Verification of Enhanced Low Dose Rate Sensitivity (ELDRS) Accelerated Test Method

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Abstract
Low dose rate testing was performed at AIT using the accelerated switching test method developed at Université de Montpellier 2. Experiments were aiming at trying to validate the accelerated low dose rate test method for the selected parts.

Introduction
The enhanced degradation exhibited at low dose rates by many bipolar technology components is a major reliability issue for spacecraft electronics. As an accelerated ELDRS test method, an approach has been suggested that makes use of sequenced high dose rate and low dose rate exposures, the so called accelerated switching test method, developed at the University of Montpellier II [1] - [5]. It is based on the important observation that the degradation rate of device parameters after a high dose rate exposure is equal to the degradation rate recorded at low dose rate, independent at what total dose level the dose rate is switched from high to low. The dose level at which the dose rate is switched is called dose switch. Thus a high dose rate step can be used to reach a certain degradation level. With a subsequent low dose rate exposure the characteristics of the low dose rate degradation from this degradation level on can be measured. However, a shift in the (low dose rate) degradation curve is observed. This shift may be assigned to degrading species (holes and protons) that are not contributing to the degradation process during the high dose rate exposure. It is assumed, that these species are lost after the high dose rate exposure and do not affect the subsequent low dose rate irradiation. Consequently, the high dose rate degradation curve has no effect on the shape of the following low-dose-rate degradation curve [1], [2]. By using multiple switches several points on the low dose rate degradation curve can be reached. Thus it is possible to measure several segments of the low dose rate characteristics in parallel which in turn leads to a significant reduction of testing time. Finally, a prediction curve of the low dose rate degradation characteristic is constructed from the various measured segments by shifting them to the left (in terms of total dose) until an overlap of the segments is achieved (for details see [4] and Fig. 1).

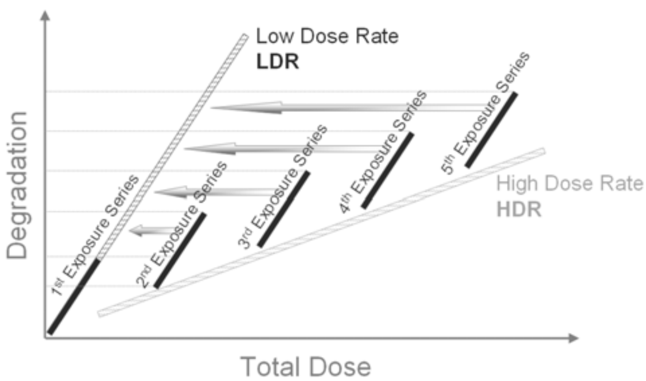


Figure. 1. schematic illustration of the switching test method to predict LDR degradation of bipolar devices. The five dark lines (denoted with 1st to 5th exposure series) correspond to data obtained from LDR measurements performed at the same time. The 1st exposure series is irradiated without a dose switch, all other using a dose switch. LDR prediction curves are obtained by shifting the data of the 2nd to 5th exposure series until an overlap is achieved (Figure is taken from [4]).

In this paper we will report on the results of an extensive study [6] that investigates the applicability of this test method to several linear integrated circuits.

Objectives of the study

The main objective of the study is to validate the applicability of the accelerated switching test method by applying it to characterize the low dose rate degradation of an extensive set of parameters of many bipolar microcircuits.

Method

The structure of the workflow is presented in Figure 2. At first all units that are used for the experiments are electrically characterized and faulty parts are rejected. The low dose rate degradation is determined with the switching test method and in addition with a reference measurement. The switching test method makes use of combining exposures at high dose rate (HDR-S) and low dose rate (LDR-S) and a subsequent data analysis to determine the estimate for the low dose rate degradation. The reference measurement makes use of a single low dose rate exposure (LDR-C) that serves to validate the results of the switching test method. Nine microcircuits are selected for testing: five operational amplifiers, three comparators, and a voltage reference (see Table 1). The electrical parameters that are selected for validating the accelerated switching test method with operational amplifiers and comparators are the offset voltage (VOS), the positive and negative supply currents (IS+ and IS-), the bias currents (Ib, Ib+, Ib-, and IOS), the open loop gain (AVO), the common mode rejection ratio (CMRR), the positive and negative power supply rejection ratio (PSRR and PSRR-), the positive and negative output voltage swing (V0+ and V0-), the positive and negative short circuit current (ISC+ and ISC-), and the slew rate (SR). The parameter selected for validating the accelerated switching test method with the voltage reference is the output voltage (VOUT).

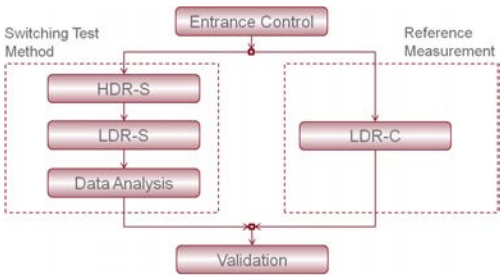


Figure 2: Workflow to verify the applicability of the accelerated switching test method.

Table 1: Microcircuits selected for testing.

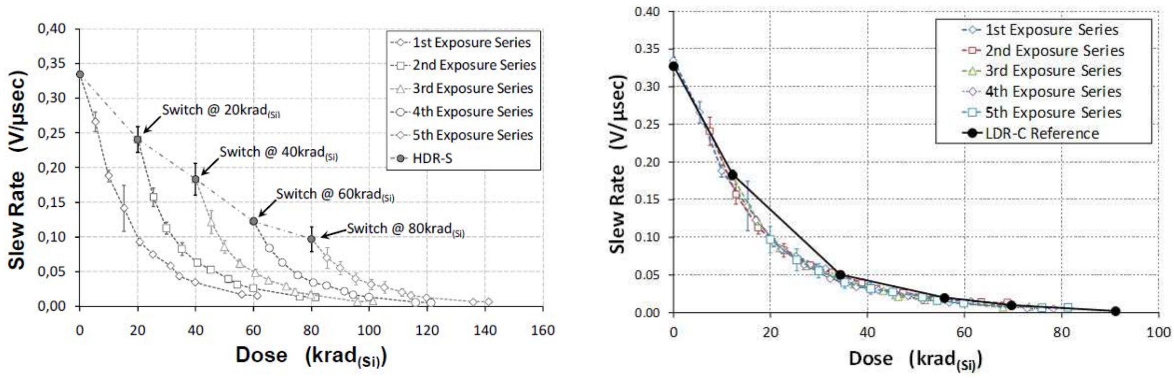
Microcircuit	Description	LOT #
LM324AN	Operational Amplifier	CZ8P1667D019
LM158AJ	Operational Amplifier	C6X405476
LM339AN	Comparator	EM8V3371G019
LM311N	Comparator	EM8V7541K019
HS-OP470ARH	Operational Amplifier	DCEVVJA
HS9-139RH	Comparator	DTCJCDD
OP470	Operational Amplifier	E163778.3 (biased units) E165098.3 (unbiased units)
OP177GS	Operational Amplifier	AE37195.17
LM336-2.5	Voltage Reference	CZAT2047E019

Tests are conducted in biased and unbiased configuration. In the unbiased configuration all terminals of the microcircuits are held at ground potential. When exposing the microcircuits in biased condition the devices are driven in a typical operational condition. Operational amplifiers are biased in a non inverting DC gain configuration, comparators are exposed in a basic comparator configuration, and the voltage reference is operated as a 2.5 V Zener diode. The switching experiment makes use of four dose switches that are set at 20 krad(Si), 40 krad(Si), 60 krad(Si), and 80 krad(Si). For the experiments the exposed units are grouped in so-called exposure series that are composed of five units each (also denoted as “sample size: 5”). All the units of one exposure series are treated identically. Sample size 5 is used to assure a good statistics of the test results. The 1st exposure series is only exposed at LDR-S, the 2nd to 5^{th} exposure series are exposed at HDR-S. Hereby the 2nd exposure series is irradiated to a dose level of 20 krad(Si), the 3rd to a dose level of 40 krad(Si), the 4th to a dose level of 60 krad(Si), and the 5th to a dose level of 80 krad(Si). Subsequent to the HDR-S all exposure series are exposed at LDR-S (for details of the switching test method see [1] - [5]). The exposure is performed according to ESCC specification No. 22900 [8] at a dose rate of approximately 1.2 rad(Si)/s, the low dose rate exposure LDR-S is performed at 10 mrad(Si)/s. The radiation source is 60Co gamma point source. To ensure charged particle equilibrium at the position of the DUTs during exposure a build up plate is used that is made from PMMA with a thickness of 3 mm.

Results

The low dose rate degradation of 256 parameters – exposure of nine microcircuits exposed in two biasing conditions – are characterized using the switching test method. From the comparison of switching data with reference data it can be seen for each individual parameter of every microcircuit whether the accelerated switching test method can be applied or not. Figures 3(a) and 3(b) show for the slew rate of the LM158AJ how the data from the various exposure series are shifted to the left (in terms of total dose) until an overlap is achieved. The reference measurement obtained from continuous low dose rate data (LDR-C) is shown as well.

In the following figures, the analysed data is superimposed with the results of the reference measurements denoted in the graphs as LDR-C Reference (black symbols).



(a) (b)

Figure 3: Results of the experimental method to determine the low-dose-rate degradation curve of the LM158AJ microcircuit's slew rate. (a) degradation derived from the HDR-S / LRD-S measurements of all five exposure series using dose switches at 20, 40, 60 and 80 krad(Si). (b) The low dose rate prediction curve with superimposed the LDR-C reference curve.

Fig. 4 and Fig. 5 present four prediction curves of the low-dose- rate degradation for the LM158AJ microcircuit when exposed in biased and unbiased configuration, respectively. Prediction curves are presented for the parameters: positive supply current (IS+), the input bias current at the non-inverting input (Ib-), the open loop gain (AVO), and the common mode rejection ratio (CMRR).

Fig. 6 and Fig. 7 present four prediction curves for the low-dose-rate degradation for the LM339AN microcircuit when exposed in biased and unbiased configuration, respectively. Prediction curves are presented for the parameters: positive supply current (IS+), the input bias current at the inverting input (Ib-), the negative short circuit current (ISC-), and the slew rate (SR).

In all the presented cases, the low dose rate prediction curves generated by switching test method are in good agreement with the LDR-C reference measurement even for devices that are designed to be radiation hard.

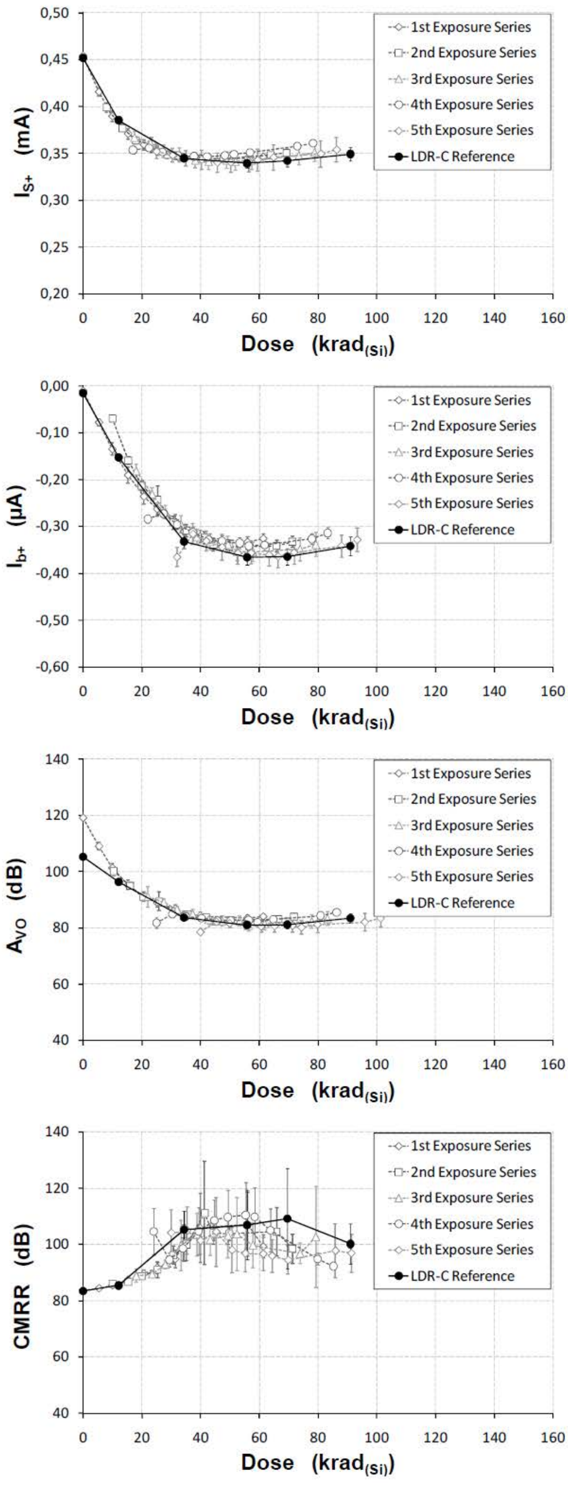


Figure 4: Results obtained with the switching test method to determine the low-dose-rate degradation curves of the LM158AJ microcircuit when exposed in biased configuration. Presented are the low-dose-rate prediction curves of four parameters (hollow symbols) with superimposed the LDR-C reference curves (full symbols). (Figure from [6])

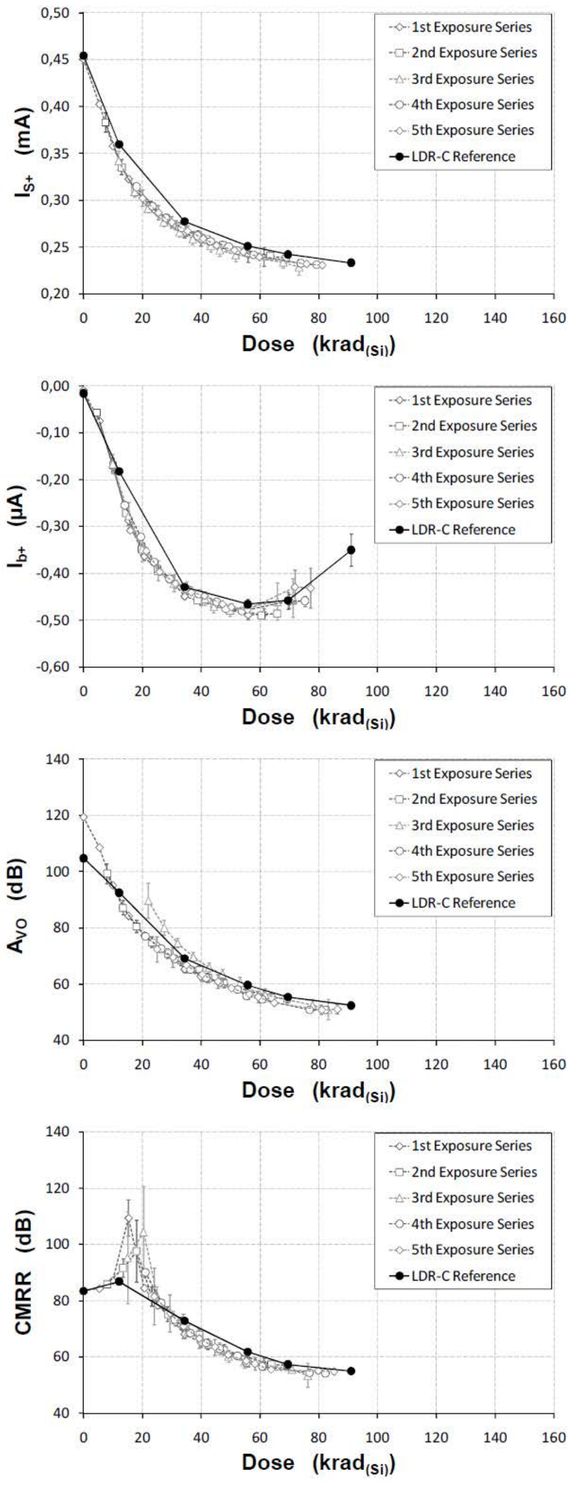


Figure 5: Results obtained with the switching test method to determine the low-dose-rate degradation curves of the LM158AJ microcircuit when exposed in unbiased configuration. Presented are the low dose rate prediction curves of four parameters (hollow symbols) with superimposed the LDR-C reference curves (full symbols). (Figure from [6])

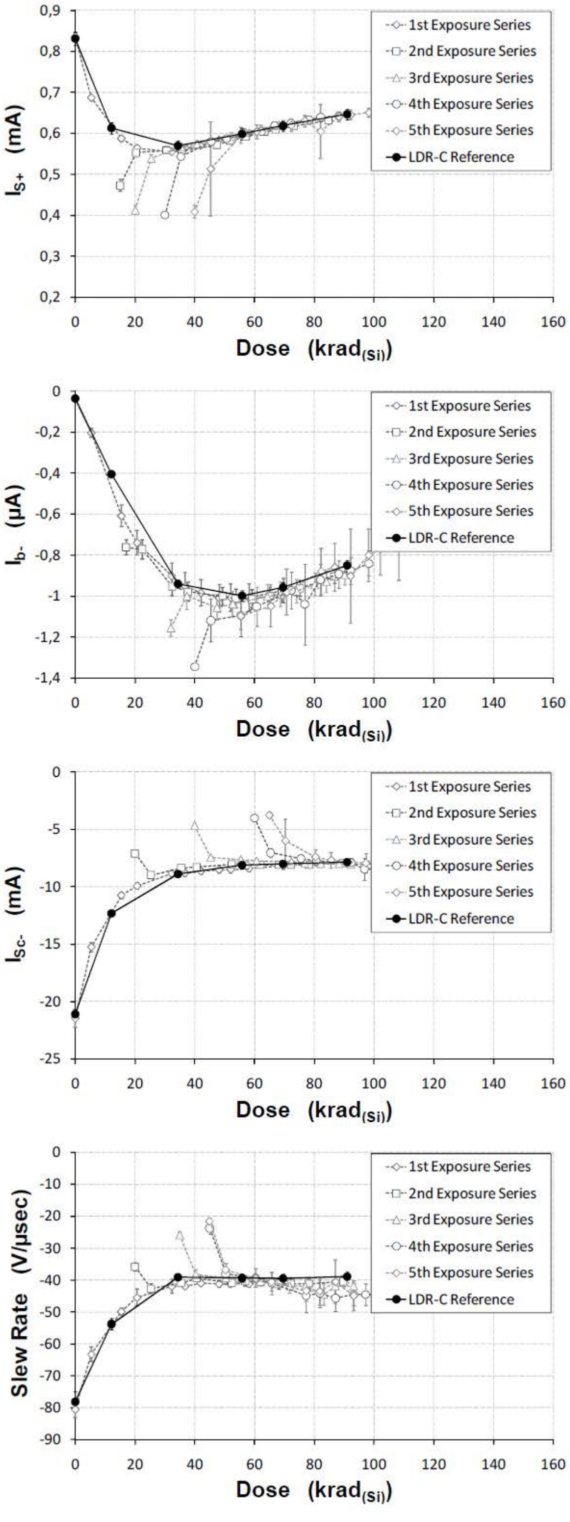


Figure 6: Results obtained with the switching test method to determine the low-dose-rate degradation curves of the LM339AN microcircuit when exposed in biased configuration. Presented are the low-dose-rate prediction curves of four parameters (hollow symbols) with superimposed the LDR-C reference curves (full symbols). (Figure from [6])

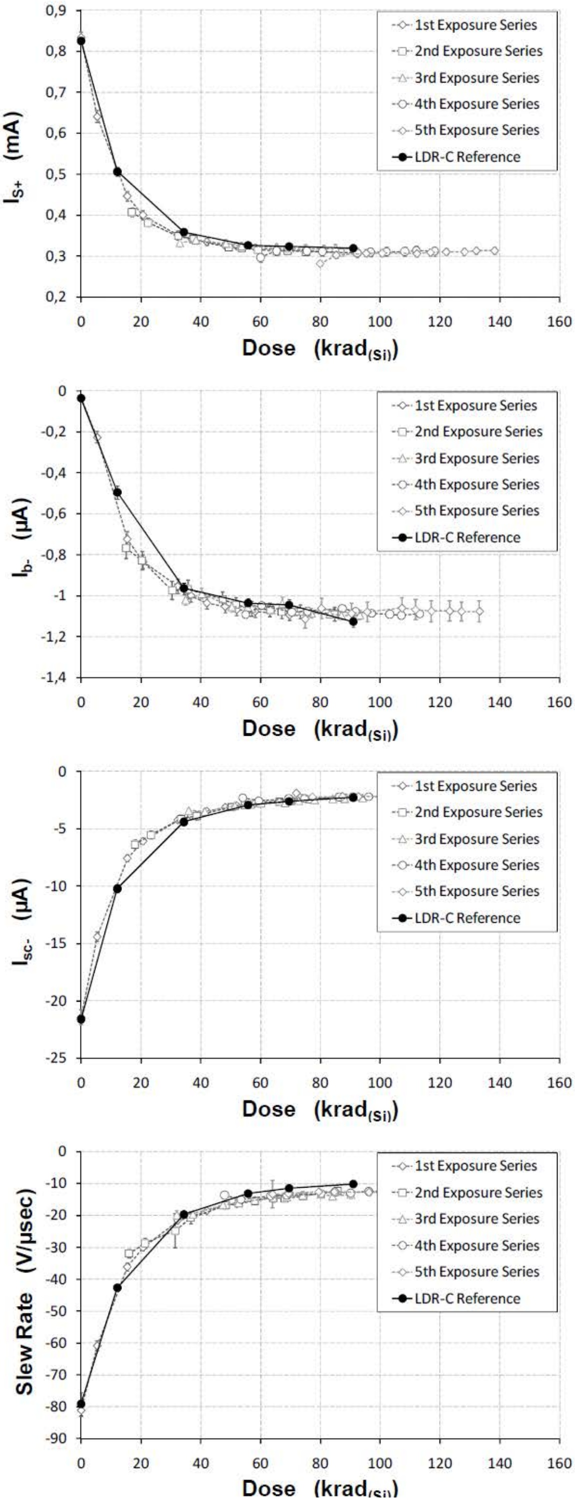


Figure 7: Results obtained with the switching test method to determine the low-dose-rate degradation curves of the LM339AN microcircuit when exposed in unbiased configuration. Presented are the low-dose-rate prediction curves (hollow symbols) of four parameters with superimposed the LDR-C reference curves (full symbols). (Figure from [6])

Summary and Conclusion

The present work covers investigation on low dose rate degradation of 256 parameters of nine bipolar microcircuits in biased and unbiased configurations. Experiments are performed using the accelerated switching test method and a continuous low dose rate irradiation as reference measurement. In total more than 100,000 data points are assessed. The method works fairly well for the investigated microcircuits and parameters. However, an acceptable fit is not observed for all measured parameters, care should therefore be taken in the implementation of this test method. Additionally, in the frame of this study, for each device type, 70 samples were used which can represent significant added costs in the case of high reliability components. The complexity associated with the practical implementation of the method (large samples size, switching dose rates at various time intervals), should not be underestimated either. It seems therefore premature to implement this test method in the European ESCC22900 TID test guidelines [8]. To improve the results, further investigations with larger dose rate applied during HDR-S are suggested in the literature. Statistical methods could potentially be used to limit the number of test samples while still maintaining an acceptable confidence level.

Acknowledgements

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