

ELDRS - Verification of Enhanced Low Dose Rate Sensitivity Accelerated Test Method

ESTEC - Contract No. 22051/NL/PA

Project Coordinator:

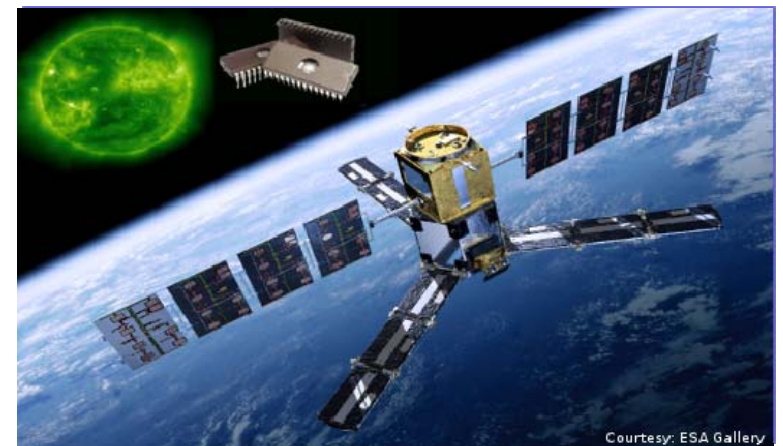
Peter Beck

Project Team:

**Michael Wind
Marcin Latocha**

ESA Technical Project Officer:

Marc Poizat



Content

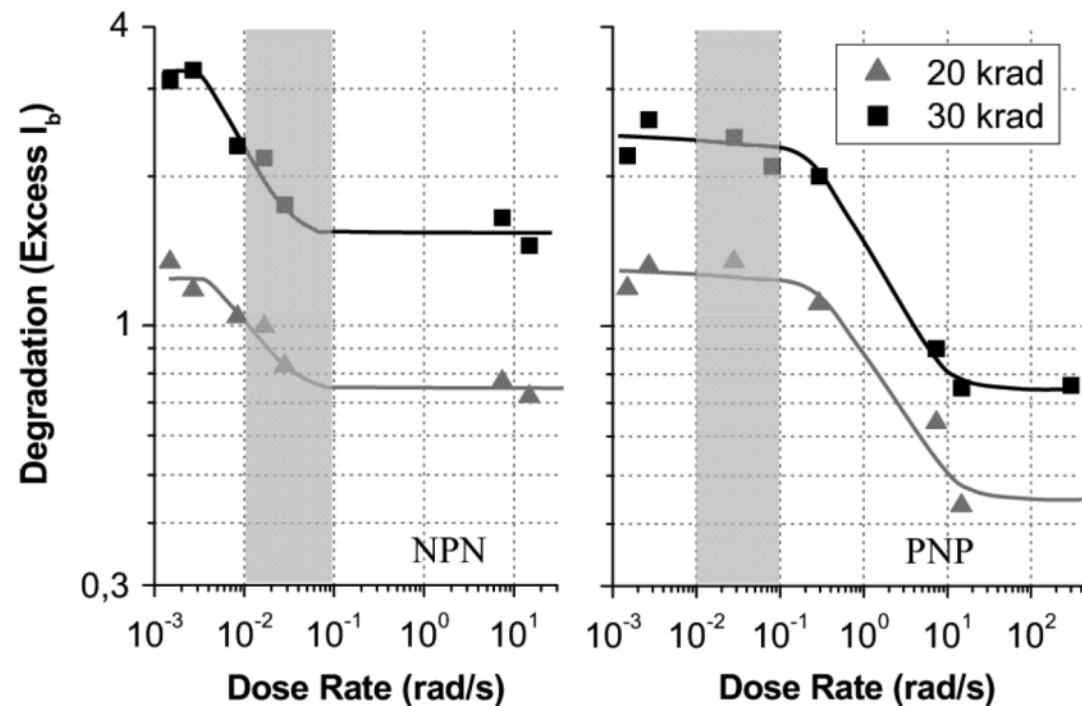
- ELDRS Test Method
- Proposed Parts List
- Verification Test Plan
- Preliminary Test Results
- Statistical Analysis with ANOVA
- Conclusion and Outlook
- ELDRS Website eldrs.net

ELDRS Test Method

Motivation

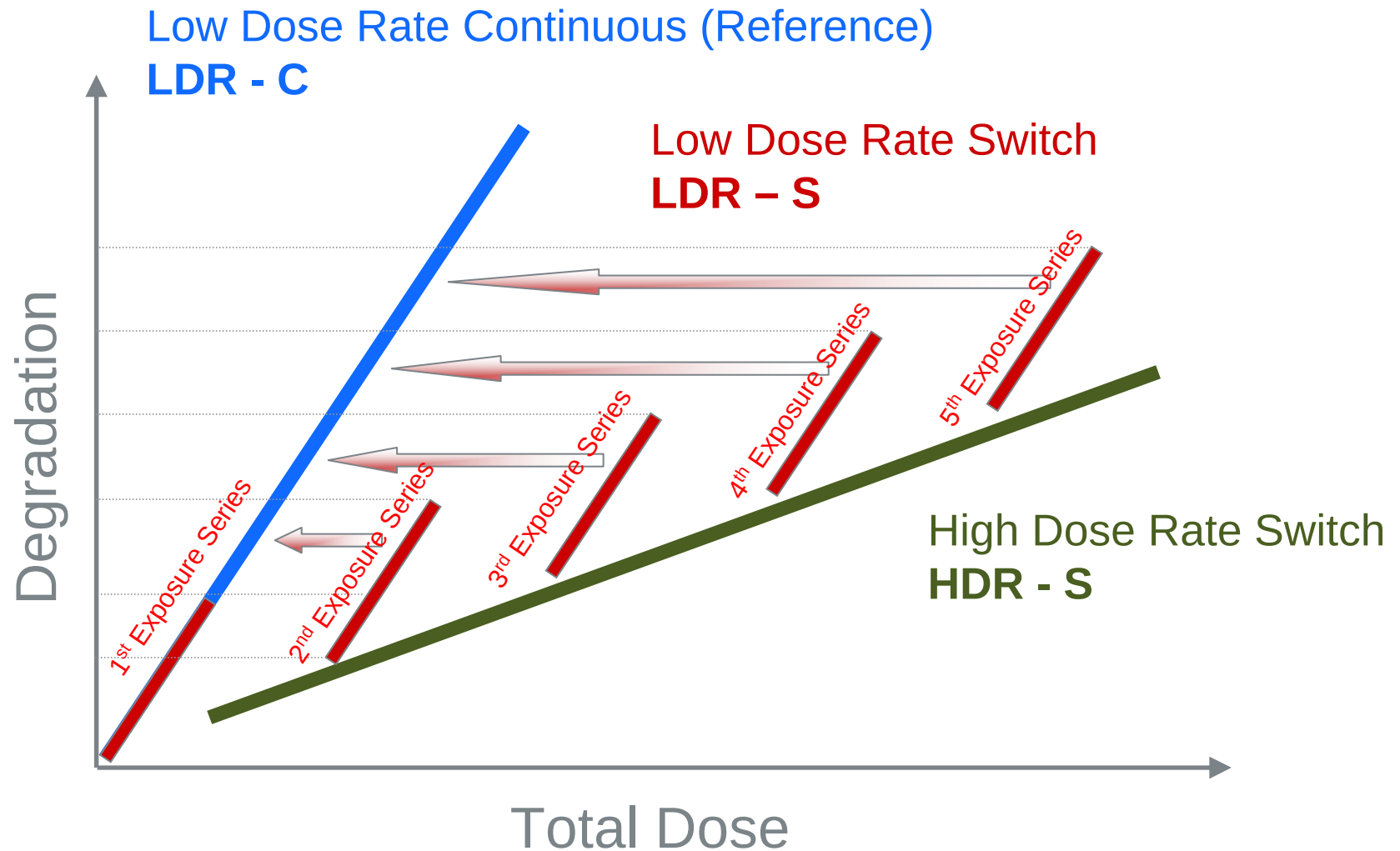
- Concern for **bipolar technology** used in space
- Low dose rate testing is **time consuming** !
 - e.g. 100krad:
10 mrad/sec → 4 months
 - 1 mrad/sec → ~3.5 years
- **Accelerated switching dose rate method** proposed by UM2
- ELDRS project checks the **applicability** of UM2 test method

Degradation of the base current, I_b for NPN and PNP transistors
Total dose: 20 and 30 krad (SiO_2)



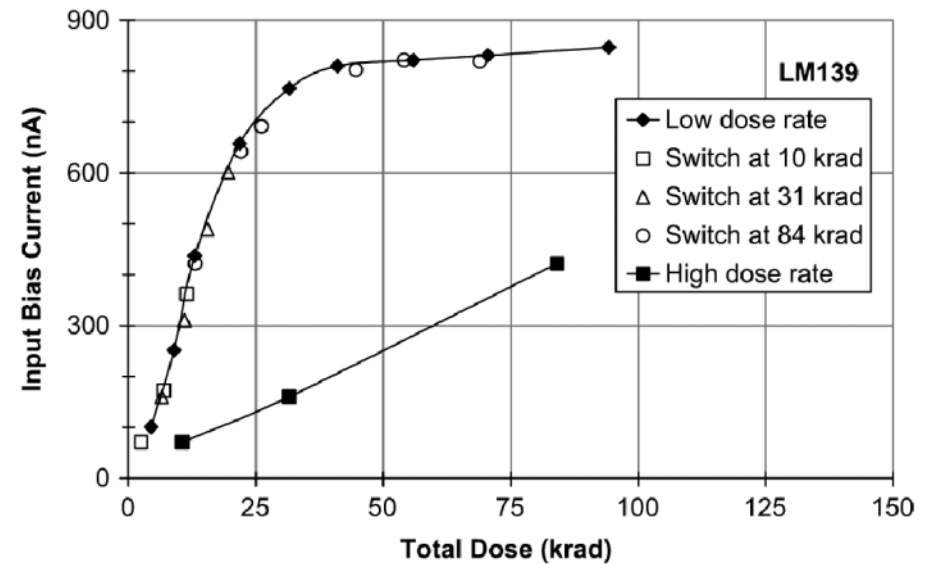
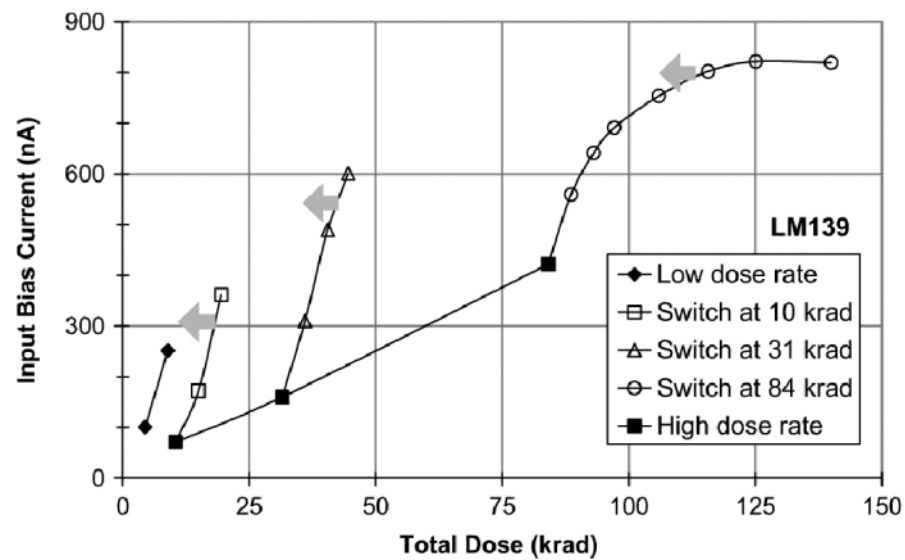
Reference: J. Boch, et.al., „Physical model for low dose rate effect in bipolar devices“, IEEE-TNS, vol. 53, p. 3655, December 2006

The Accelerated Switching Test Method



Example: ELDRS Effect for LM139

Accelerated switching test for input bias current of LM139



Ref: .J. Boch, et.al., „The Use of a Dose –Rate Switching Technique to Characterize Bipolar Devices“, IEEE-TNS, vol. 56 (6), p. 3347, December 2006

Proposed Parts List

Selection of parts for the experiments

- **Basis:** Approved component list by ESA CTB radiation working group
- **Selection Parameter:**
 - **E (0,1):** ELDRS sensitivity (literature)¹⁾
 - **I (0,1):** pnp Input stage¹⁾
 - **S (0,1):** availability of 70 units from one wafer lot (SLDC)
 - **P(0,0.5,1):** Price < 5000 Euro for 70 units
- **Selection Formula:** $S = E \cdot I \cdot S \cdot P^{1)}$
- **Selection Criteria:**
 - $S \geq 0.5$

¹⁾ If ELDRS sensitivity is not known from literature information about “pnp stage” is considered to be sufficient.

Part Types used for 1st Measurement Campaign

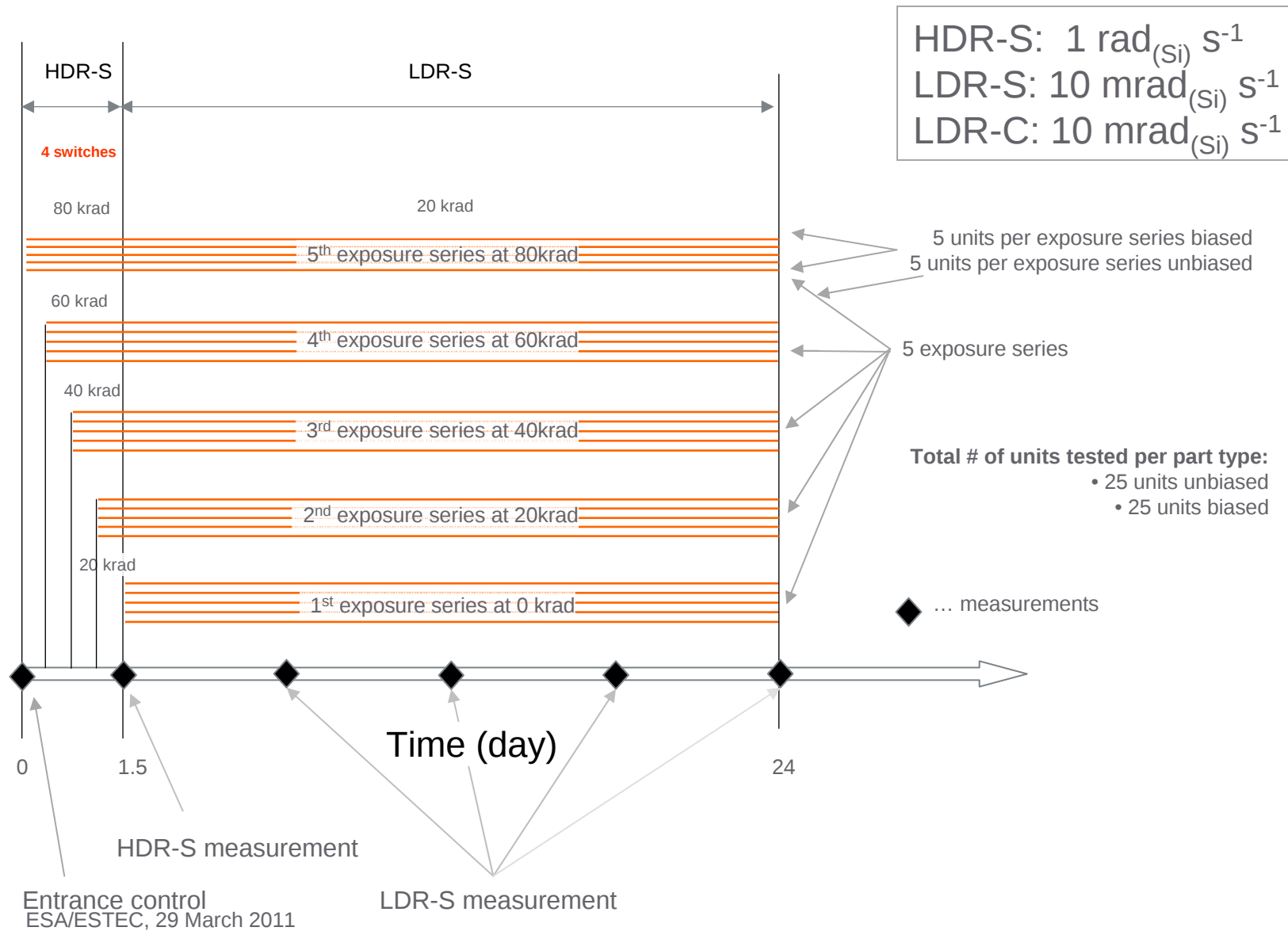
Part Type	Description	Manufacturer	Picture
LM324AN	Operational Amplifier	National Semiconductor	
LM158AJ	Operational Amplifier	National Semiconductor	
LM311N	Comparator	National Semiconductor	
LM339AN	Comparator	National Semiconductor	
HS9-OP470ARH	Radiation Hard Operational Amplifier	Intersil	

Part Types used for 2nd Measurement Campaign

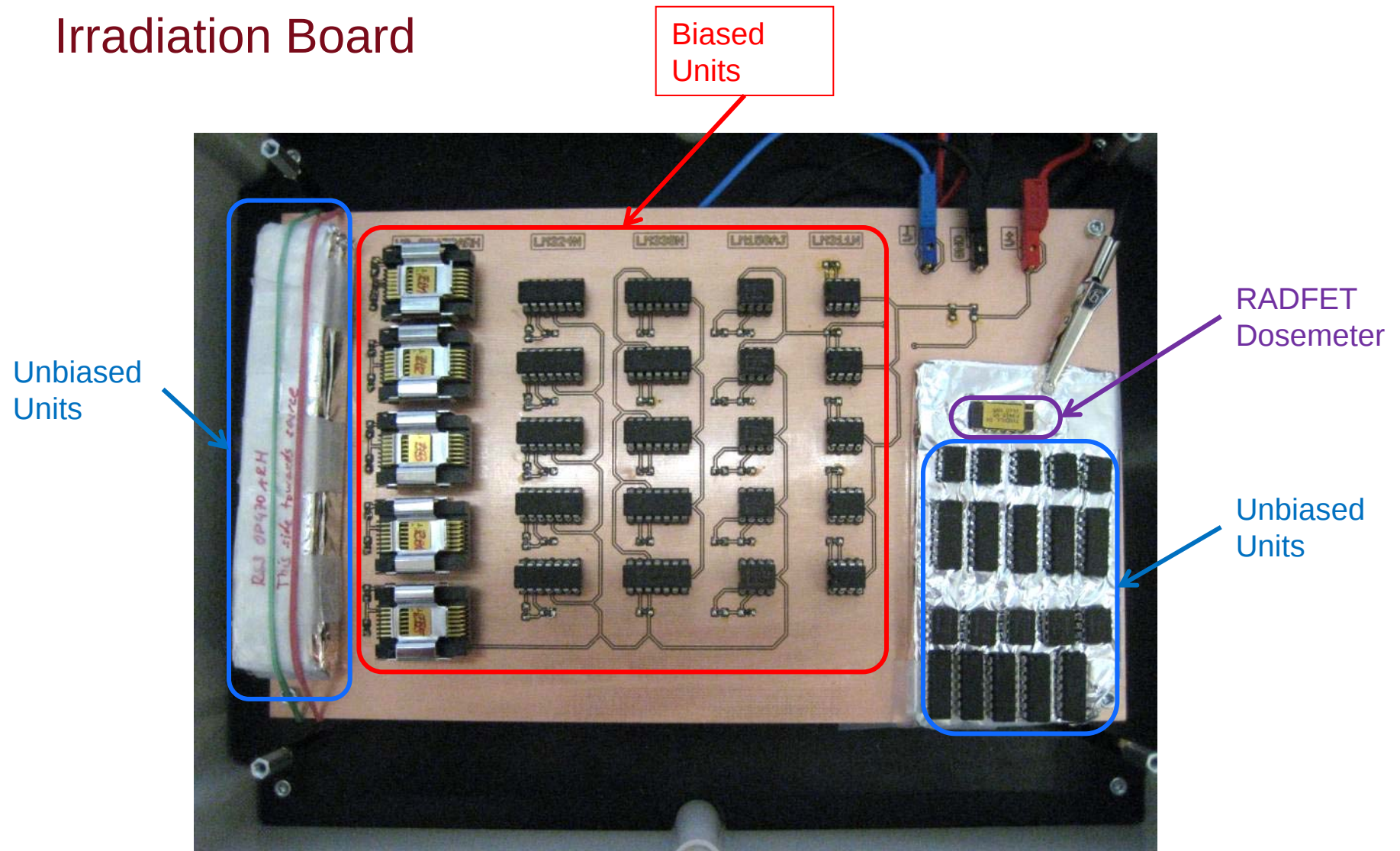
Part Type	Description	Manufacturer	Picture
HS9-139RH	Radiation Hard Comparator	Intersil	
OP470	Operational Amplifier	Analog Devices	
OP177	Operational Amplifier	Analog Devices	
LM336-2.5	Reference Diode	National Semiconductor	
LM317	Voltage Reference	National Semiconductor	

Verification Test Plan

Irradiation Plan

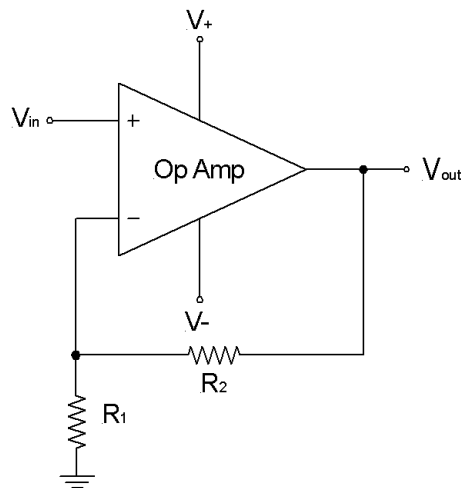


Irradiation Board



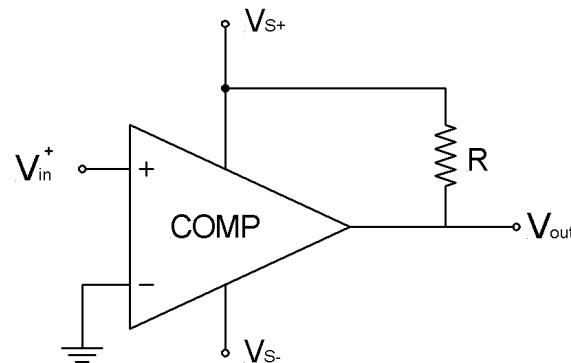
Biasing Conditions During Exposure

Operational Amplifier



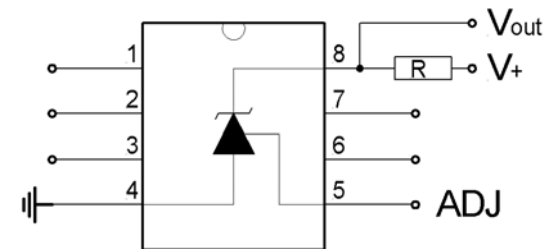
$V_+ = +15V$; $V_- = -15V$
 $V_{in} = \sim 0.5V$; $V_{out} = \sim 5V$
 $R_1 = 1k\Omega$; $R_2 = 10k\Omega$; $f = 11$

Comparator



$V_+ = +15V$; $V_- = -15V$
 $V_{in} = \sim 0.5V$; $V_{out} = V_{OS+}$
 $R = 15k\Omega$

Voltage Reference



$V_{in} = +5V$
 $R = 2.5 k\Omega$

Note: Unbiased configuration is achieved by mounting DUTs in antistatic IC Foam that is enwrapped in Aluminium foil.

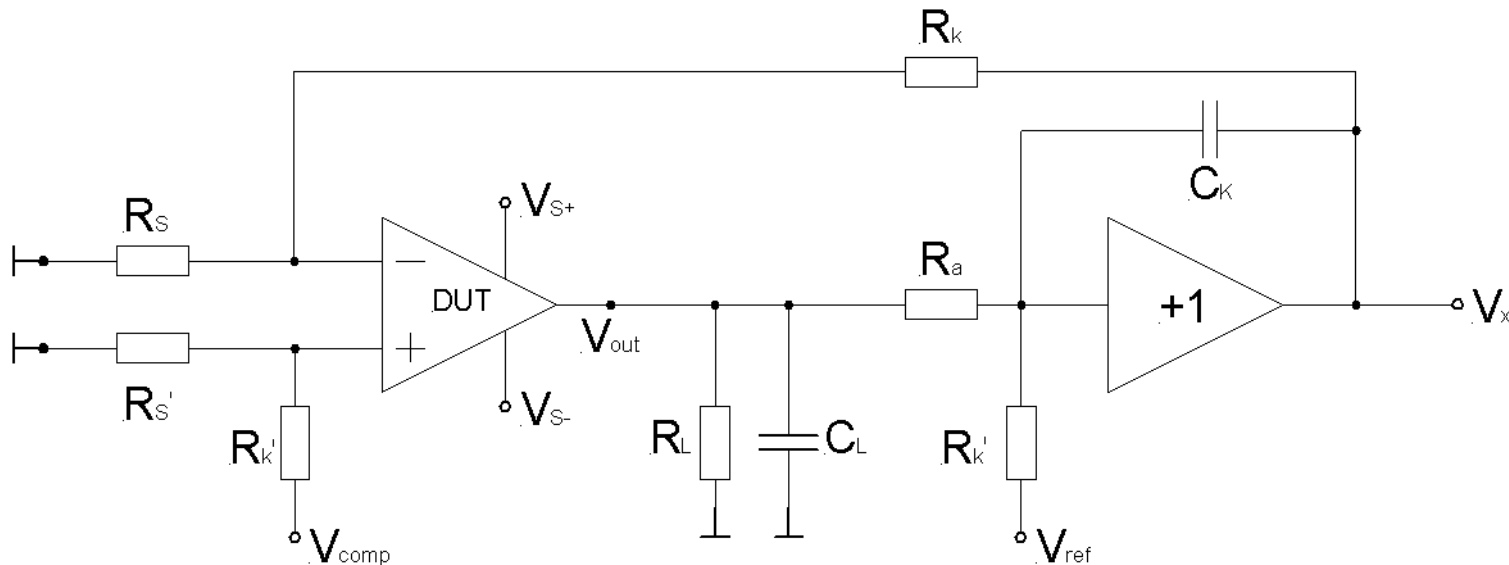
Parameters for Investigation of Degradation

Operational Amplifiers and Comparators	
Parameter	Symbol
Offset Voltage	V_{OS}
Quiescent Current	$+I_S / -I_S$
Bias Currents	I_{b+} / I_{b-}
Open Loop Gain	A_{VO}
Common Mode Rejection Ratio	CMRR
Slew Rate	SR
Power Supply Rejection Ratio	PSRR
Output Voltage Swing	$+V_O / -V_O$
Short Circuit Current	I_{SC}

Voltage Regulator	
Parameter	Symbol
Output Voltage	V_O
Line Regulation	RegLine
Load Regulation	RegLoad
Quiescent Current	I_q
Drop Out Voltage	D_{OV}

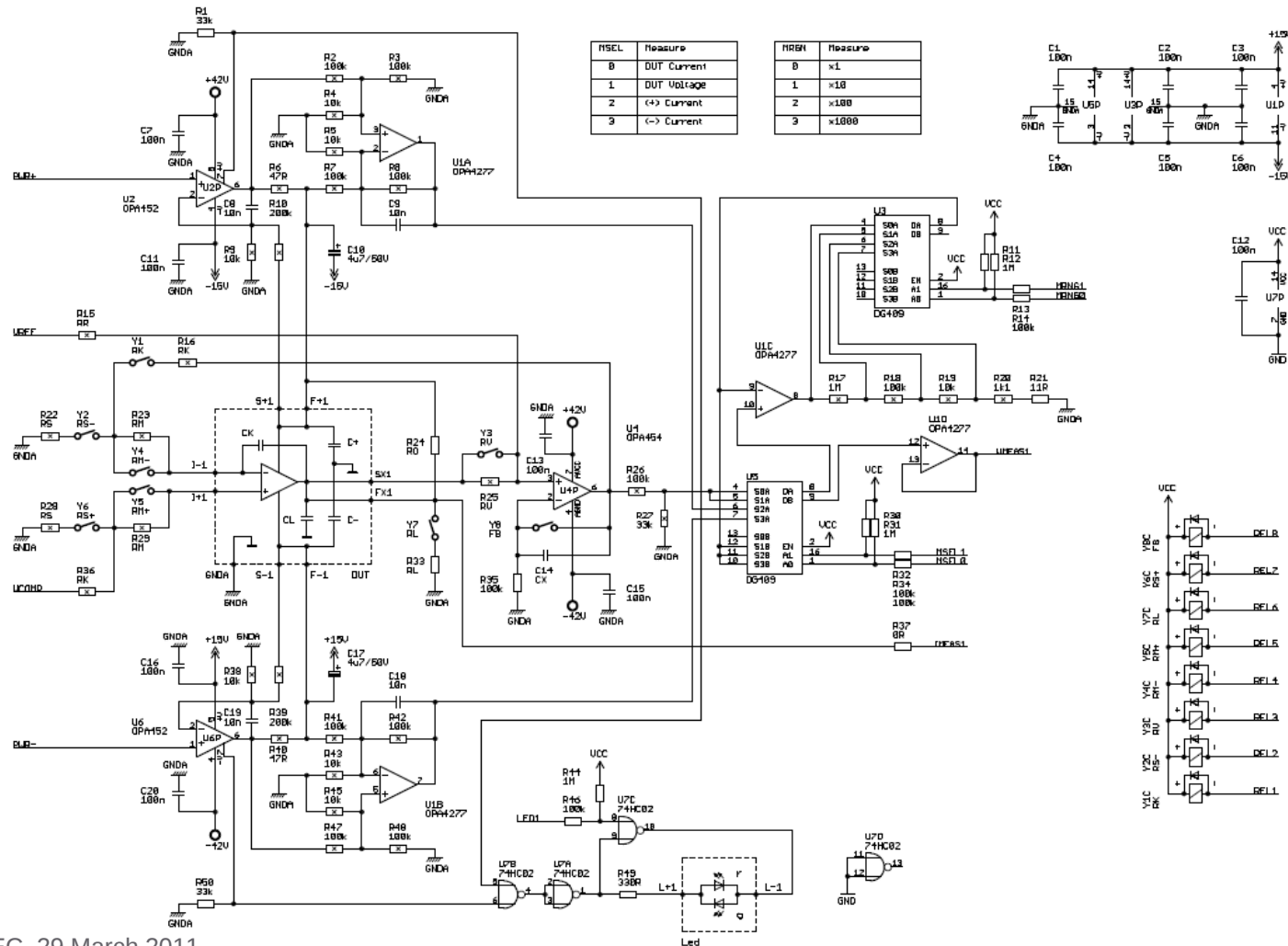
Voltage Reference	
Parameter	Symbol
Output Voltage	V_O

Example: Test Circuitry for Open-Loop-Gain, A_{VO}

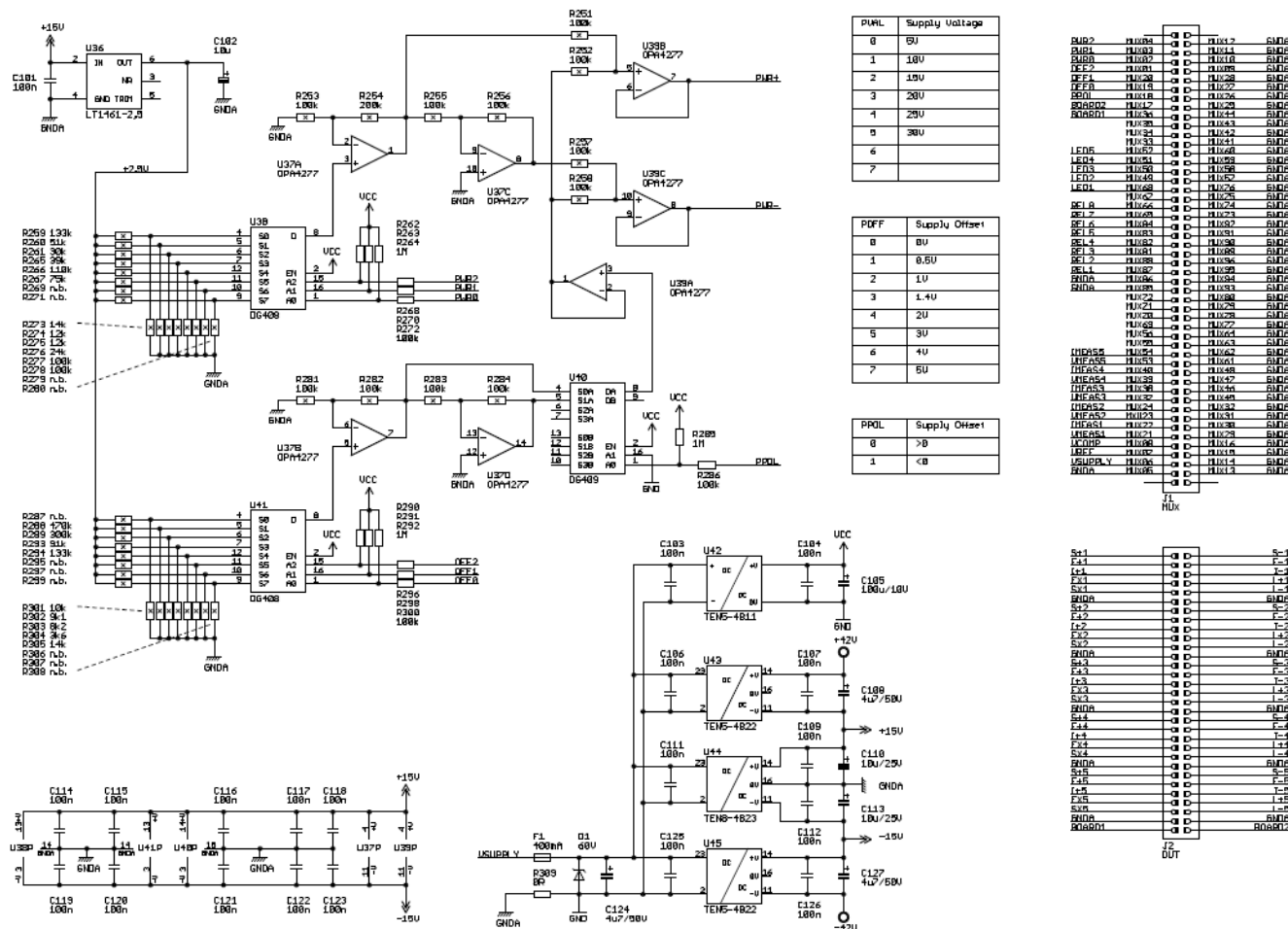


- DUT is operated in a feed back loop
- e.g. Measurement of Open Loop Gain
 - Certain Output Voltage is forced $\rightarrow \Delta V_{in}$ is measured
 - A_{VO} is determined

Test Circuitry for Test board - Part 1

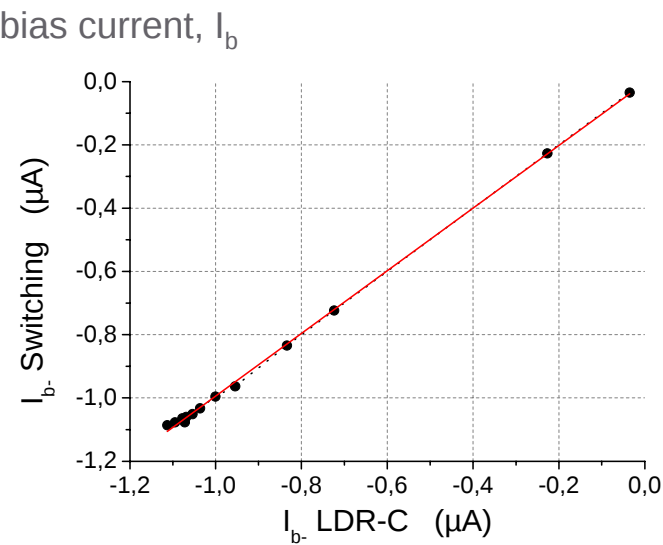
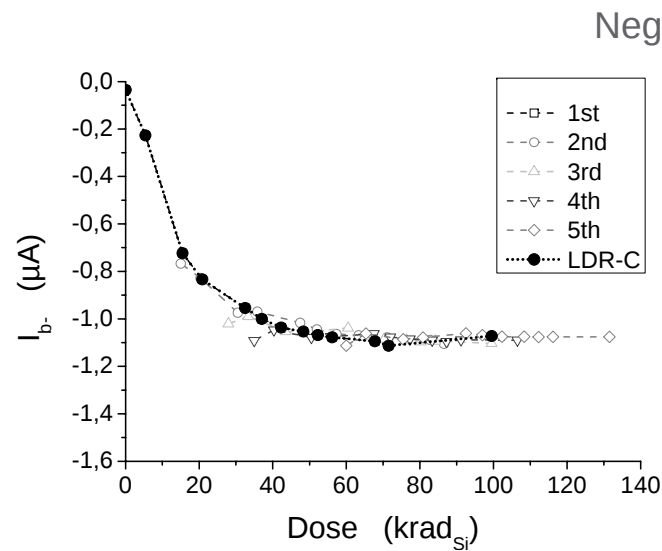
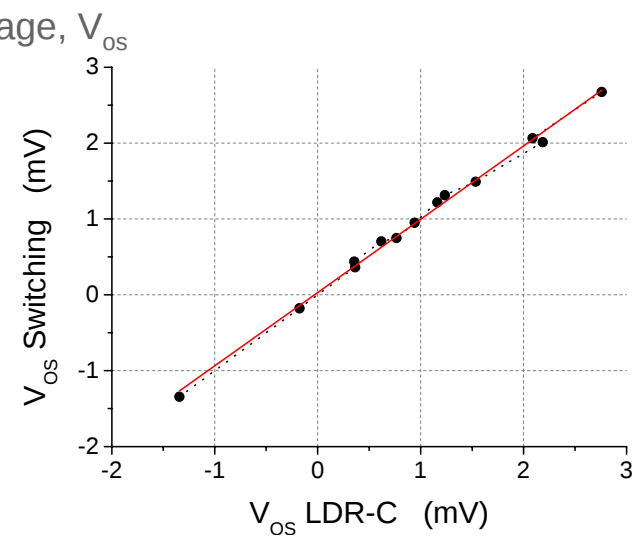
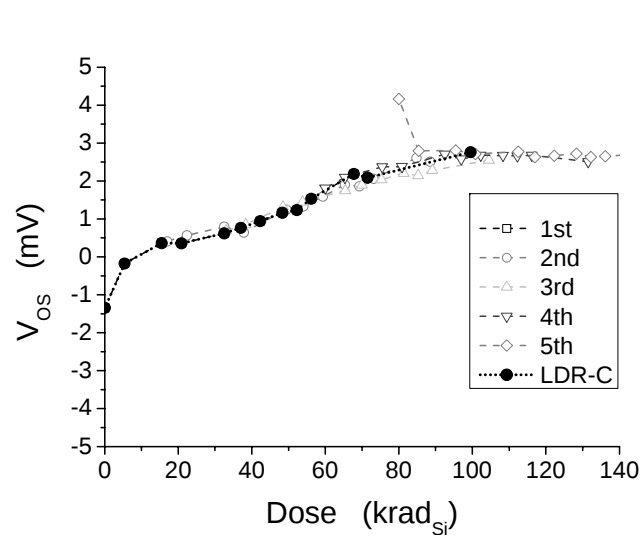


Test Circuitry for Test board – Part 2



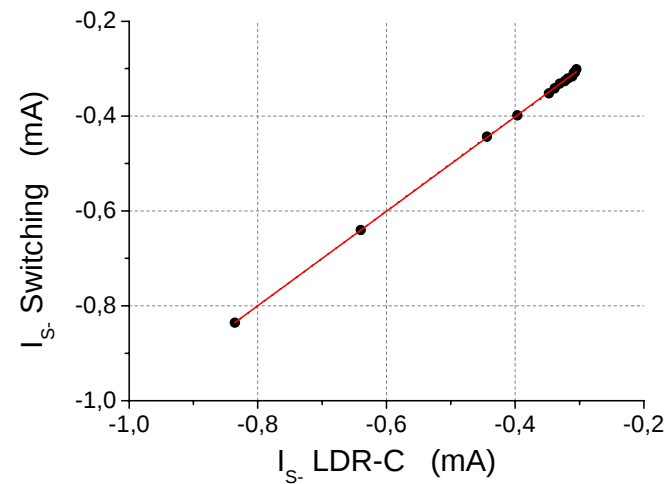
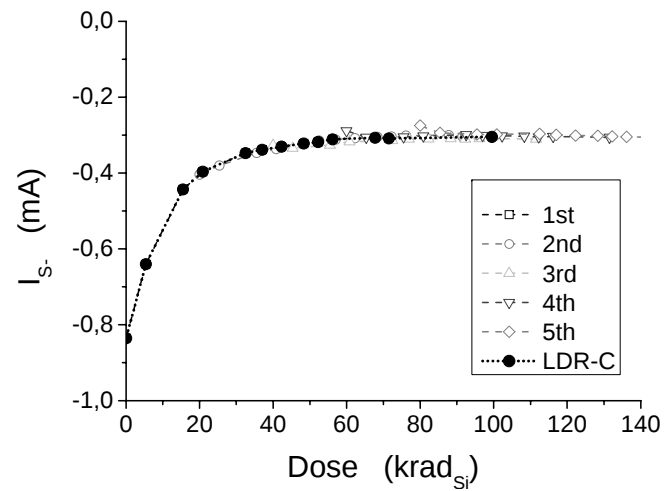
Preliminary Test Results

LM339AN: Unbiased

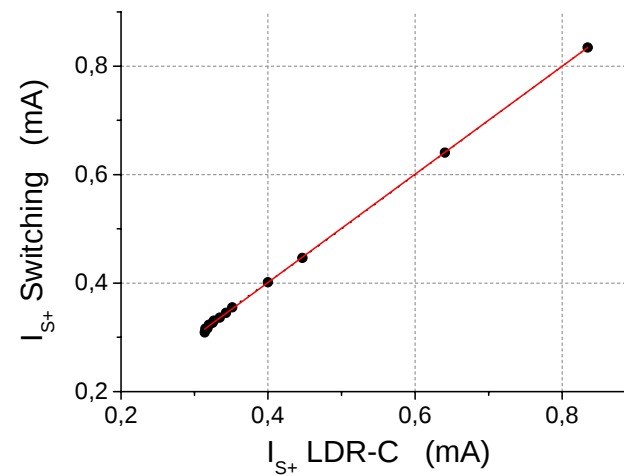
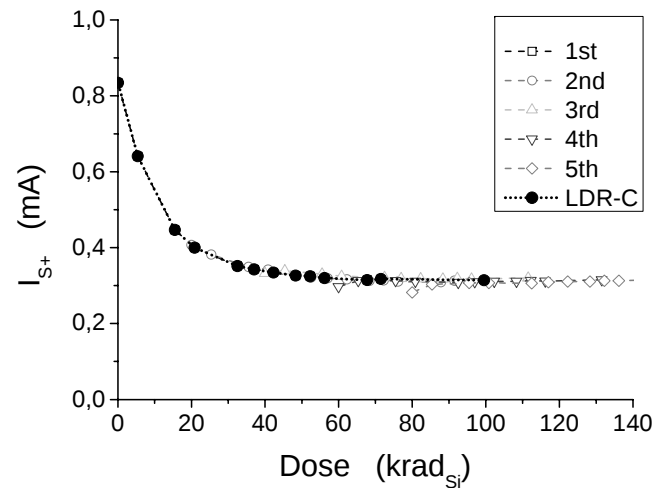


LM339AN: Unbiased

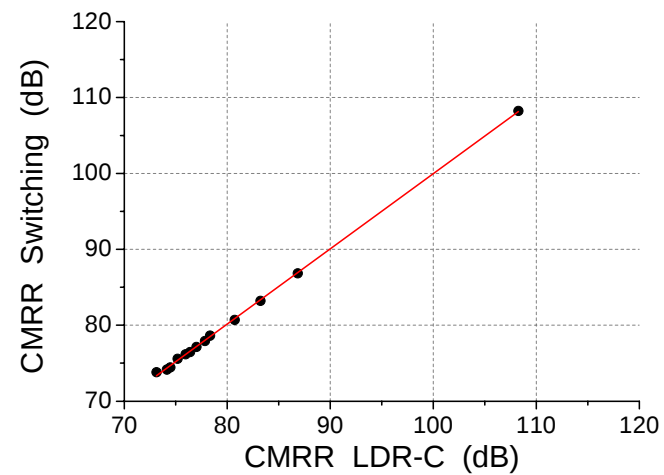
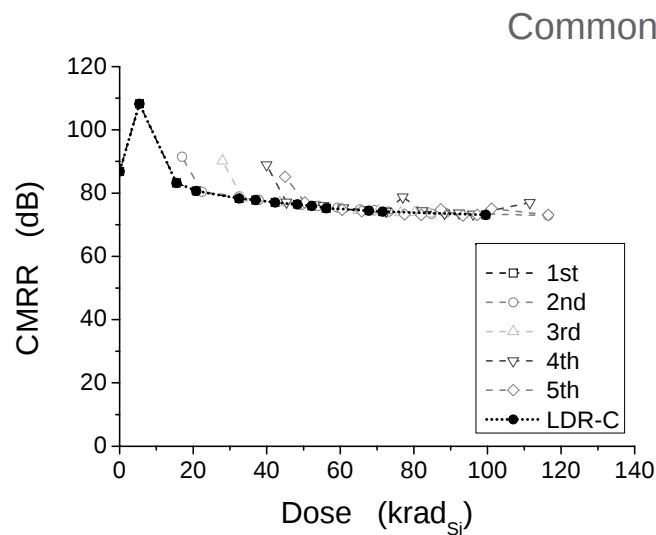
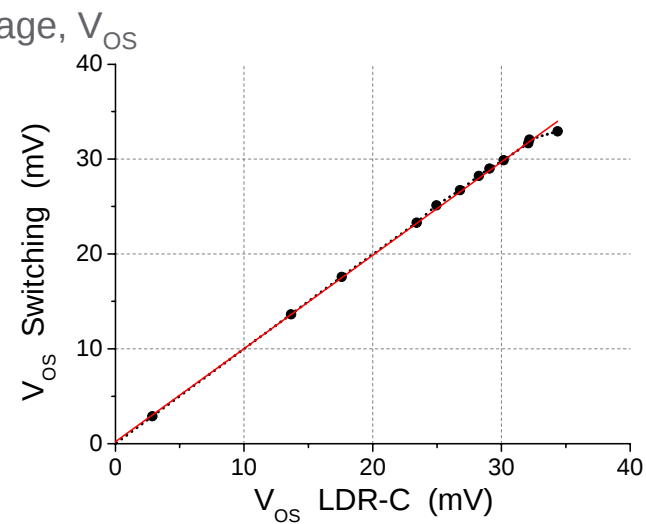
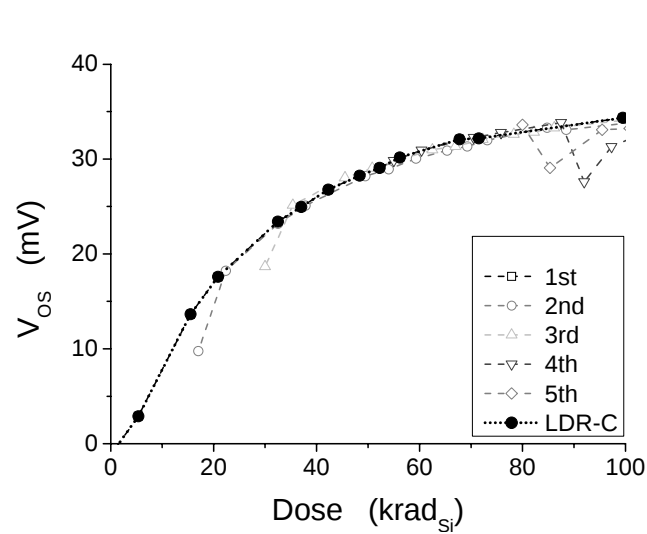
Negative Supply Current, I_{S-}



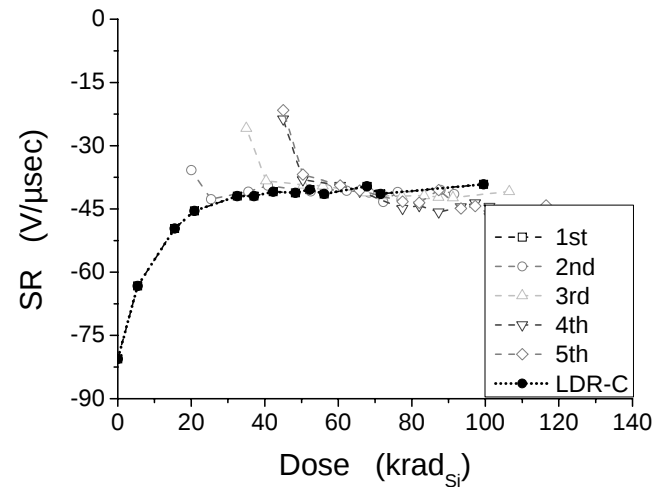
Positive Supply Current, I_{S+}



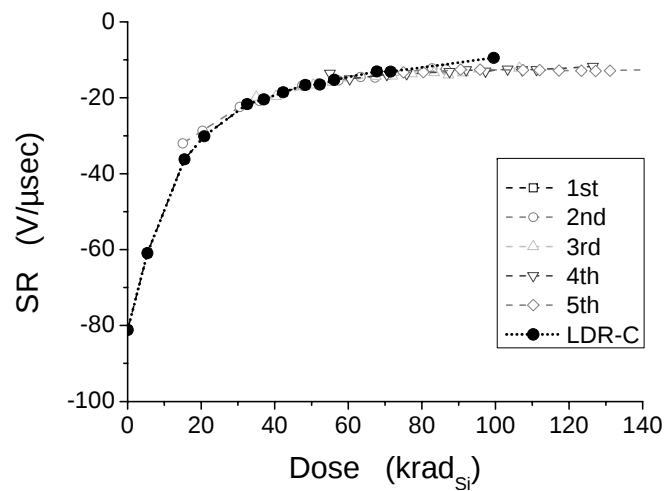
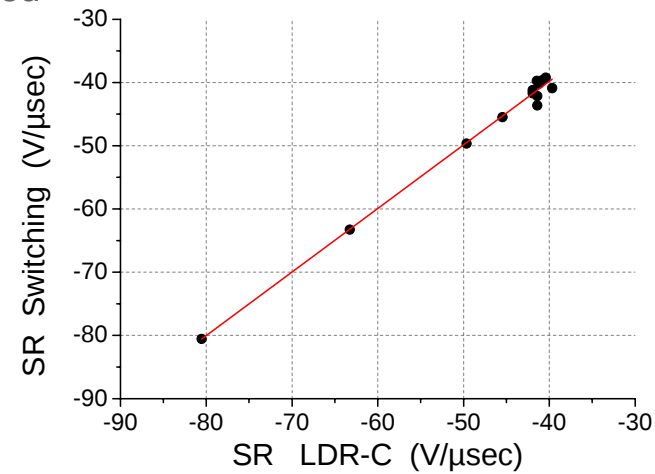
LM339AN: Biased



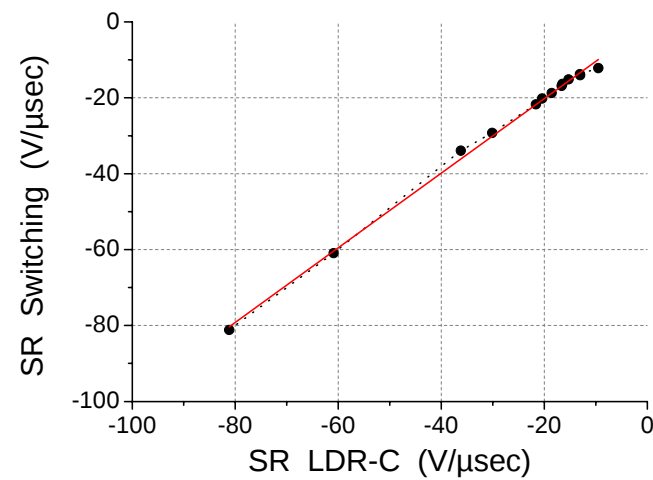
LM339AN: Slew Rate SR



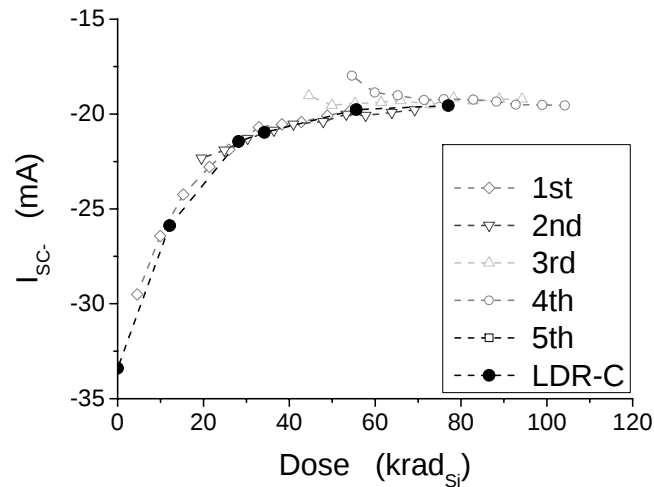
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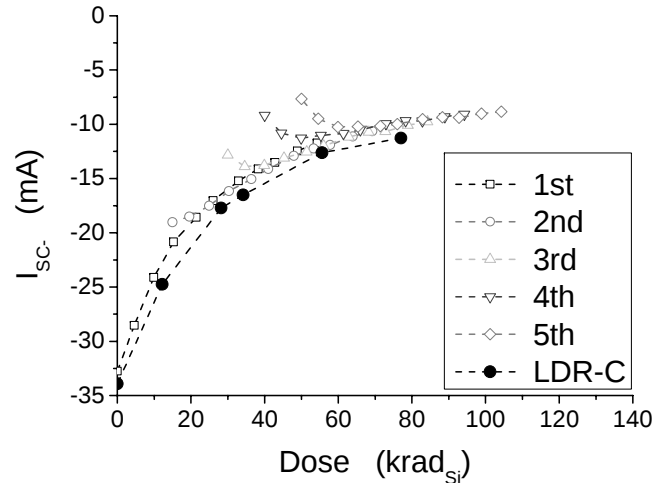
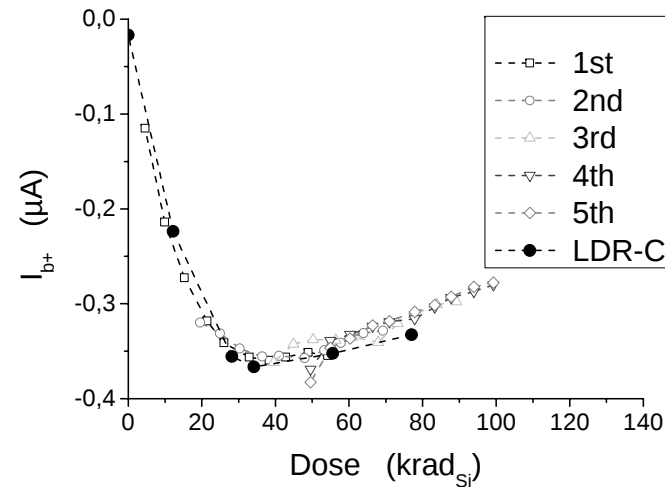
Unbiased



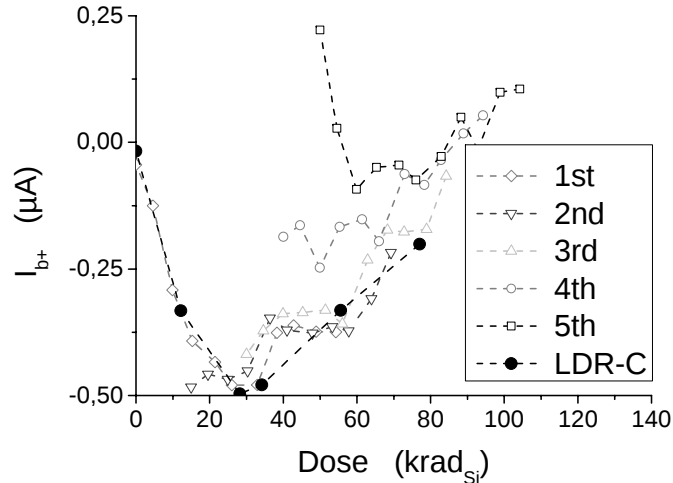
LM324AN: Short Circuit Current I_{SC-} , Positive Input Bias Current, I_{b+}



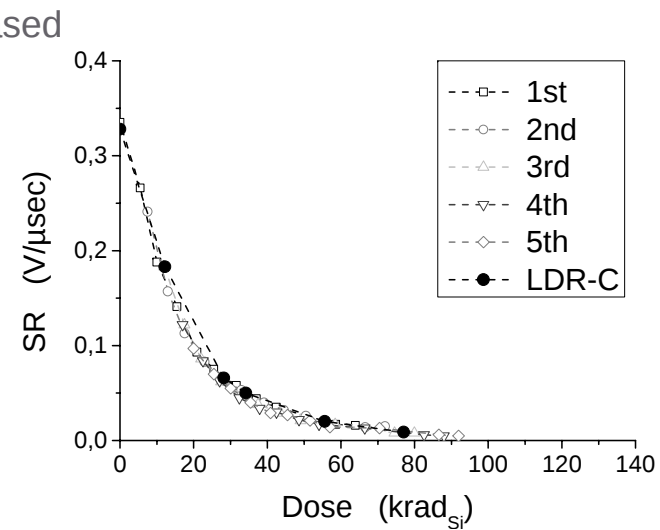
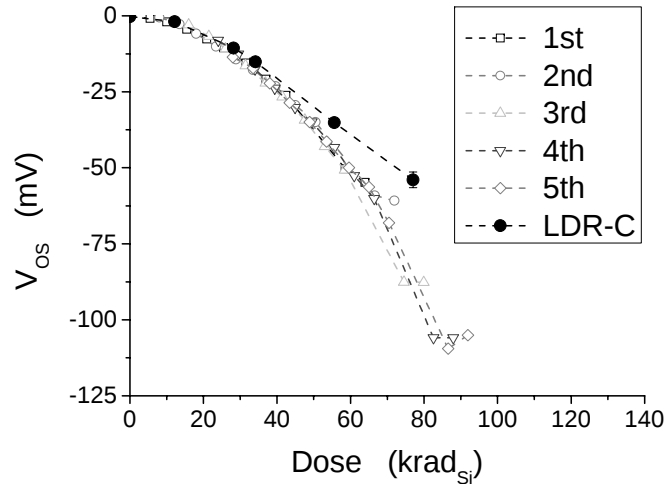
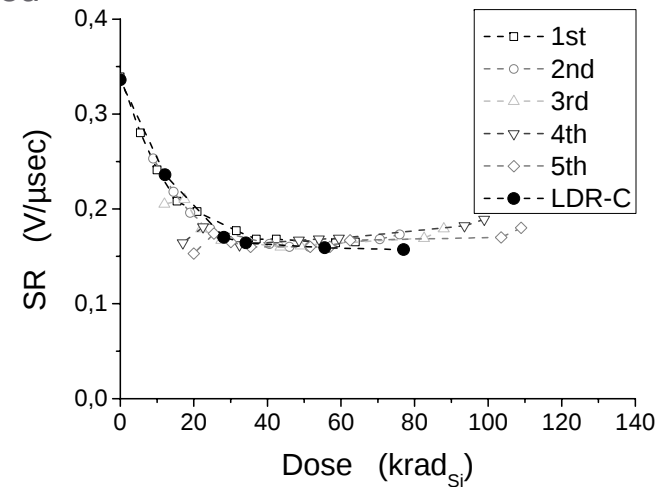
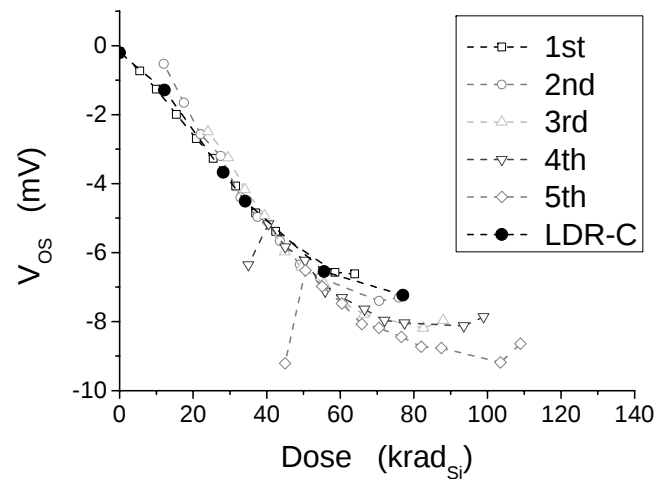
Biased



Unbiased

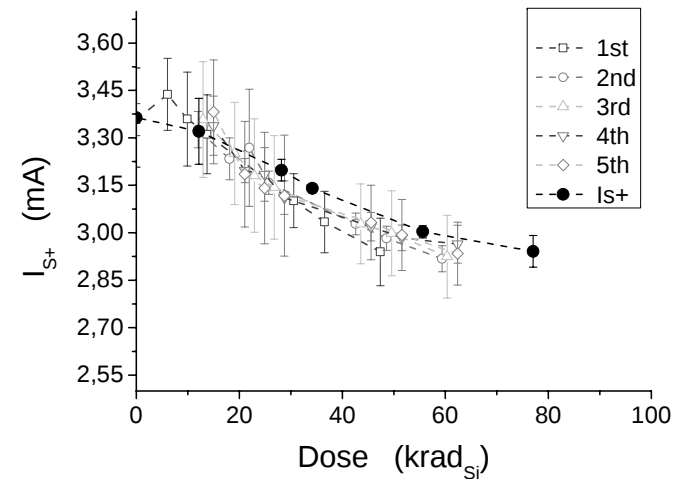
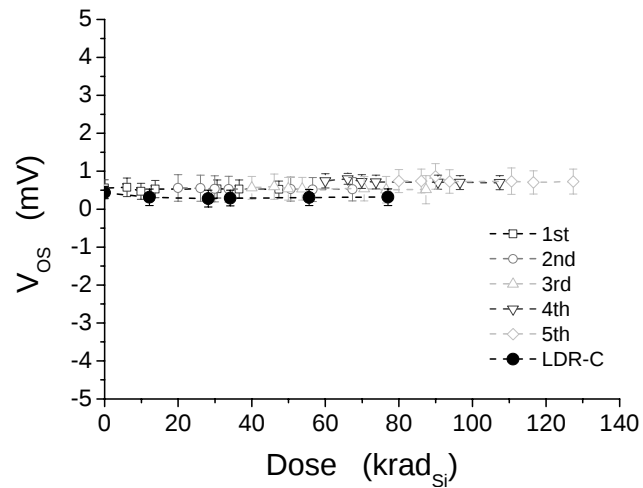


LM158AJ: Offset Voltage, V_{OS} , Slew Rate SR

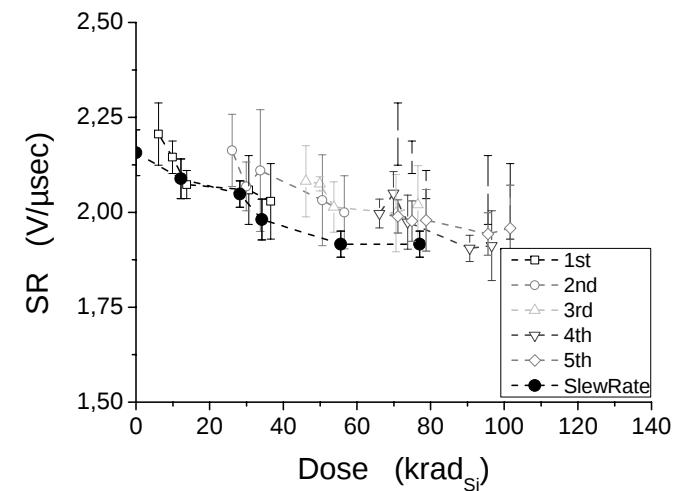
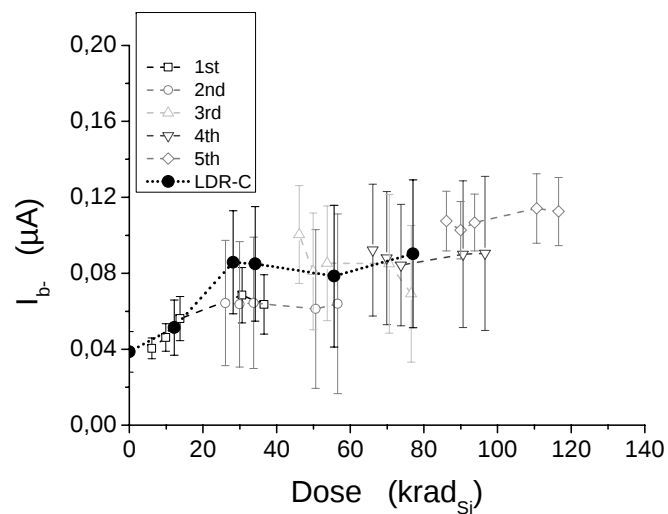


HS9-OP470ARH (radiation hard): V_{OS} , I_{b-} , I_{S+} , SR

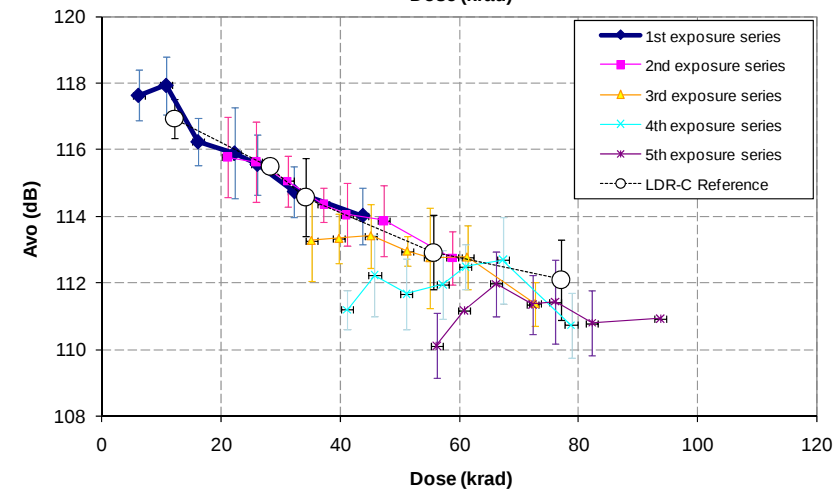
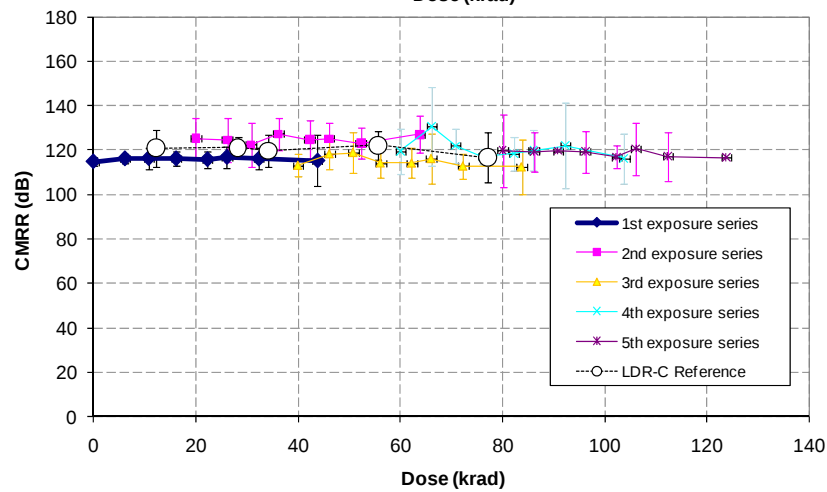
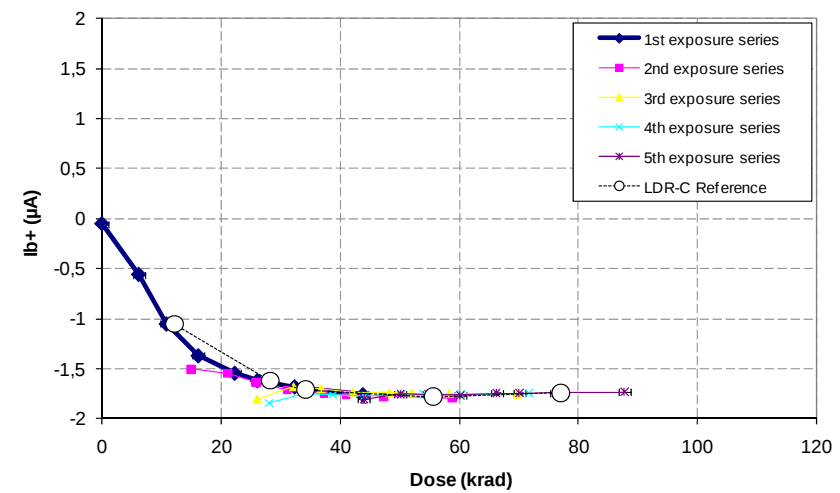
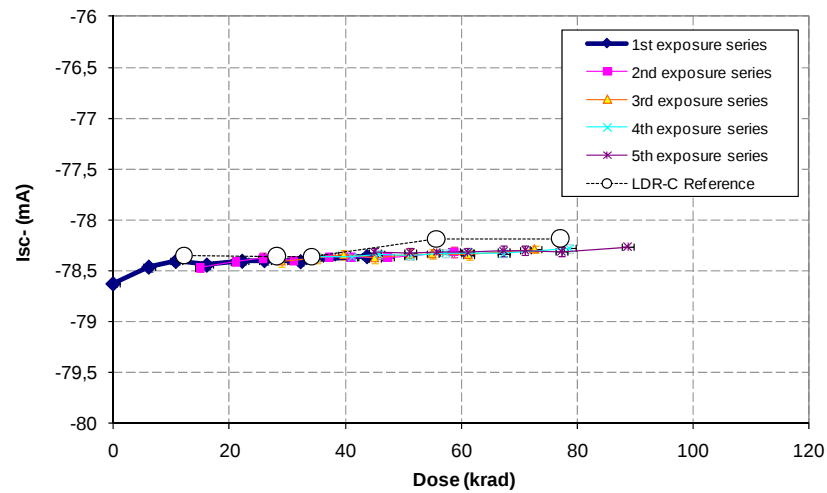
Biased



Unbiased

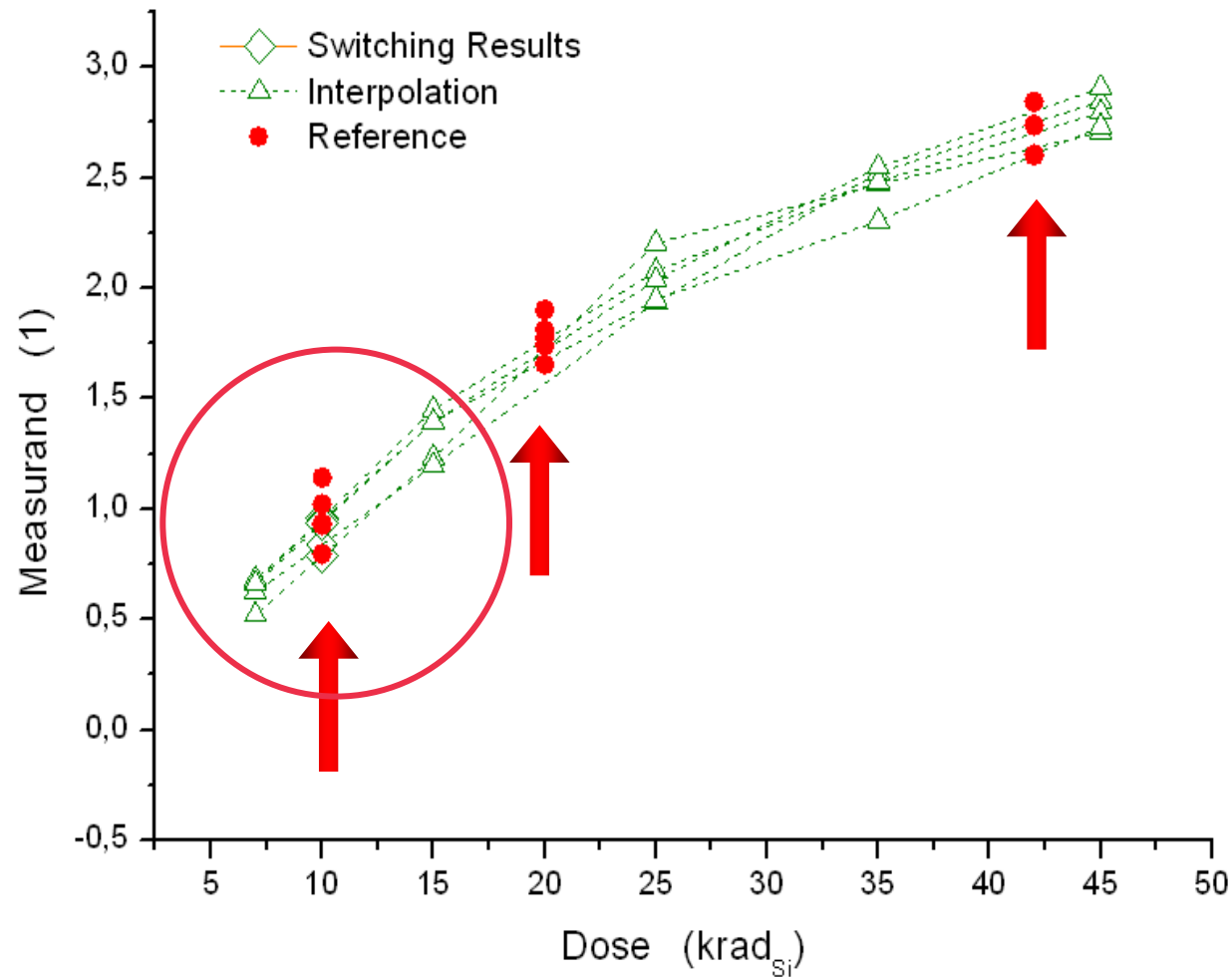


LM311N: Unbiased, I_{SC-} , I_{b+} , CMRR, A_{VO}

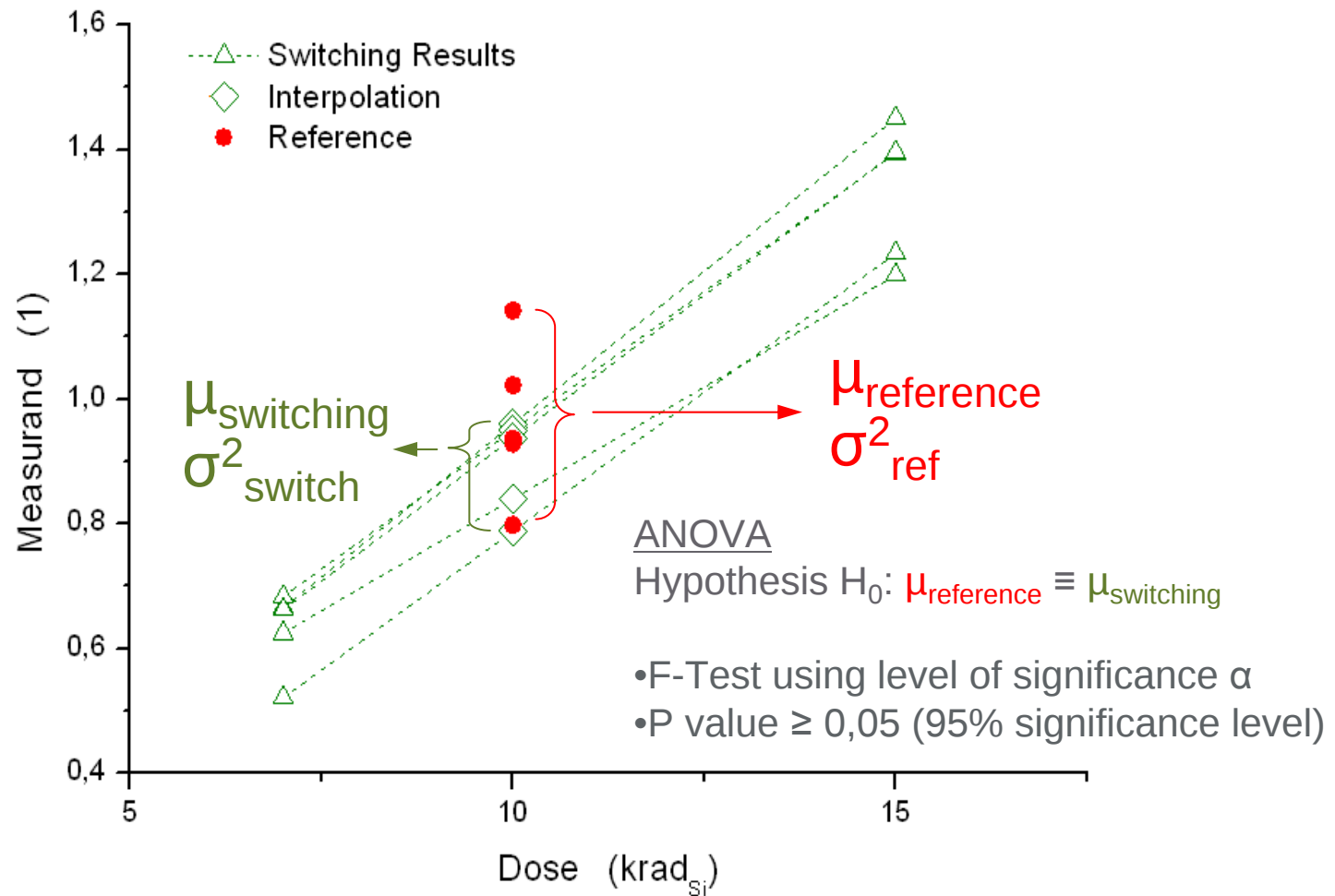


Statistical Analysis with ANOVA

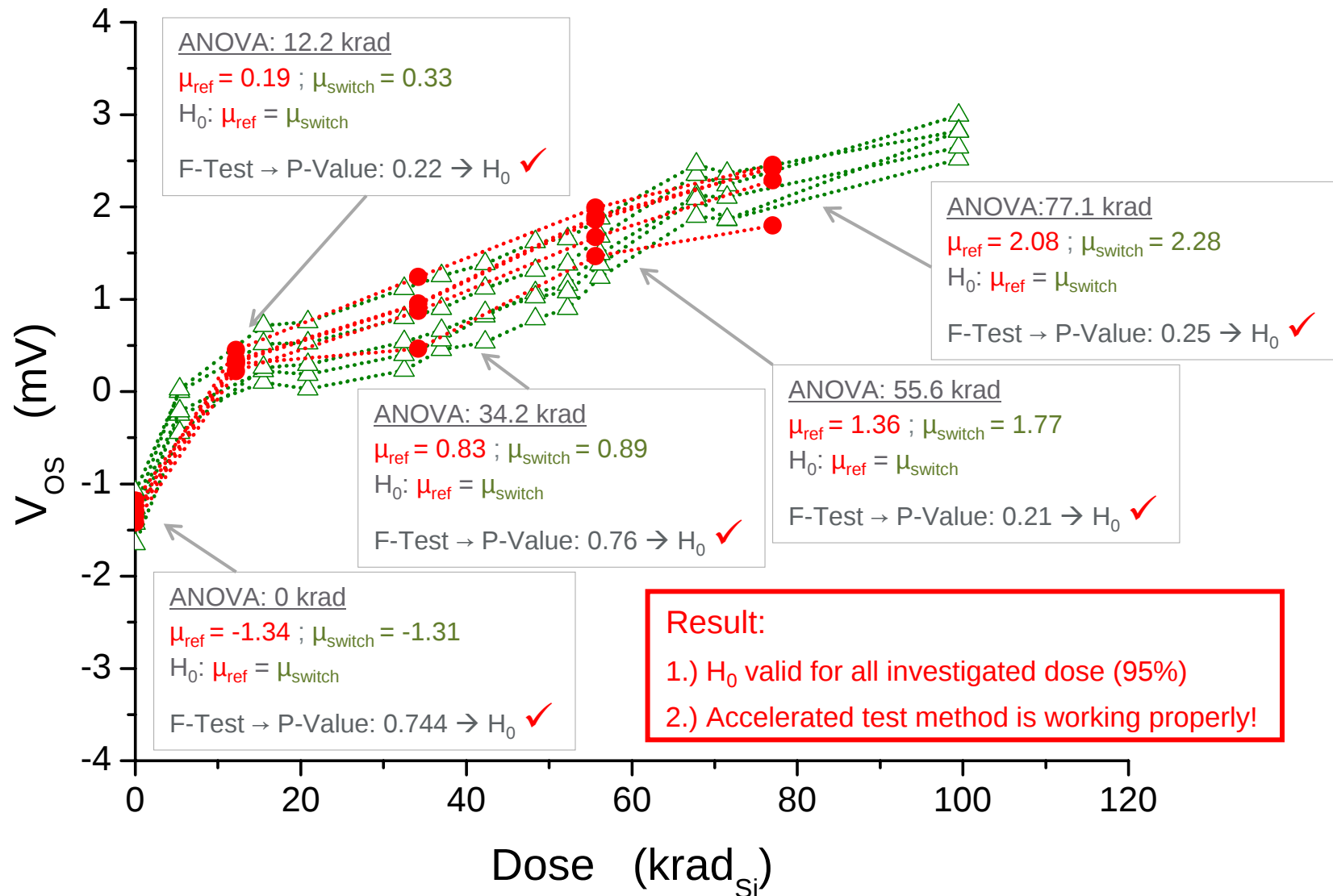
Statistical Analysis of Results



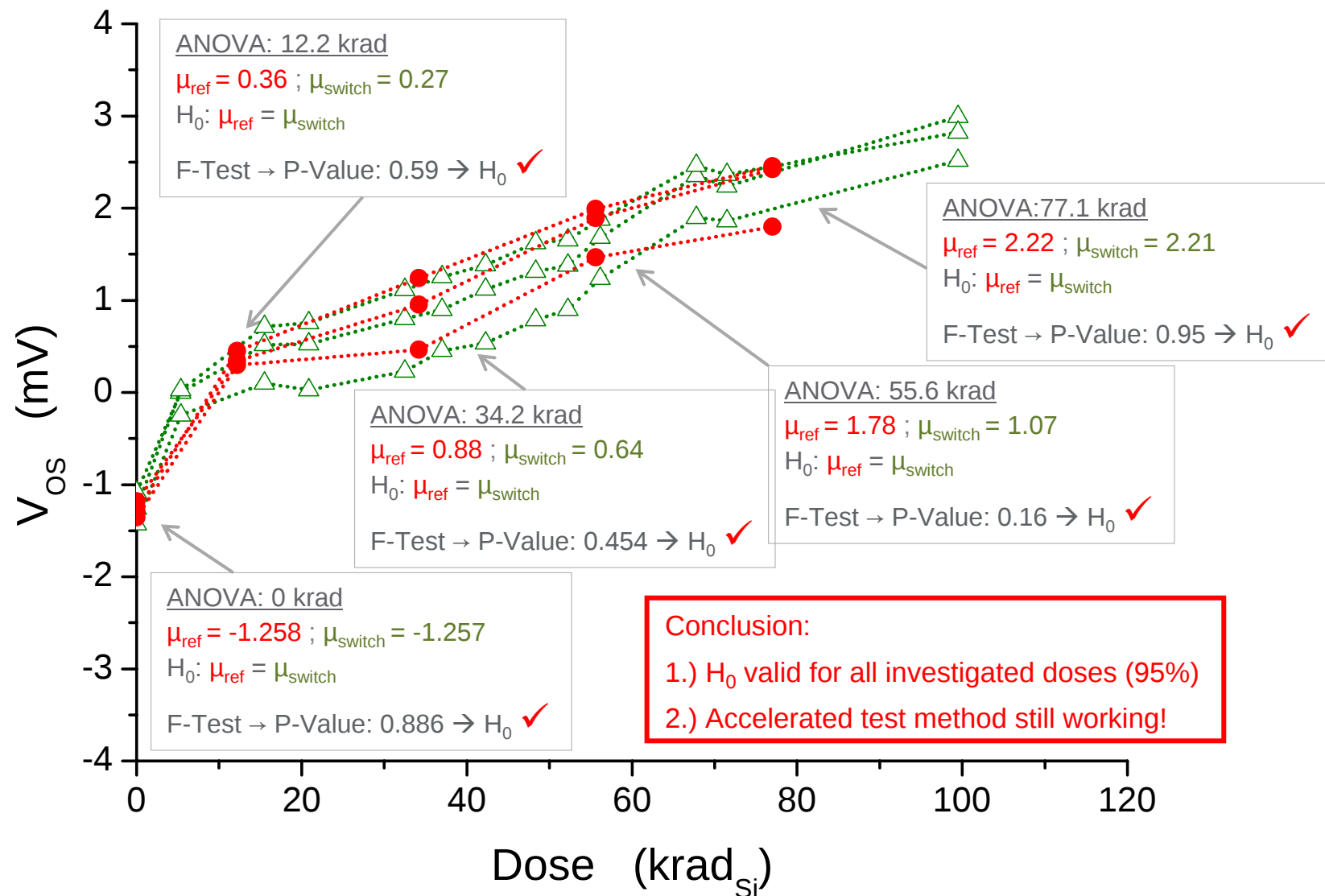
Statistical Analysis of Results



Example: Offset Voltage, V_{OS} for LM339AN



Reduction of Sample Size from 5 → 3



Conclusion and Outlook

- **10 different part types** selected for tests with **operational amplifiers, comparators, voltage regulator** and **voltage reference**
- **700 units** investigated on ELDRS for a wide range of parameters
- In general the **accelerated switching test method worked very well** for all degraded parameters for all part types
- The **variance of a parameter** might be a limiting quantity for the method
- Preliminary results for **LM324AN, LM339N, LM158AJ** indicate good comparison of **accelerated switching test method** with the **reference exposure**
- For **LM311N** the variance of the CMRR is larger than the degradation (**weak-degraded**)
- **HS9-OP470ARH** (radiation hard) show **weak-degraded** and **degraded parameters**
- For **weak-degraded** parameters further analysis is needed
- Statistical analysis with **ANOVA** looks promising
- ANOVA will be used to investigate **reduction of sample size**
- Continue and complete **irradiation measurements** and **data analysis**
- Project will be finished in **Summer 2011**

ELDRS Website: eldrs.net



The screenshot shows the ELDRS website interface. At the top, there is a blue header with the ELDRS logo. Below the header, the main content area is divided into three columns. The left column contains a 'Menu' with links to 'ELDRS project', 'Project overview', 'The ELDRS effects', 'Test method', 'Test procedures', 'Irradiated components', 'Test reports', 'Publications', 'Contacts & Links', and 'Restricted area'. The middle column features a large image of a satellite in space, with a green globe in the background. Below the image, the text reads 'ELDRS Project' and 'Traditionally, Total Ionising Dose (TID) characterisation of bipolar based EEE components is performed at high dose rates reducing test time at irradiation facilities and hence costs. The dose rates employed are usually significantly higher than those experienced by components in-flight. Over the last decade Enhanced Low Dose Rate Sensitivity (ELDRS) has been observed and reported in the literature and considered to be of serious concern, demonstrating the need for radiation testing performed at low dose rate. The ELDRS effect is manifested as increased component degradation with decreasing TID dose rate. ELDRS affects bipolar technologies. Today, ELDRS testing of components is comprised at low dose rates, representing a significant cost item and complicating project schedule depending on project TID requirements. This is in particular true for high TID level projects such as telecommunication and navigation. To address some of these issues a number of accelerated ELDRS test methods have been proposed. One of them, the so-called accelerated switching test method, is investigated within the scope of this project. This test method has been shown to reduce low dose rate testing time significantly for selected part types and electric parameters. Its general applicability on a comprehensive set of electric parameters will be investigated using a large set of different part types.' The right column contains 'Contact' information for 'Dr. Peter Beck' and 'Dr. Michael Wind', both from AIT Austrian Institute of Technology GmbH, Donau-City-Strasse 1 | 1220 Vienna | Austria. The footer of the website includes the text '© AIT Austrian Institute of Technology GmbH, 2010. All rights reserved. Imprint Disclaimer'.

Status: ELDRS Website – Irradiated Components



Irritated components

In total 10 different part types are tested to verify the switching selection are ELDRS sensitivity, availability of 70 units from 0 types selected are:

Operational Amplifiers:

- LM324
- LM158A
- HS-OP470 ARH
- OP470

Voltage Comparators:

- LM311
- LM339
- HS-139RH
- OP77

Voltage Regulator:

- LM317

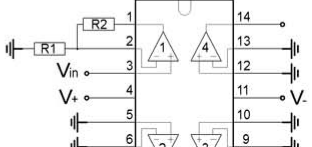
Voltage Reference:

- LM336-2.5

LM324

The LM124 (LM324) series consist of four independent, high compensated operational amplifiers which are designed to supply over a wide range of voltages. Operation from a split p and the low power supply current drain is independent of the voltage.

Pin out and electric configuration used for the biased irradiati



ELDRS
Enhanced Low Dose Rate Sensitivity

Low Dose Rate Test Report
Date: 14/03/2011
Page: 7/11
Issue: 1
Revision: 0




Figure 1: The set-up of the low dose rate experiment. Radiography camera and irradiation boxes housing the irradiation boards are mounted on an Aluminum frame that is positioned inside the heavy shielded box.

Figure 2: Irradiation box; the PCB, the PMMA build-up plate and the leads for positive and negative power supply as well as the lead for ground potential are all mounted inside the box. Only one plug is lead to the 'outside'.

6 Test Results

The measurement results of the LM324AN irradiations exposing the DUTs in biased configuration are presented in the following. The parameter degradation as a function of total dose is presented in Figure 3 to Figure 11 for the biased configuration and in Figure 12 to Figure 20 for the unbiased configuration. The data points presented in the figures are calculated as the mean value of the measured data of five units treated identically. Uncertainty bars are included in the figures as well; they are calculated as the standard deviation of the result of the five samples. In case the uncertainty bars cannot be seen they are smaller than the data points.

Biased Results:

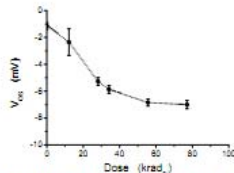
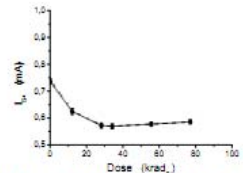



Figure 3: Degradation of the offset Voltage V_{os} of the LM324AN microcircuit exposed in biased configuration; low dose rate response.

Figure 4: Degradation of the positive supply current I_{q+} of the LM324AN microcircuit exposed in biased configuration; low dose rate response.

References

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- J. Boch, F. Saigné, R.D. Schrimpf, J.-R. Vaillé, L. Dusseau, S. Ducret, M. Bernard, E. Lorfèvre, and C. Chatry, *Estimation of Low-Dose-Rate Degradation on Bipolar Linear Integrated Circuits Using Switching Experiments*, IEEE-TNS, vol. 52 (6), p. 2616, December 2005
- J. Boch, Y. Gonzalez Velo, F. Saigné, N. J-H. Roche, R.D. Schrimpf, J.-R. Vaillé, L. Dusseau, C. Chatry, E. Lorfèvre, R. Ecoffet, A.D. Touboul, *The use of a Dose-Rate Switching Technique to Characterize Bipolar Devices*, IEEE-TNS, vol. 56 (6), p. 3347, December 2009
- L. Dusseau, M. Bernard, J. Boch, Y. Gonzalez velo, N. Roche, E. Lorfèvre, F. Bezerra, P. Calvel, R. Marec, F. Saigné, *Review and Analysis of the Radiation-Induced Degradation Observed for the Input Bias Current of Linear Integrated Circuits*, IEEE-TNS, vol. 55 (6), p.3174, December 2008

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- The support by **National Semiconductor** (Kirby Kruckmeyer)and **Intersil** (Nick van Vonno) with part types for testing is acknowledged!
- The support by **Tyndall** (Aleksander Jaksic) with RADFETS for reference measurements is acknowledged!
- The project is contracted by the **European Space Agency (ESA)** under Contract No. 22051/NL/PA (GSTP) and supported by the **Austrian Federal Ministry for Transport, Innovation and Technology**. National coordination is done by the **Austrian Promotion Agency FFG**.

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ELDRS

ELDRS Project

Menu

- ELDRS project
- Project overview
- The ELDRS effects
- Test method
- Test procedures
- Irradiated components
- Test reports
- Publications
- Contacts & Links
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ELDRS Project

Traditionally, Total Ionising Dose (TID) characterisation of bipolar based EEE components is performed at high dose rates reducing test time at irradiation facilities and hence costs. The dose rates employed are usually significantly higher than those experienced by components in-flight. Over the last decade Enhanced Low Dose Rate Sensitivity (ELDRS) has been observed and reported in the literature and considered to be of serious concern, demonstrating the need for radiation testing performed at low dose rate. The ELDRS effect is manifested as increased component degradation with decreasing TID dose rate. ELDRS affects bipolar technologies.

Today, ELDRS testing of components is comprised at low dose rates, representing a significant cost item and complicating project schedule depending on project TID requirements. This is in particular true for high TID level projects such as telecommunication and navigation. To address some of these issues a number of accelerated ELDRS test methods have been proposed. One of them, the so-called accelerated switching test method, is investigated within the scope of this project. This test method has been shown to reduce low dose rate testing time significantly for selected part types and electric parameters. Its general applicability on a comprehensive set of electric parameters will be investigated using a large set of different part types.

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