ESA STUDY CONTRACT REPORT

No ESA Study Contract Report will be accepted unless this sheet is inserted at the beginning of each volume of the Report.

ESA Contract No:	SUBJECT:	CONTRACTOR:
4000105666/12/NL/SFe	**COO5: Heavy Ion SEE Testing of RHFPM4424 low side MOSFET driver and SEB/SEGR Testing of power MOSFET from STmicroelectronics**	**TRAD**
* ESA CR( )No:	No. of Volumes: **1** This is Volume No: **1**	CONTRACTOR'S REFERENCE: **TRAD/TI/RHFPM4424/XXX1/ESA/APD/1405Rev1**

ABSTRACT:

This document is **deliverable D3: RHFPM4424 Test Report**, under the Frame Contract 4000105666 with ESA on the Radiation Characterisation of Commercial EEE Components for Space Applications and more specifically on the fifth Call-of-Order for the Heavy-ion SEE Testing of RHFPM4424 low side MOSFET driver.

This report includes the test results of the heavy ions Single Event Effects (SEEs) test sequence carried out on the RHFPM4424, a Rad-Hard 4.5A Dual Low Side MOSFET driver from STMicroelectronics. This test was performed for ESA at U.C.L. (Université Catholique de Louvain, Belgium) on July 10th till 12th, 2014 for which 15 samples were irradiated. The ESA Technical Officer, Christian Poivey, participated in the test campaign. The main objective of this test was to investigate on the sentivitivy of the RHFPM4424 versus Single Event Transients (SETs) and Single Event Burn-outs (SEBs) induced by heavy ions with different incidence angles.

SETs were observed on the RHFPM4424 under the Xenon and the Krypton Heavy Ion for all Tilt of each Roll (LET value from 46.1 MeV.cm².mg-1 to 105.32 MeV.cm².mg-1), and for all Power Supply (VCC from +15V to +19V)

For VCC=+18V, no SEB was observed for an LET value of 56.84 MeV.cm².mg-1 (Krypton heavy ions with 55° of Tilt).

For VCC=+16V, no SEB was observed for an LET value of 70.09 MeV.cm².mg-1 (Xenon heavy ions with 15° of Tilt).

For VCC=+16V, no SEB was observed for an LET value of 71.83 MeV.cm².mg-1 (Krypton heavy ions with 63° of Tilt).

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** NAME OF ESA STUDY MANAGER:	** ESA BUDGET HEADING:
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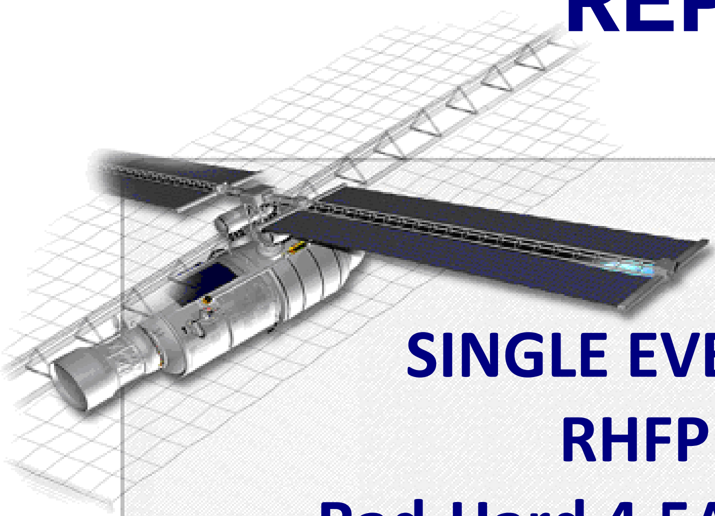
* Sections to be completed by ESA

** Information to be provided by ESA Study Manager

HEAVY IONS TEST REPORT



SINGLE EVENT EFFECTS
RHFPM4424
Rad-Hard 4.5A Dual Low Side MOSFET driver
From
STMicroelectronics

TRAD/TI/RHFPM4424/XXX1/ESA/APD/1405		Labège, 08 August 2014
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Revision: 0	Document created	22/07/2014
Revision: 1	Table 4 updated and description added for Tables 5 & 6	

To:	**ESA** **POIVEY Christian**	Project/Program: COO5 Ref: ESA contract 4000105666

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1. Introduction

This report includes the test results of the heavy ions Single Event Effects (SEEs) test sequence carried out on the RHFPM4424, a Rad-Hard 4.5A Dual Low Side MOSFET driver from STMicroelectronics.

This test was performed for ESA at U.C.L. (Université Catholique de Louvain, Belgium) on July 10th till 12th, 2014 for which 15 samples were irradiated. The ESA Technical Officer, Christian Poivey, participated in the test campaign.

The main objective of this test was to investigate on the sentivitivy of the RHFPM4424 versus Single Event Transients (SETs) and Single Event Burn-outs (SEBs) induced by heavy ions with different incidence angles.

2. Documents

2.1. Applicable documents

Technical Proposal: TRAD/P/ESA/COO5/AV/020414 Rev0
Irradiation Test Plan: COO5 D1: TRAD/ITP/ESA/COO5/PG/040614 Rev1

2.2. Reference documents

Data Sheet: STMicroelectronics ver0.5 of March 2013

3. Organization of Activities

The devices sent by ESA to TRAD were delidded. The testing board and the testing software were developed by TRAD. Before the campaign the samples were checked-out and the test bench was validated with a californium test at TRAD. The heavy ions campaign was performed by TRAD under the supervision Mr Poivey from ESA. The next table summarises the responsible entity for each activity of involved in this project.

1	Procurement of delidded Test Samples	ESA
2	Preparation of Test Hardware and Test Program	TRAD
3	Samples Check out	TRAD
4	Accelerator Test	TRAD and ESA
5	Heavy Ion Test Report	TRAD

Table 1: Organization of activities

4. Parts information

4.1. Device description

RHFPM4424 is a flexible, high-frequency dual low-side driver specifically designed to work with high capacitive MOSFETs and IGBTs in a high radiation environment such as space.

4.2. Identification

Type:	RHFPM4424
Manufacturer:	STMicroelectronics
Function:	Rad-Hard 4.5A Dual Low Side MOSFET driver

4.3. Procurement information

Packaging:	FP-16
Customer P/O:	1480
Sample size:	36 parts provided by ESA.

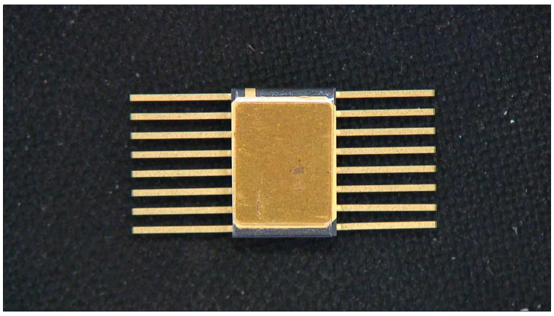
4.4. Sample Preparation

All parts were received delidded. A functional test sequence was performed on samples to check that devices were functional.
Among the 36 delidded samples available for the test campaign, 15 were irradiated and 21 were not used.

4.5. Sample pictures

4.5.1. External view

The next figures show an external view of the parts. The left figure is a view of the top and the right figure shows a view of the bottom of the part. As it can be seen, no markings were present on the parts.



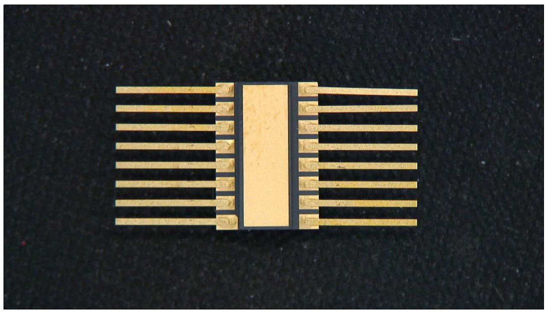


Figure 1: package marking

4.5.2. Internal view

Figure 2 gives an overview of the die. Figure 3 presents two views of the internal marking of the die. The two views on figure 3 are located in the middle right side indicated by the two circles on figure 2.

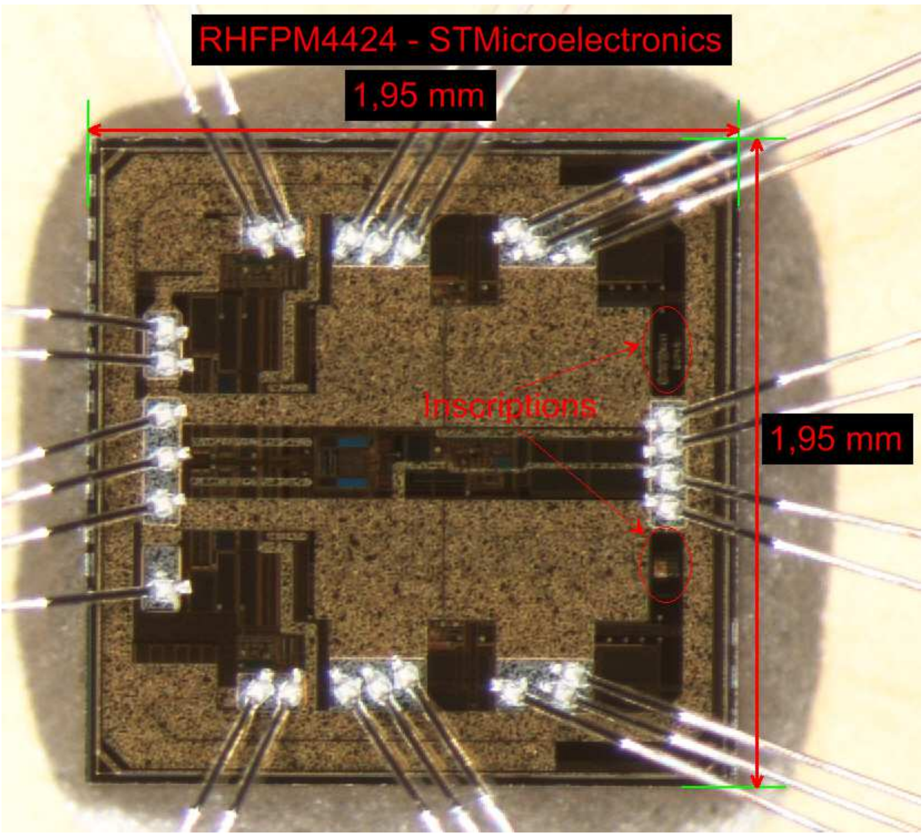


Figure 2: Internal overall view

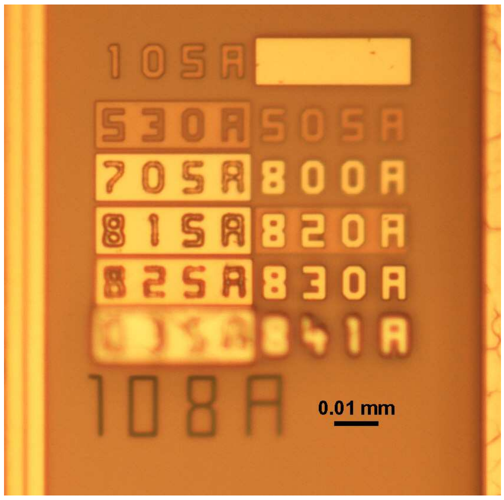


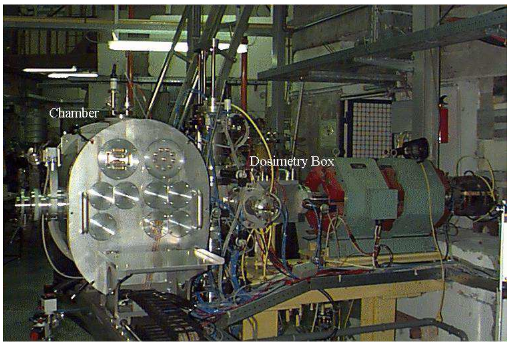
Figure 3: Die marking

5. Dosimetry and Irradiation Facilities

Tests were performed at U.C.L (Université Catholique de Louvain) from July 10th to July 12th, 2014. 15 delidded samples were irradiated.

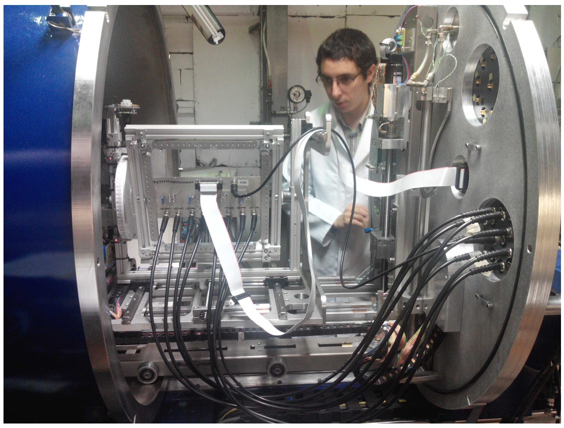
5.1. UCL Heavy Ion Test Facility (Université Catholique de Louvain - Belgium)

The CYClotron of LOuvain la NEuve (CYCLONE) is a multi-particle, variable energy, cyclotron capable of accelerating protons (up to 85 MeV), alpha particles and heavy ions.
For the heavy ions, the covered LET range is between 1.2 MeV.cm².mg^{-1} and 67.7 MeV.cm².mg^{-1}. Heavy ions available are separated in two “Ion Cocktails” named M/Q=5 and M/Q=3.3.



One of the main advantages of the UCL Heavy Ion Test Facility is the fast changing of ion species. Within the same cocktail, it takes only a few minutes to change from one ion to another.

The chamber has the shape of a barrel stretched vertically; its internal dimensions are 71 cm in height, 54 cm in width and 76 cm in depth. One side flange is used to support the board frame (25 X 25 cm) and user connectors.
The chamber is equipped with a vacuum system.
The right picture was taken during the experiment and shows the test board inside the vacuum chamber.



5.2. Dosimetry

To control and monitor the beam parameters, a dosimetry box is placed in front of the chamber. It contains a faraday cup, 2 Parallel Plate Avalanche Counters (PPAC).
Two additional surface barrier detectors are placed in the test chamber.
The faraday cup is used during beam preparation at high intensity.
A beam uniformity measurement is performed with a collimated surface barrier detector. This detector is placed on a X and Y movement. The final profile is drawn and the ± 10 % width is calculated. The Homogeneity is ± 10 % on a 25 mm diameter.
During the irradiation, the flux is integrated in order to give the delivered total fluence (particule.cm^{-2}) on the device.

5.3. Beam characteristics

The beam flux is variable between a few particles $s^{-1}cm^{-2}$ and $10^4 s^{-1}cm^{-2}$ and is set depending on the device sensitivity.
At UCL, Heavy ions available are separated in two “Ion Cocktails”, one for the High LET (M/Q=5) and a second one for the High Range (M/Q=3.3). On table 2 and 3 the characteristics of each cocktail can be found (heavy ions used during the experiment are yellow highlighted).

Ion	Energie (MeV)	Range (µm(Si))	LET ($MeV.cm^2.mg^{-1}$)
$^{15}N^{3+}$	60	59	3.3
$^{20}Ne^{4+}$	78	45	6.4
$^{40}Ar^{8+}$	151	40	15.9
$^{84}Kr^{17+}$	305	39	40.4
$^{124}Xe^{25+}$	420	37	67.7

Table 2 : UCL cocktail M/Q=5

Ion	Energie (MeV)	Range (µm(Si))	LET ($MeV.cm^2.mg^{-1}$)
$^{13}C^{4+}$	131	292	1.1
$^{22}Ne^{7+}$	235	216	3
$^{40}Ar^{12+}$	372	117	10.2
$^{58}Ni^{18+}$	567	100	20.4
$^{83}Kr^{25+}$	756	92	32.6

Table 3 : UCL cocktail M/Q=3.3

6. Test Procedure and Setup

6.1. Test procedure

6.1.1. Description of the test method

In order to investigate on the sensitivity of RHFPM4424 to show Single Event Burn-out, we focused our attention on the LET value, the incidence angle and the voltage supply. To do that, for each ion, two rolls (0° and 90°) and different tilts were used.

Runs were performed up to a fluence of 1.10^7 cm^{-2}. This configuration allowed to verify the SET and SEB sensitivity of the device for two different Rolls and for different values of the voltage supply (Vcc). The test started with a VCC voltage at 15V and was increased up to 18V (by step of 1V) if no SEB occurred. The greater pass condition reached was confirmed on a second part.
The goal was to define the highest Vcc allowed (causing no failure) for the greatest Tilt of each Roll. The test was terminated when the maximum fluence was reached or when we got a permanent damage on the component.

The next figure gives a description of the different rolls used during the experiment:

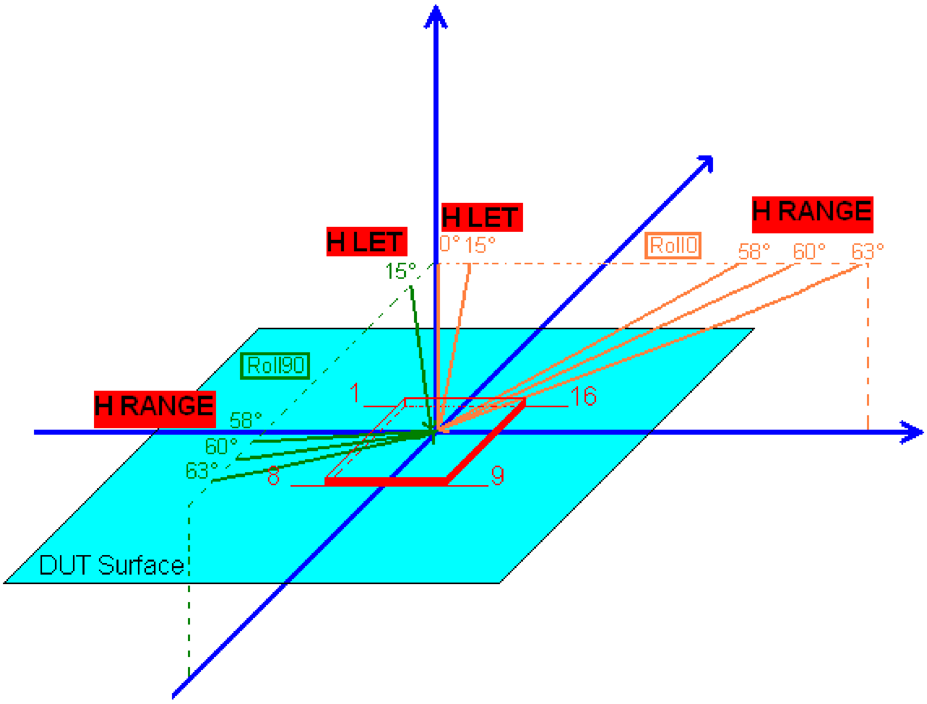


Figure 4: Rolls schematic description

6.1.2. SET Test Principle

Single Event Transient is an event described by a voltage amplitude and a timing parameter. To detect these events, the two outputs of the component are monitored.
As the input of the device is dynamic, a mask on the two output signals is created. If one of the two outputs goes over the mask, an event is counted and the screenshot is saved by the oscilloscope. An internal counter is incremented for the mask which presents a failure.

$\Delta T=1.5\mu s$

$\Delta V=1.2V$

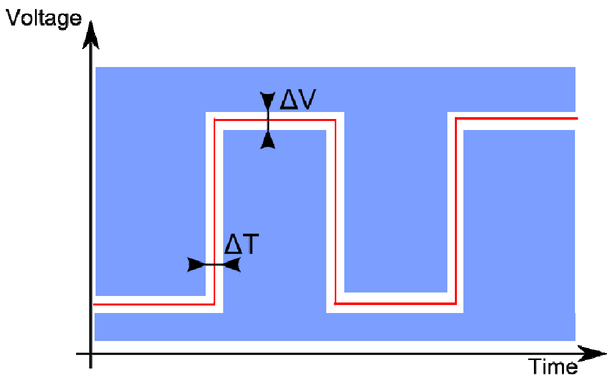


Figure 5: Output signal in dynamic mode

At the end of each run, the test program downloads the records currents waveforms to store them.

6.1.3. SEB Test Principle

This test is destructive. The output voltage is measured by an oscilloscope and the power consumption is recorded by an ampmeter. If an SEB occurs, an overconsumption appears and outputs abruptly go out of the mask defined before. The test is stopped as soon as an SEB occurs, or when the overall fluence on the component reaches 1.10^7 cm^{-2}.

6.2. Test bench description

6.2.1. Preparation of test hardware and program

TRAD has developed a specific test program and a specific motherboard to feed power supply to components.
The test board allows to visualize the two output voltages and to monitor the input current. The test program allows the user to set the different conditions of the test and to follow the number of SEE and the profile of detected errors in real time, through a standard IEEE488 and Ethernet communication interface. All signals are delivered and monitored by this equipment and SEE curves are saved to the hard disk for storage. An overall description of the test system is given in Figure 6. Before performing the heavy ion test, the whole system (delidded sample, test board and software) was assembled and tested in V.A.S.C.O (Vacuum System for Californium Operation).

6.2.2. Test Bench description

Figure 6 gives a global view of the test bench. It is composed by an oscilloscope, a multimeter, a test board (the biasing under irradiation is shown in figure 7), a power supply and a computer.

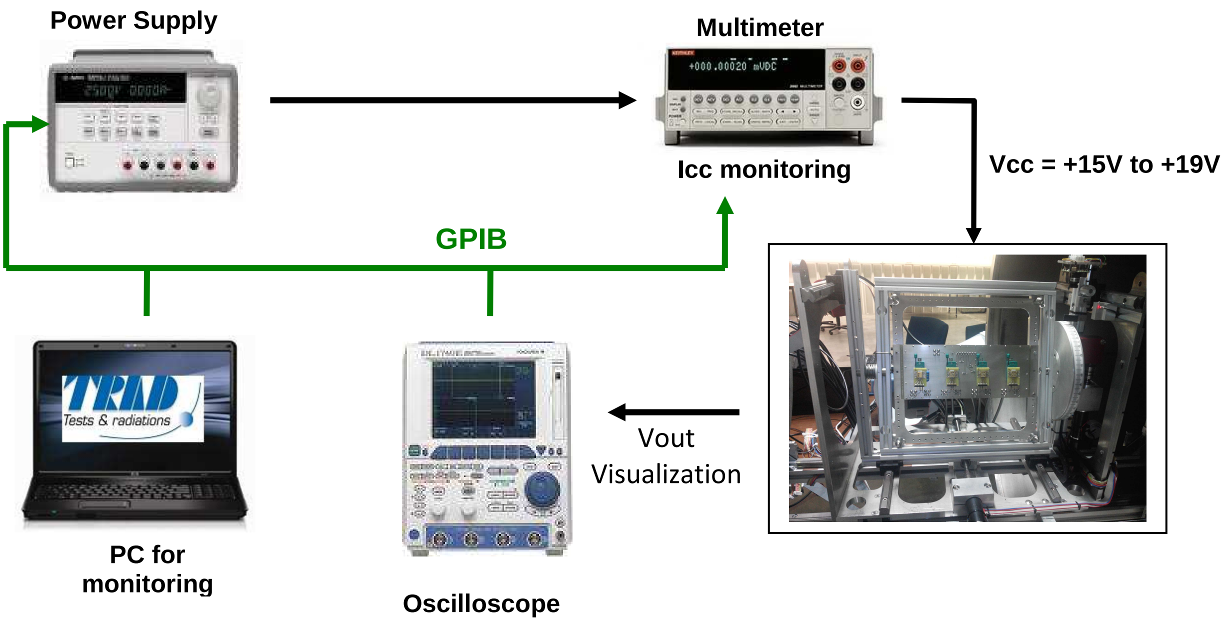


Figure 6: test system description

Figure 7 shows the biasing under irradiation of the part. A voltage square signal with 50% duty cycle and with a frequency of 100KHz was applied on inputs PWM_1 and PWM_2. Icc was monitored during the whole test with the a multimeter and was also recorded. SET (Single Event Transient) was monitored at the output of the DUT thanks to a scope. When the scope triggers, the screenshot was recorded.

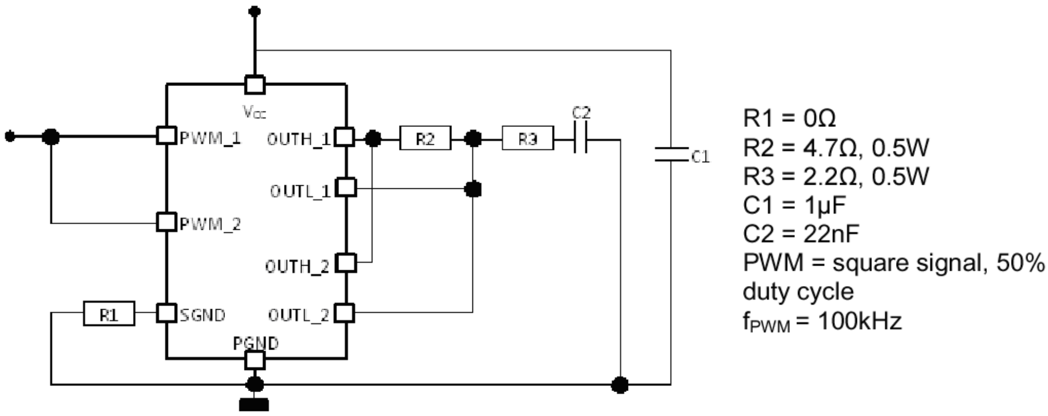


Figure 7: Test board schematic

6.2.3. Test equipment identification

The tests were carried out with evaluation test boards developed by TRAD.

COMPUTER	MI-OP-058
REF. TEST BOARD	TRAD/CT1/I/PM442/ZIP16/MV/1311
EQUIPMENT	MI-60; MI-42; GR-53; MI-71
TEST PROGRAM	RHFPM4424_TI_xxx1_Bi_V10.spf

7. RESULTS

Here above, the device under test was described, the irradiation facility was presented and finally the overall view of the test bench and a test description was performed. This chapter will present the results obtained during the campaign.

7.1. Summary of runs

The choice of the configuration tested and the fluence for each run to optimise test time, were taken with the supervision of Mr Poivey from ESA.
On the next page a table listing all the Runs and configurations performed during the campaign can be found.

RHFPM4424 VCC=15 to 19V																							Icc		
Run	Part	Vcc	Roll	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Tilt (°)	Eff. LET (MeV.cm²/mg)	Eff. Range (µm Si)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	SET on OUTH (CH1)	OUTH Cross Section	SET on OUTL (CH2)	OUTL Cross Section	SEB	Cross Section	SEB RESULT	Before RUN	After RUN	COMMENTS
High LET M/Q=5																									
1	1	15	90	124Xe 26+	420	37	67.7	0	67.70	37.0	9.07E+03	1102	1.00E+07	10.832	10.832	5	5.00E-07	8	8.00E-07	0	<1.00E-09	Pass	34mA	34mA	
2	1	16	90	124Xe 26+	420	37	67.7	0	67.70	37.0	1.05E+04	954	1.00E+07	10.832	21.664	1	1.00E-07	3	3.00E-07	0	<1.00E-09	Pass	36mA	36mA	Oscilloscope resolution increased to 5k
3	1	17	90	124Xe 26+	420	37	67.7	0	67.70	37.0	1.05E+04	953	1.00E+07	10.832	32.496	2	2.00E-07	2	2.00E-07	0	<1.00E-09	Pass	39mA	39mA	Oscilloscope resolution increased to 20k Time base put to 4µs/div
4	1	18	90	124Xe 26+	420	37	67.7	0	67.70	37.0	1.03E+04	967	1.00E+07	10.832	43.328	3	3.00E-07	3	3.00E-07	0	<1.00E-09	Pass	41mA	41mA	Oscilloscope resolution increased to 1k ime base restored to 5µs/div
5	2	18	-	124Xe 26+	420	37	67.7	0	67.70	37.0	1.01E+04	994	1.00E+07	10.832	10.832	7	7.00E-07	9	9.00E-07	0	<1.00E-09	Pass	42mA	41mA	
6	2	15	90	124Xe 26+	420	37	67.7	15	70.09	35.7	9.90E+03	1010	1.00E+07	11.214	22.046	8	8.00E-07	8	8.00E-07	0	<1.00E-09	Pass	35mA	35mA	
7	2	16	90	124Xe 26+	420	37	67.7	15	70.09	35.7	9.75E+03	1026	1.00E+07	11.214	33.260	6	6.00E-07	7	7.00E-07	0	<1.00E-09	Pass	37mA	37mA	
8	2	17	90	124Xe 26+	420	37	67.7	15	70.09	35.7	9.53E+03	1049	1.00E+07	11.214	44.474	6	6.00E-07	6	6.00E-07	0	<1.00E-09	Pass	39mA	39mA	
9	2	18	90	124Xe 26+	420	37	67.7	15	70.09	35.7	9.55E+03	1047	1.00E+07	11.214	55.688	6	6.00E-07	5	5.00E-07	0	<1.00E-09	Pass	41mA	41mA	
10	3	18	90	124Xe 26+	420	37	67.7	15	70.09	35.7	9.22E+03	1085	1.00E+07	11.214	11.214	2	2.00E-07	3	3.00E-07	0	<1.00E-09	Pass	41mA	40mA	
11	3	15	0	124Xe 26+	420	37	67.7	15	70.09	35.7	9.82E+03	1018	1.00E+07	11.214	22.428	3	4.00E-07	4	4.00E-07	0	<1.00E-09	Pass	34mA	34mA	
12	3	16	0	124Xe 26+	420	37	67.7	15	70.09	35.7	1.01E+04	995	1.00E+07	11.214	33.642	8	8.00E-07	9	9.00E-07	0	<1.00E-09	Pass	36mA	36mA	
13	3	17	0	124Xe 26+	420	37	67.7	15	70.09	35.7	1.01E+04	990	1.00E+07	11.214	44.856	3	3.00E-07	3	3.00E-07	0	<1.00E-09	Pass	38mA	38mA	
14	3	18	0	124Xe 26+	420	37	67.7	15	70.09	35.7	9.82E+03	1018	1.00E+07	11.214	56.071	4	4.00E-07	4	4.00E-07	0	<1.00E-09	Pass	41mA	41mA	
15	4	18	0	124Xe 26+	420	37	67.7	15	70.09	35.7	9.70E+03	1031	1.00E+07	11.214	11.214	4	4.00E-07	5	5.00E-07	0	<1.00E-09	Pass	42mA	41mA	
16	4	18	0	124Xe 26+	420	37	67.7	30	78.17	32.0	1.02E+04	978	1.00E+07	12.508	23.722	6	6.00E-07	9	9.00E-07	0	<1.00E-09	Pass	41mA	41mA	
17	4	18	0	124Xe 26+	420	37	67.7	40	88.38	28.3	1.02E+04	985	1.00E+07	14.140	37.862	3	3.00E-07	3	3.00E-07	0	<1.00E-09	Pass	41mA	41mA	
18	4	18	0	124Xe 26+	420	37	67.7	45	95.74	26.2	9.61E+03	166	1.60E+06	2.445	40.307	0	<6.27E-09	0	<6.27E-09	1	6.27E-07	Fail	41mA	1A	Internal limitation of Vcc Power supply reached durring Irradiations
19	5	18	0	124Xe 26+	420	37	67.7	45	95.74	26.2	1.00E+04	1994	2.00E+07	30.638	30.638	10	5.00E-07	11	5.50E-07	0	<0.50E-09	Pass	41mA	40mA	
20	5	19	0	124Xe 26+	420	37	67.7	15	70.09	35.7	1.01E+04	990	1.00E+07	11.214	41.852	4	4.00E-07	6	6.00E-07	0	<1.00E-09	Pass	42mA	42mA	
21	6	18	0	124Xe 26+	420	37	67.7	50	105.32	23.8	1.05E+04	955	1.00E+07	16.852	16.852	5	5.00E-07	5	5.00E-07	0	<1.00E-09	Pass	41mA	40mA	
22	6	18	0	124Xe 26+	420	37	67.7	45	95.74	26.2	1.04E+04	959	1.00E+07	15.319	32.170	5	5.00E-07	5	5.00E-07	0	<1.00E-09	Pass	40mA	40mA	
High Range M/Q=3.3																									
23	7	18	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.09E+03	971	7.86E+06	7.732	7.732	-	<1.27E-09	-	<1.27E-09	1	1.27E-07	Fail	41mA	0.9A	Don't take into account SET observed* Internal limitation of Vcc Power supply reached durring Irradiations
24	8	17	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.14E+03	1229	1.00E+07	9.843	9.843	9	9.00E-07	10	1.00E-06	0	<1.00E-09	Pass	40mA	39mA	
25	8	18	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.19E+03	288	2.36E+06	2.323	12.166	-	<4.24E-09	-	<4.24E-09	1	4.24E-07	Fail	41mA	0.917A	Internal limitation of Vcc Power supply reached durring Irradiations
26	9	17	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	7.71E+03	11	8.48E+04	0.083	0.083	-	<0.12E-06	-	<0.12E-06	1	1.18E-05	Fail	39mA	1A	Don't take into account SET observed* Internal limitation of Vcc Power supply reached durring Irradiations
27	10	16	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.03E+03	1245	1.00E+07	9.843	9.843	0	<1.00E-09	0	<1.00E-09	0	<1.00E-09	Pass	37mA	36mA	Don't take into account SET observed*
28	10	17	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.04E+03	1244	1.00E+07	9.843	19.686	10	1.00E-06	12	1.20E-06	0	<1.00E-09	Pass	38mA	38mA	
29	10	16	0	83 Kr 25+	756	92	32.6	60	65.20	46.0	7.63E+03	1310	1.00E+07	10.432	30.118	5	5.00E-07	7	7.00E-07	0	<1.00E-09	Pass	36mA	36mA	
30	10	16	0	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.93E+03	1442	1.00E+07	11.489	41.607	6	6.00E-07	6	6.00E-07	0	<1.00E-09	Pass	36mA	36mA	
31	10	18	0	83 Kr 25+	756	92	32.6	45	46.10	65.1	1.08E+04	926	1.00E+07	7.377	48.984	3	3.00E-07	4	4.00E-07	0	<1.00E-09	Pass	40mA	40mA	
32	10	18	0	83 Kr 25+	756	92	32.6	55	56.84	52.8	8.75E+03	1143	1.00E+07	9.094	58.078	5	5.00E-07	5	5.00E-07	0	<1.00E-09	Pass	40mA	40mA	
33	10	17	0	83 Kr 25+	756	92	32.6	60	65.20	46.0	7.69E+03	1301	1.00E+07	10.432	68.510	6	6.00E-07	6	6.00E-07	0	<1.00E-09	Pass	38mA	38mA	
34	10	17	0	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.93E+03	1444	1.00E+07	11.489	79.999	4	4.00E-07	5	5.00E-07	0	<1.00E-09	Pass	38mA	38mA	
35	10	18	0	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.98E+03	39	2.72E+05	0.313	80.312	-	<0.04E-06	-	<0.04E-06	1	3.67E-06	Fail	40mA	1A	Overconsumption up to 69mA. Internal limitation of Vcc Power supply reached after the end of irradiation.
36	11	16	0	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.97E+03	1434	1.00E+07	11.489	11.489	6	6.00E-07	8	8.00E-07	0	<1.00E-09	Pass	36mA	36mA	
37	11	17	0	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.93E+03	1444	1.00E+07	11.489	22.978	4	4.00E-07	5	5.00E-07	0	<1.00E-09	Pass	39mA	39mA	
38	11	18	0	83 Kr 25+	756	92	32.6	55	56.84	52.8	8.73E+03	1146	1.00E+07	9.094	32.072	7	7.00E-07	7	7.00E-07	0	<1.00E-09	Pass	41mA	41mA	
39	11	18	0	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.06E+03	1240	1.00E+07	9.843	41.915	3	3.00E-07	4	4.00E-07	0	<1.00E-09	Pass	41mA	41mA	
40	11	18	0	83 Kr 25+	756	92	32.6	60	65.20	46.0	7.59E+03	1317	1.00E+07	10.432	52.347	7	7.00E-07	6	6.00E-07	0	<1.00E-09	Pass	41mA	41mA	
41	11	18	0	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.81E+03	33	2.25E+05	0.258	52.605	-	<0.04E-06	-	<0.04E-06	1	4.45E-06	Fail	41mA	1A	Internal limitation of Vcc Power supply reached durring Irradiations
42	12	16	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.74E+03	1483	1.00E+07	11.489	11.489	-	-	-	-	0	<1.00E-09	Pass	37mA	36mA	Don't take into account SET observed**
43	13	16	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.95E+03	1439	1.00E+07	11.489	11.489	5	5.00E-07	7	7.00E-07	0	<1.00E-09	Pass	37mA	37mA	
44	13	17	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	7.03E+03	1422	1.00E+07	11.489	22.978	11	1.10E-06	11	1.10E-06	0	<1.00E-09	Pass	39mA	39mA	
45	13	18	90	83 Kr 25+	756	92	32.6	55	56.84	52.8	8.87E+03	1128	1.00E+07	9.094	32.072	3	4.00E-07	4	4.00E-07	0	<1.00E-09	Pass	41mA	41mA	
46	13	18	90	83 Kr 25+	756	92	32.6	58	61.52	48.8	8.05E+03	1242	1.00E+07	9.843	41.915	4	4.00E-07	5	5.00E-07	0	<1.00E-09	Pass	41mA	41mA	
47	13	18	90	83 Kr 25+	756	92	32.6	60	65.20	46.0	7.69E+03	1300	1.00E+07	10.432	52.347	5	5.00E-07	4	4.00E-07	0	<1.00E-09	Pass	41mA	41mA	
48	13	18	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.90E+03	1450	1.00E+07	11.489	63.837	2	2.00E-07	3	3.00E-07	0	<1.00E-09	Pass	41mA	41mA	
49	14	17	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.84E+03	1463	1.00E+07	11.489	11.489	8	8.00E-07	9	9.00E-07	0	<1.00E-09	Pass	38mA	38mA	
50	14	18	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.98E+03	1433	1.00E+07	11.489	22.978	8	8.00E-07	8	8.00E-07	0	<1.00E-09	Pass	40mA	40mA	
51	15	18	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	7.11E+03	1406	1.00E+07	11.489	11.489	6	6.00E-07	6	6.00E-07	0	<1.00E-09	Pass	41mA	40mA	
52	12	18	90	83 Kr 25+	756	92	32.6	63	71.81	41.8	6.78E+03	1475	1.00E+07	11.489	22.978	6	6.00E-07	5	5.00E-07	0	<1.00E-09	Pass	42mA	40mA	
53	12	18	90	83 Kr 25+	756	92	32.6	65	77.14	38.9	6.31E+03	1584	1.00E+07	12.342	35.321	8	8.00E-07	8	8.00E-07	0	<1.00E-09	Pass	40mA	40mA	

Table 4: RHFPM4424 test results

*: These run are not representative for SET; they were performed to investigate on SET pulse width detection.

**: This run is not representative for SET; The Oscilloscope lost the mask configuration and was reinitialised for the next run.

On the next tables the cross section obtained on the output OUTL and OUTH for SET is presented. Cells in red background highlight the run were SEB failure was observed. *Xe ion highlighted in yellow and Kr ion highlighted in blue.*

	Roll 0					Roll 90			
LET Eff (MeV.cm².mg^{-1})	+15V	+16V	+17V	+18V	+19V	+15V	+16V	+17V	+18V
105.32 (50°)	-	-	-	5.00E-07	-	-	-	-	-
95.74 (45°)	-	-	-	5.50E-07	-	-	-	-	-
88.38 (40°)	-	-	-	3.00E-07	-	-	-	-	-
78.17 (30°)	-	-	-	9.00E-07	-	-	-	-	-
77.14 (65°)	-	-	-	-	-	-	-	-	8.00E-07
71.81 (63°)	-	8.00E-07	5.00E-07		-	-	7.00E-07	1.10E-06	8.00E-07
70.09 (15°)	4.00E-07	9.00E-07	3.00E-07	5.00E-07	6.00E-07	8.00E-07	7.00E-07	6.00E-07	5.00E-07
67.7 (0°)	8.00E-07	3.00E-07	2.00E-07	9.00E-07	-	8.00E-07	3.00E-07	2.00E-07	9.00E-07
65.2 (60°)	-	7.00E-07	6.00E-07	6.00E-07	-	-	-	-	4.00E-07
61.52 (58°)	-	-	1.20E-06	4.00E-07	-	-	-	-	5.00E-07
56.84 (55°)	-	-	-	7.00E-07	-	-	-	-	4.00E-07
46.1 (45°)	-	-	-	4.00E-07	-	-	-	-	-

Table 5: OUTL cross section results

	Roll 0					Roll 90			
LET Eff (MeV.cm².mg^{-1})	+15V	+16V	+17V	+18V	+19V	+15V	+16V	+17V	+18V
105.32 (50°)	-	-	-	5.00E-07	-	-	-	-	-
95.74 (45°)	-	-	-	5.00E-07	-	-	-	-	-
88.38 (40°)	-	-	-	3.00E-07	-	-	-	-	-
78.17 (30°)	-	-	-	6.00E-07	-	-	-	-	-
77.14 (65°)	-	-	-	-	-	-	-	-	8.00E-07
71.81 (63°)	-	6.00E-07	4.00E-07		-	-	5.00E-07	1.10E-06	8.00E-07
70.09 (15°)	3.00E-07	8.00E-07	3.00E-07	4.00E-07	4.00E-07	7.00E-07	6.00E-07	6.00E-07	6.00E-07
67.7 (0°)	5.00E-07	1.00E-07	2.00E-07	7.00E-07	-	5.00E-07	1.00E-07	2.00E-07	7.00E-07
65.2 (60°)	-	5.00E-07	6.00E-07	7.00E-07	-	-	-	-	5.00E-07
61.52 (58°)	-	-	1.00E-06	3.00E-07	-	-	-	-	4.00E-07
56.84 (55°)	-	-	-	7.00E-07	-	-	-	-	3.00E-07
46.1 (45°)	-	-	-	3.00E-07	-	-	-	-	-

Table 6: OUTH cross section results

On the next paragraphs, SEB and SET results will be discussed separately.

7.2. SEB tests results

Single Event Burnout inducing permanent damage on components were observed on 6 different parts:

- Roll 0:
  - During the irradiation with the Xenon Heavy Ion, Tilt=45°C (LET=95.74 MeV.cm².mg^{-1}) at VCC=+18V (part 4)
  - During the irradiation with the Krypton Heavy Ion, Tilt=58°C (LET=61.52 MeV.cm².mg^{-1}) at VCC=+18V (part 7 and 8) and VCC=+17V (part 9)
  - During the irradiation with the Krypton Heavy Ion, Tilt=63°C (LET=71.81 MeV.cm².mg^{-1}) at VCC=+18V (part 10 and 11)

- Roll 90: No SEB observed during this test under Xenon (0°, 15°) and Krypton (55°, 58°, 60°, 63°, 65°)

Please note that all SEB observed were for a supply voltage equal or greater than 17V.

7.2.1. Description of events observed

Under Krypton irradiation and for Roll 0, some parts were damaged at VCC=+17V and at VCC=+18V and some parts presented no events.

Figures 8, 9 and 10 show the supply current in milliamp (blue) versus time.

In figures 8 and 10, a sudden over consumption can be observed (up to 1A and limited by the power supply) due to an event.

On figure 9, run n°40 shows no event. Consumption decreases a little bit during the run. This is due to the temperature stabilisation.

Parts were damaged (4, 7, 8, 9, 10 and 11) during irradiation by one SEB leading to an over consumption (1A instead of 40mA) at the end of the run.

Figures 11 and 12 show an example of the output signal of the DUT observed after the SEB for damaged parts n°8 and n°11. As it can be seen, the output frequency remains correct but the output levels are lower than expected and the shape of the square signal is distorted.

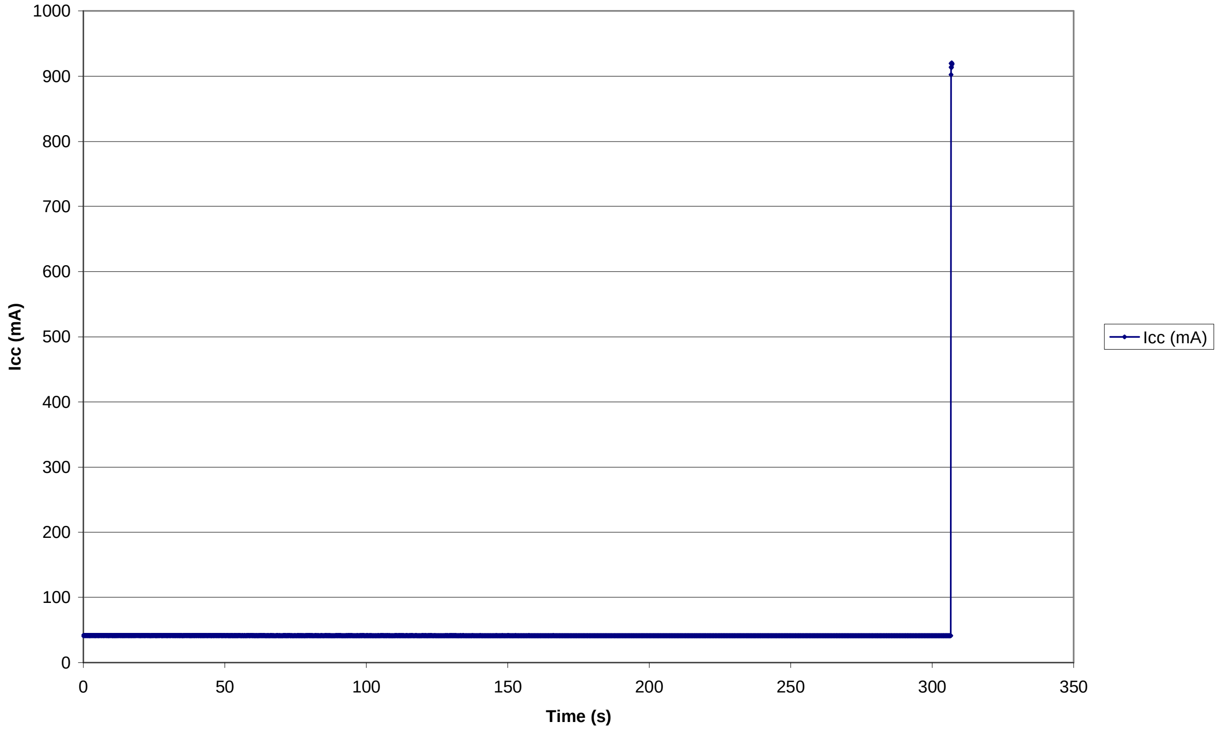


Figure 8: Power Supply monitoring, VCC=+18V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 58°, Part 8, Run n°25

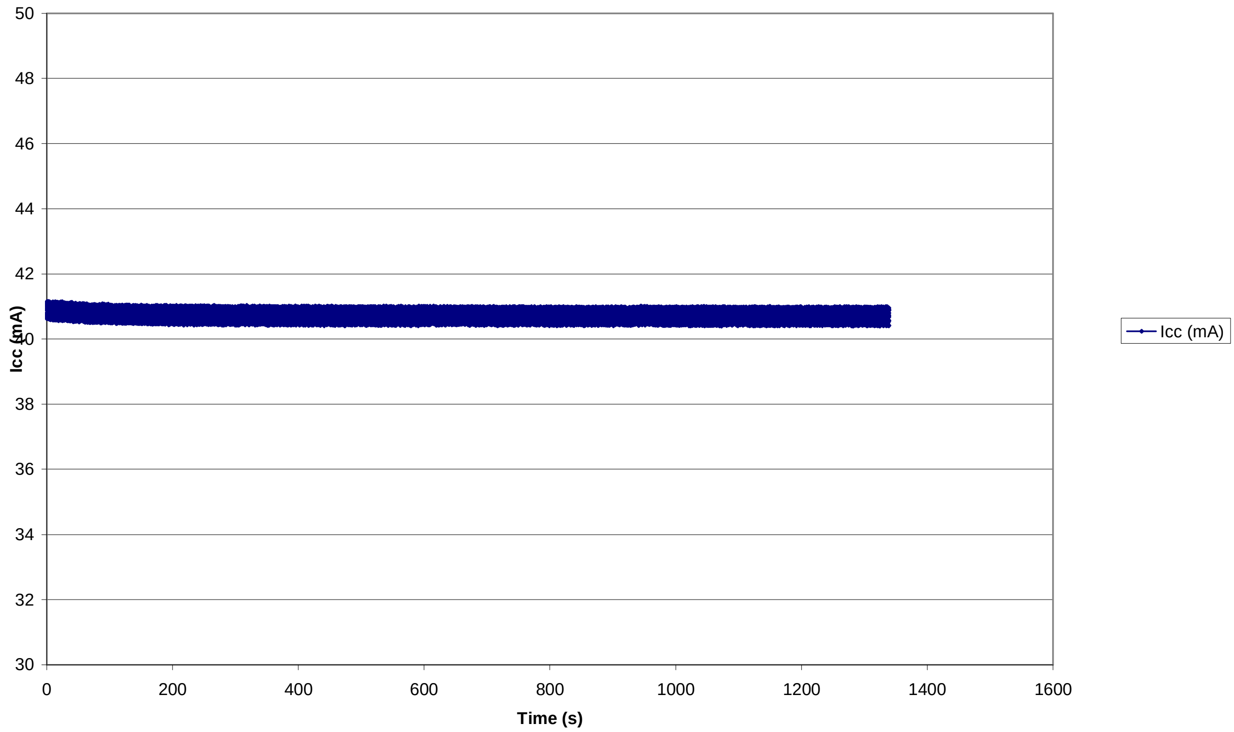


Figure 9: Power Supply monitoring, VCC=+18V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 60°, Part 11, Run n°40

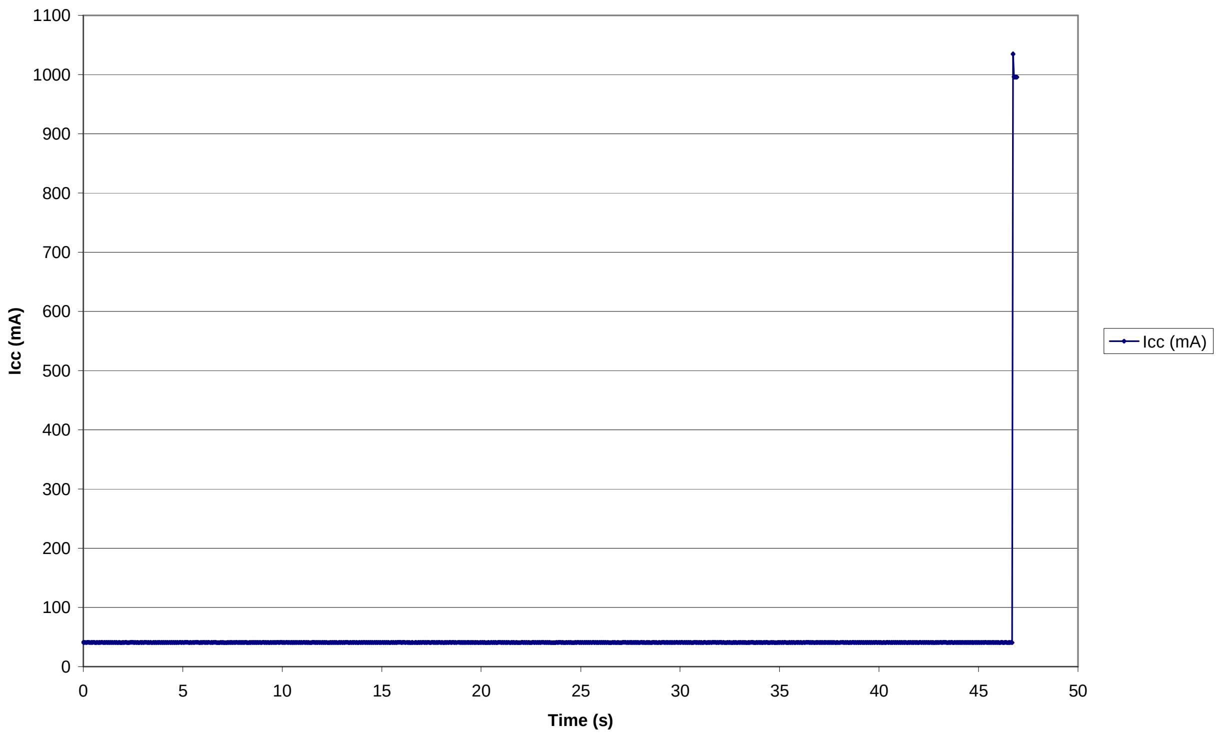
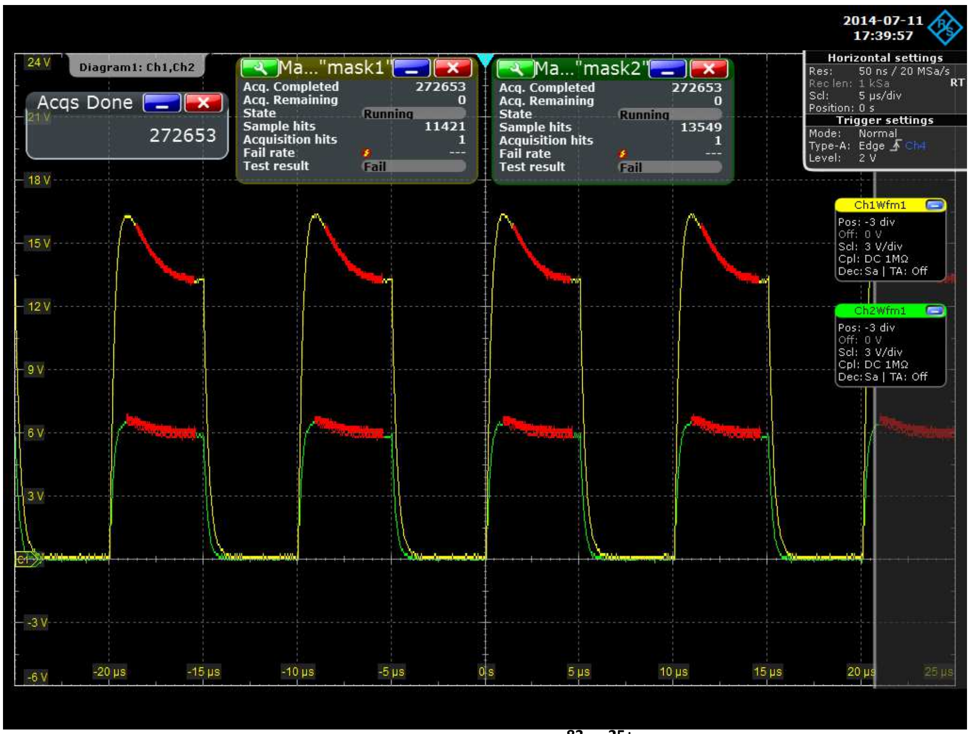
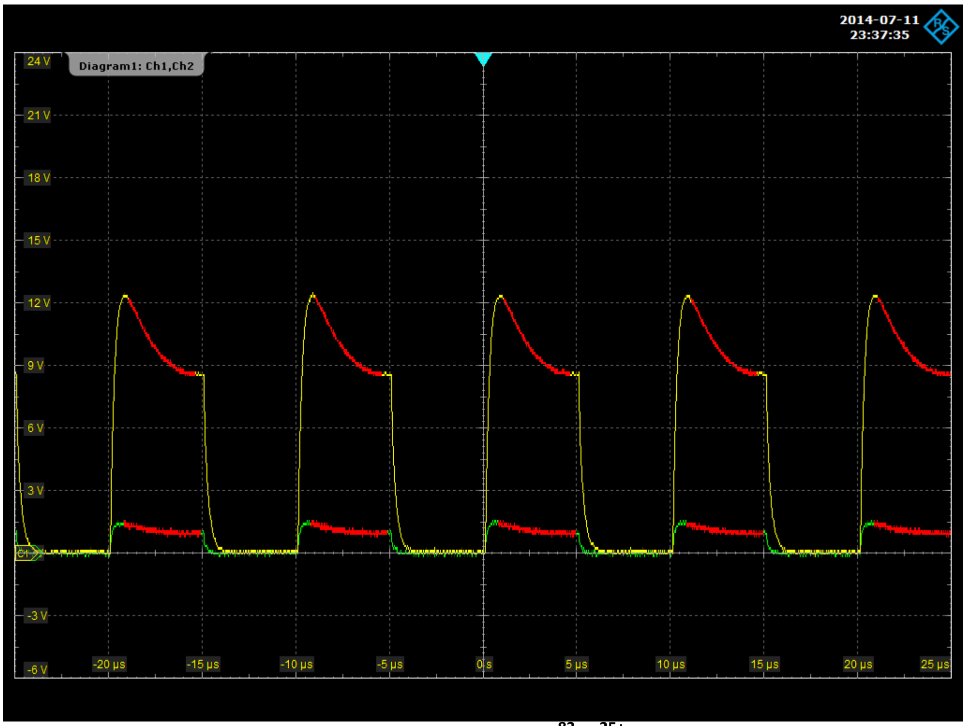


Figure 10: Power Supply monitoring, VCC=+18V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 63°, Part 11, Run n°41



CH1≡Out_H (yellow)
CH2≡Out_L (green)

Figure 11: SEB_1, VCC=+18V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 58°, Part 8, Run n°25



CH1≡Out_H (yellow)
CH2≡Out_L (green)

Figure 12: SEB_2, VCC=+18V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 63°, Part 11, Run n°41

7.3. SET test results.

SETs were observed during the irradiation under Xenon and Krypton Heavy Ions for all Tilt of each Roll whatever the supply voltage.
As it can be noted on Table 4 there is a difference between the number of SET counted on output OUTH and output OUTL. When an event occurs on OUTH or on OUTL, it generates a smaller event on the other channel. This perturbation can be too small to cross the mask level and can be missed by the second channel. So this difference is only due to the threshold detection.

Because of a problem on the scope setup during irradiation with Xenon Heavy Ion, waveforms for run 1 to run 22 can't be plotted but we can confirm that the events observed on the high LET cocktail are the same as the ones observed on the High Range cocktail. So SET worst case analysis has been done only for runs under the Krypton Heavy Ion.
The next paragraph gives an example of worst case SET observed on OUTL and OUTH.

7.3.1. Worst Cases of SET Observed

Figures 13, 14, 15 and 16, are oscillogrammes of the worst cases observed were the yellow and green plot show the initial output, and the red plot shows the SET event observed versus time.
At VCC=+16V, the worst SET cases observed with Krypton heavy Ions occur for Roll 0 on Parts n°10 and n°11, during run n°30 and n°36 (Tilt 63°, 71.81 MeV.cm².mg^{-1}).

Figure 13: SET_1, VCC=+16V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 63°, Part 10, Run n°30, Event n°7

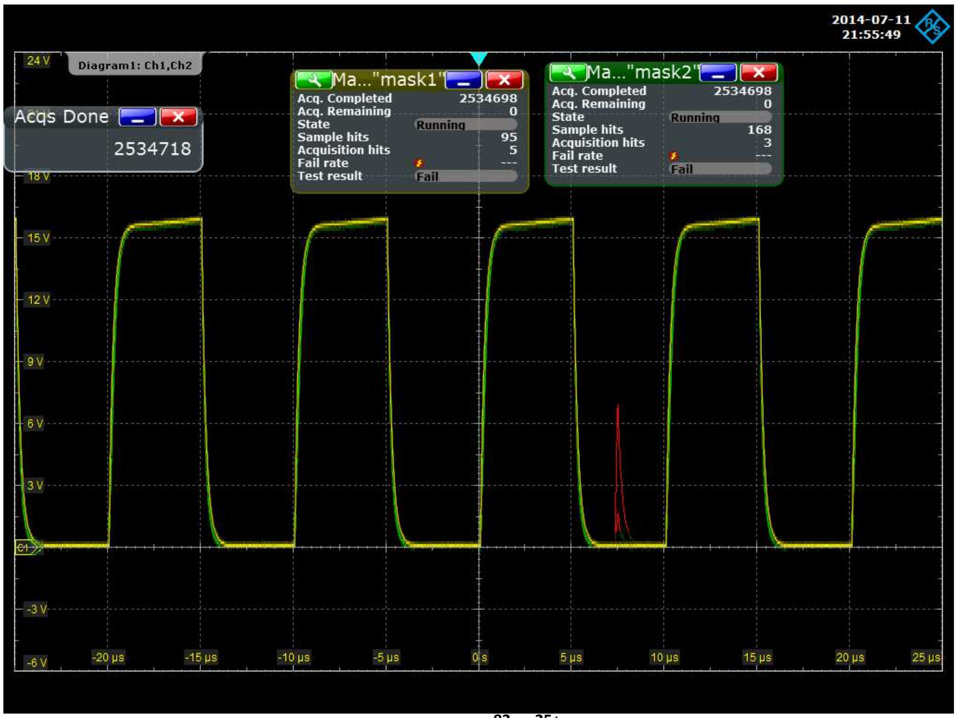


Figure 14: SET_2, VCC=+16V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 63°, Part 11, Run n°36, Event n°3

At VCC=+18V, the worst SET cases observed with Krypton heavy Ion occur for Roll 0 on Parts n°14 and n°11, during run n°50 (Tilt 63°, 71.81 MeV.cm².mg^{-1}) and n°38 (Tilt 55°, 56.84 MeV.cm².mg^{-1}).

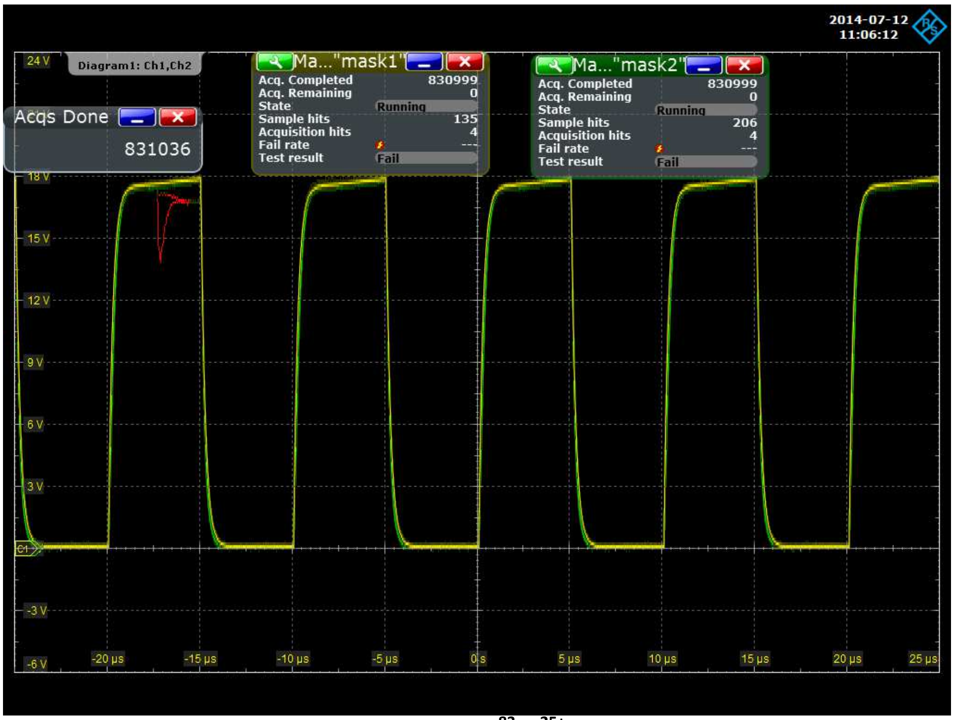


Figure 15: SET_1, VCC=+18V, Roll 90, Heavy Ion $^{83}Kr^{25+}$, Tilt 63°, Part 14, Run n°50, Event n°5

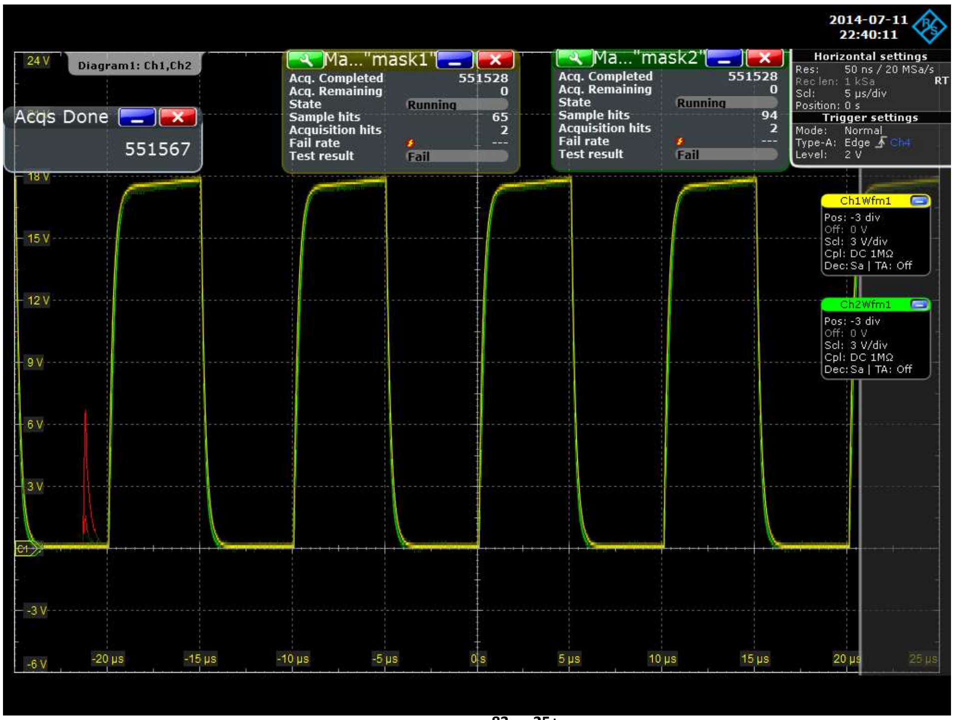


Figure 16: SET_2, VCC=+18V, Roll 0, Heavy Ion $^{83}Kr^{25+}$, Tilt 55°, Part 11, Run n°38, Event n°4

8. Conclusion

Heavy ion tests were performed on RHFPM4424. The aim of the test was to evaluate the sensitivity of the device versus SET and SEB.

SETs were observed on the RHFPM4424 under the Xenon and the Krypton Heavy Ion for all Tilt of each Roll (LET value from 46.1 MeV.cm².mg^{-1} to 105.32 MeV.cm².mg^{-1}), and for all Power Supply (VCC from +15V to +19V)

For VCC=+18V, no SEB was observed for an LET value of 56.84 MeV.cm².mg^{-1} (Krypton heavy ions with 55° of Tilt).
For VCC=+16V, no SEB was observed for an LET value of 70.09 MeV.cm².mg^{-1} (Xenon heavy ions with 15° of Tilt).
For VCC=+16V, no SEB was observed for an LET value of 71.83 MeV.cm².mg^{-1} (Krypton heavy ions with 63° of Tilt).