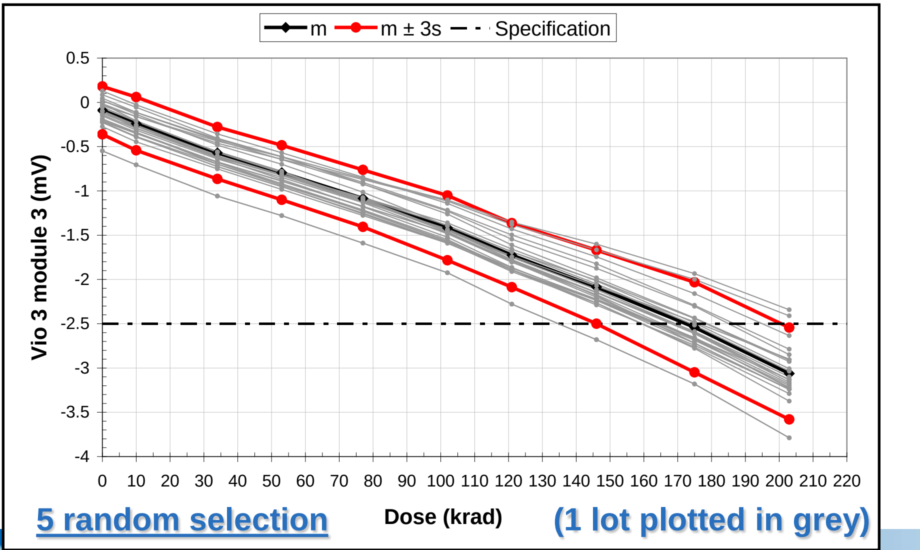


LM124AWG (TI)

LM124AWG Vio3 module 3 (mV) lot 1136A



30 tested devices (1 lot plotted in grey)



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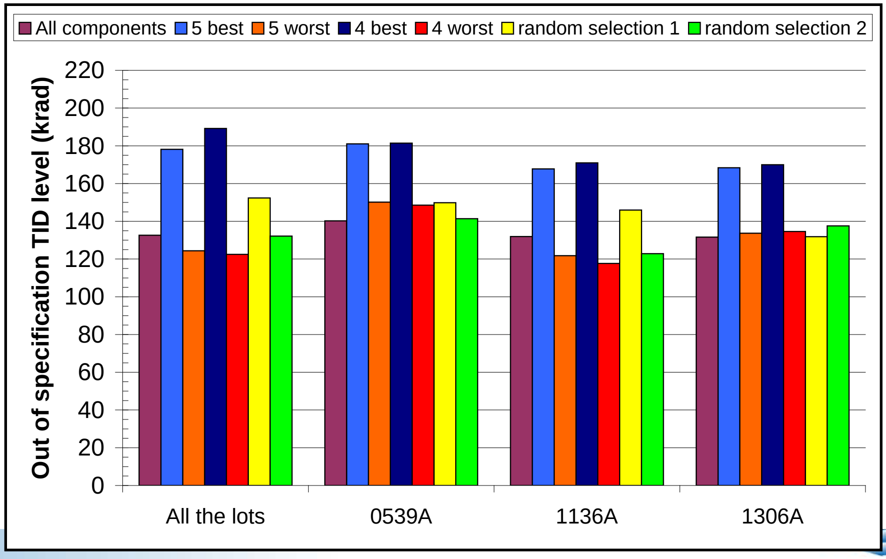


Second Level Analysis

Second level analysis

- Normal law parameters optimized with max. likelihood

Likelihood formula

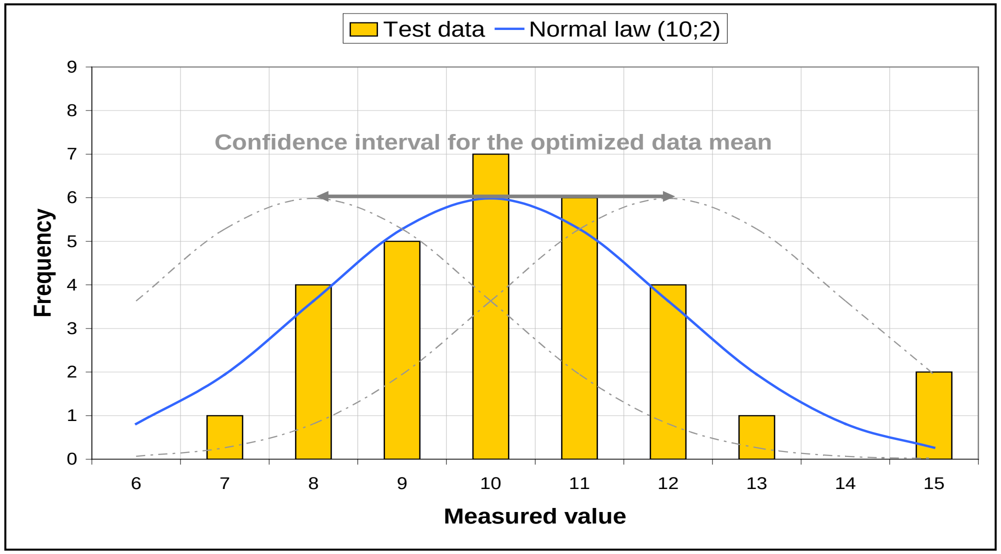
$$L = \prod_{i=1}^{n} f\left(x_i, \mu, \sigma\right) \Longrightarrow L_{\max} = \max\left(L\right)$$

Maximum likelihood

- The maximum likelihood is also used to define a confidence interval for the normal law parameters

$$\ln\left(\frac{L}{L_{\max}}\right) \geq -\frac{1}{2}\chi^2\left(1-\alpha,2\right)$$

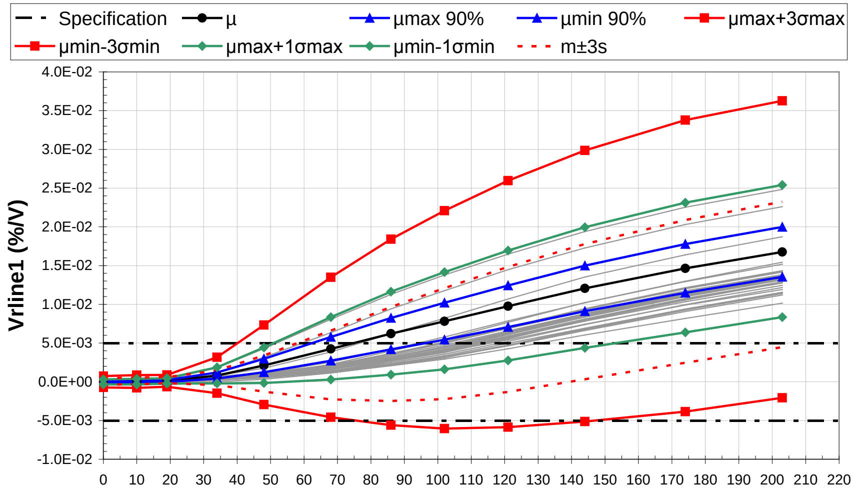
Confidence interval formula (maximum likelihood log-ratio)



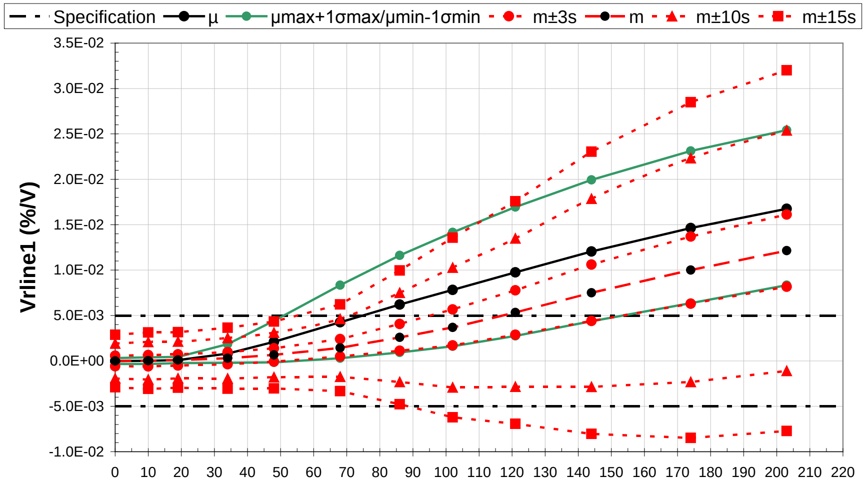
Representation of the normal fit confidence interval calculation (frequency plotted as a function of the measured value for the electrical parameter)

AD584SH (AD)

AD584SH Vrline1 (%/V) lot 0226A

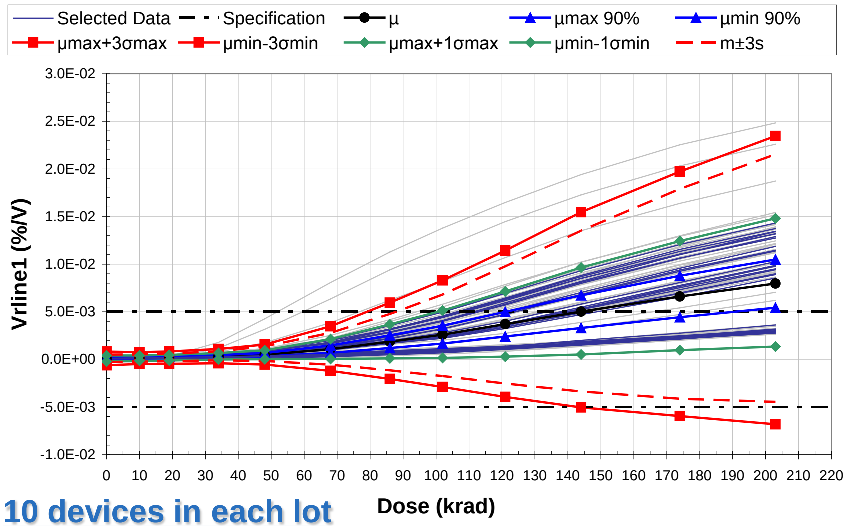


MLR confidence interval (1 lot plotted in grey)



Comparison

- Max. Likelihood Ratio method with the 30 devices in one lot
- Comparison of MLR confidence interval and 3-sigma calculation with 5 devices
  - Number of sigma to cover the confidence interval delimited by « 90% + 1σ » (green curves)
- MLR method, 10 devices selected in each one of the 3 tested lots
  - To take into account the inter-lot variability

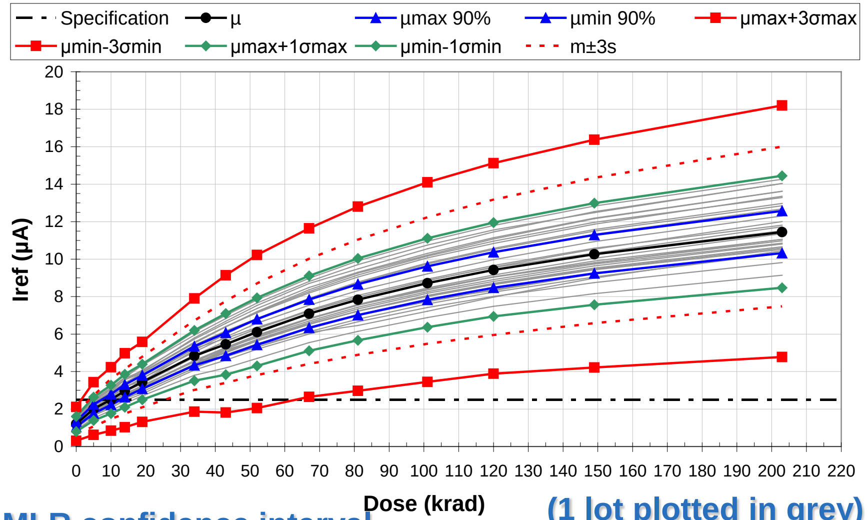


10 devices in each lot

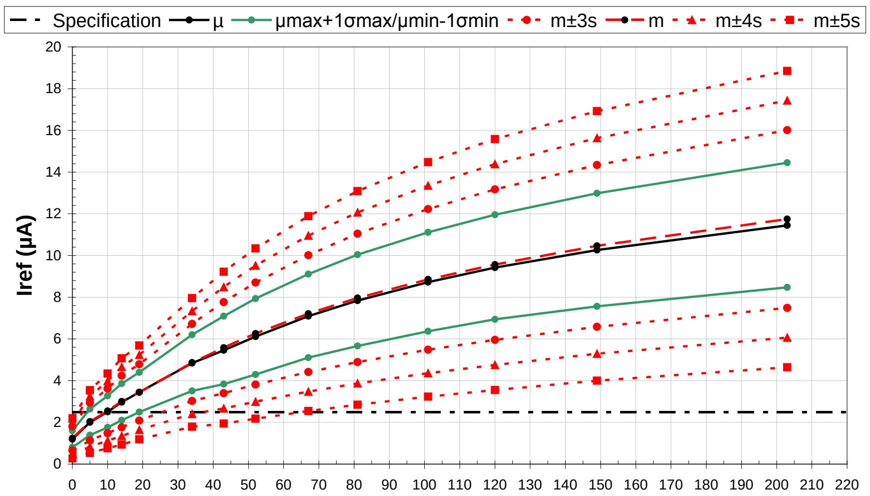
(3 lots plotted in grey, 30 selected devices in blue)

TL1431ACZ (STM)

TL1431ACZ Iref (µA) lot GE334152

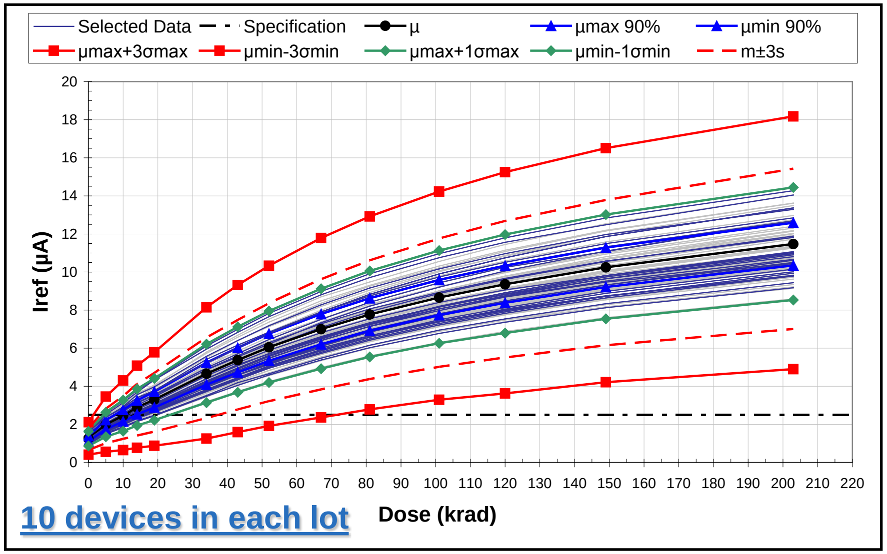


MLR confidence interval (1 lot plotted in grey)



Comparison

- Max. Likelihood Ratio method with the 30 devices in one lot
- Comparison of MLR confidence interval and 3-sigma calculation with 5 devices
  - Number of sigma to cover the confidence interval delimited by « 90% + 1σ »
- MLR method, 10 devices selected in each one of the 3 tested lots
  - To take into account the inter-lot variability



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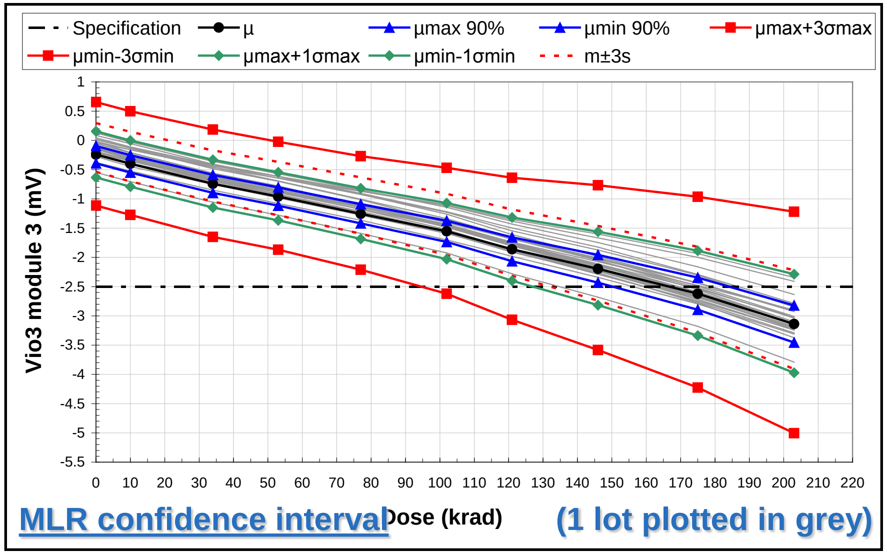
LM124AWG (TI)

LM124AWG Vio3 module 3 (mV) lot 1136A



MLR confidence interval (1 lot plotted in grey)

- Max. Likelihood Ratio method with the 30 devices in one lot
- Comparison of MLR confidence interval and 3-sigma calculation with 5 devices
  - Number of sigma to cover the confidence interval delimited by « 90% + 1σ »
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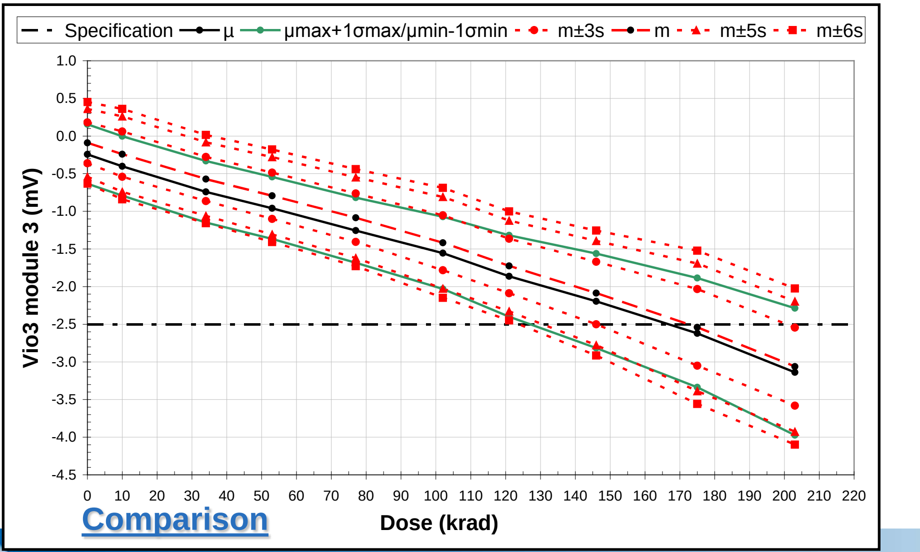
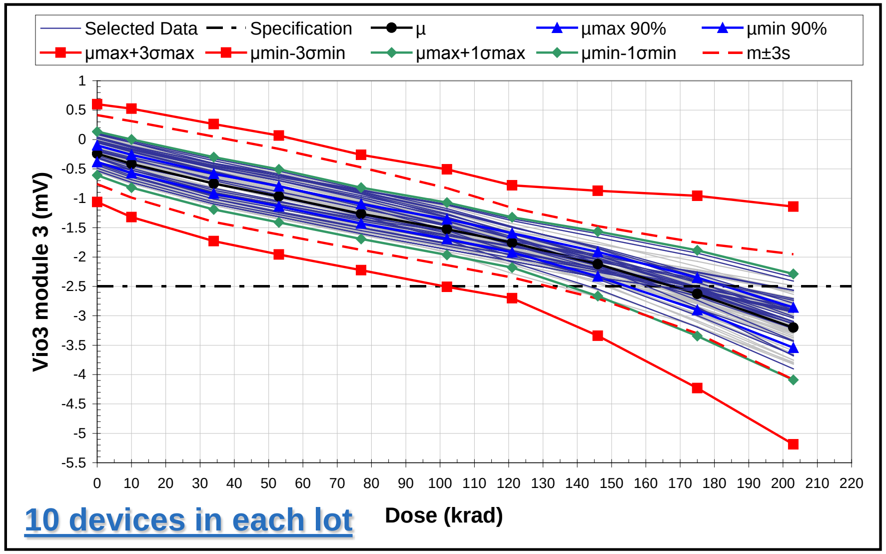


Comparison



10 devices in each lot

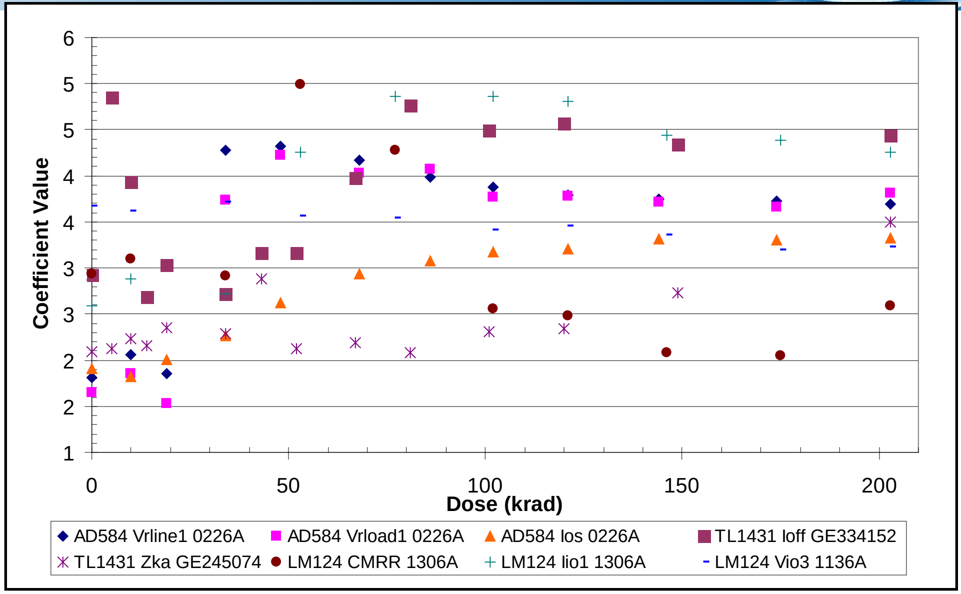
(3 lots plotted in grey, 30 selected devices in blue)

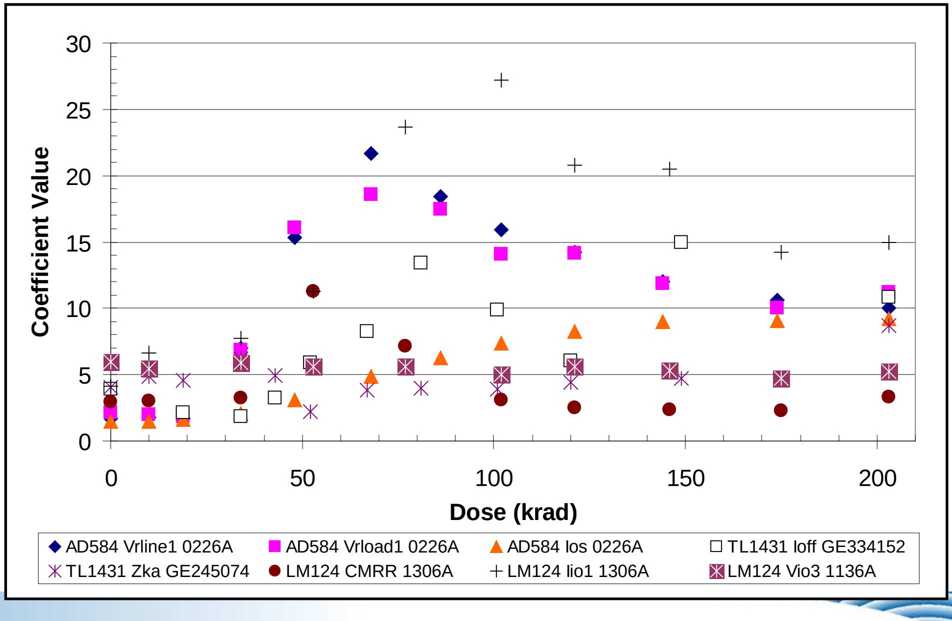
MRL Method Accuracy

- **Multiplication factor applied to sigma ‘s’ at each TID step to cover the confidence interval delimited by « 90% + 1σ » from MLR calculation**
  - **30 device lot (top graph)**
  - **5 device random selection (bottom graph)**

- **Indication of the accuracy with the MLR method corresponding to $K_{TL} = 5$ (P > 0.999 for C = 90)**

- **The impact of the lot/selection homogeneity in terms of degradation can be observed**
  - **AD584 Vrline1 exhibits atypical devices**
    - Larger margin required to cover the lot behaviour
  - **LM124 Vio3 more homogeneous**
    - Smaller margin required to cover the lot behaviour





Conclusion

- TID testing was performed on 3 lots for 3 bipolar device references
    - Analysis of the lot-to-lot and within-one-lot variability

- Data analysis objectives
    - Characterize the lot coverage based on 5-device sample size for TID testing
    - Propose and evaluate a Maximum Likelihood Ratio (MLR) method based on the use of confidence intervals

- MLR is an accurate way to estimate the lot behaviour
    - Large sample size needed (30 devices)
    - Use of a confidence interval on the mean μ of the electrical parameter measurement

- Can be applied to data groups composed with different lots
    - Increase the sample size, better calculation accuracy
    - Takes into account the lot-to-lot variability

- Perspective
    - Cost problem related to the large needed sample size
    - Adaptation of the MLR method to smaller sample sizes but keeping similar accuracy

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