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Abstract: The Ethernet PHY Test Results from the Environmental and Radiation Test Campaigns

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1. Introduction

This document serves as the final results report for the PHY transceiver characterisation campaign as set forth in the Statement of Work for the Ethernet PHY Transceiver Characterisation Appendix 1 to ESA AO/1-8074/14/NL/LF from 06.08.2014.

1.1 Applicable and Reference Documents

Reference Number	Document	Title
AD1	Statement of work ESA Express Procurement EX-PRO	Ethernet PHY Transceiver Characterisation Appendix 1 to ESA AO/1-8074/14/NL/LF from 06.08.2014
AD2	ECSS-E-ST-20 C	Electrical and Electronics
AD3	ECSS-Q-ST-60C	EEE Components
AD4	ECSS-E-ST-10-02C	Verification
AD5	ECSS-E-10-03A	Testing
AD6	ECSS-Q-ST-70-02C	Thermal vacuum outgassing test for screening of space materials
AD7	ECSS-Q-ST-70-29C	Determination of offgassing products from materials and assembled articles to be used in a manned space vehicle crew compartment
AD8	ECSS-Q-ST-70-21C	Flammability testing for the screening of space materials
AD9	ECSS-ST-60-15C	Radiation hardness assurance- EEE components (1 October 2012)
AD10	ECSS-Q-ST-70-06C	Particle and UV radiation testing for space materials
AD11	ESCC 22900	Total dose Steady-state irradiation test method
AD12	ESCC 25100	Single event effects test method and guidelines

2. Abbreviations

Abbreviations used throughout this document are defined below.

ARP	Address Resolution Protocol
ASCII	American Standard Code for Information Interchange
BCD	Binary Coded Digit
DUT	Device Under Test
EGSE	Electrical Ground Support Equipment
FPGA	Field Programmable Gate Array
GMII	Gigabit Media Independent Interface
IP / IPv4	Internet Protocol Version 4
LAN	Local Area Network
LED	Light Emitting Diode
LSB	Least Significant Bit
MAC	Media Access Controller
MDIO	Management Data Input/Output
MII	Media Independent Interface
MSB	Most Significant Bit
MTU	Maximum Transfer Unit
PHY DUT	Physical Layer Device Under Test
PHYBASE	Carrier PCB for PHYDUT and SF2 STARTER KIT
PC	Personal Computer
RGMII	Reduced Gigabit Media Independent Interface
SF2 STARTER KIT	PHY DUT Controller PCB (Smartfusion2 Starter Kit)
SEFI	Single Event Functional Interrupt
SOW	Statement of Work
UDP	User Datagram Protocol

3. Radiation testing

3.1 Total Ionising Dose (TID)

3.1.1 Test Setup

The test setup for Ethernet physical layer transceivers (PHY) characterization is designed and built by Airbus DS. The main parts of the setup are shown in Figure 3-1. More information about the test setup and the test sequence is given in Appendix 1: “PHY Characterization Test Sequence Total Dose”.

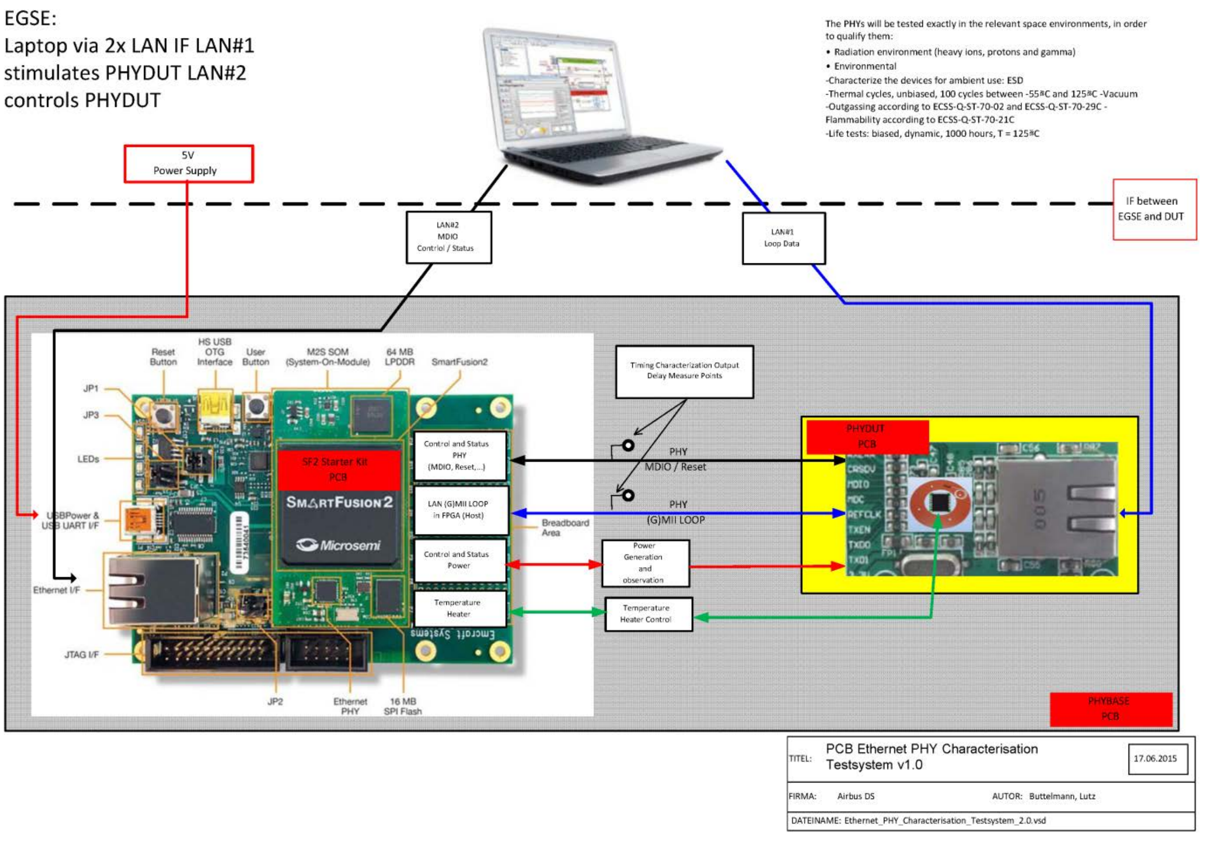


Figure 3-1 The main parts of the test system for Ethernet physical layer transceivers (PHY)

The test setup consists of three PCB groups, a 5V power supply and a Laptop.

The Laptop utilized two separate LAN interfaces to stimulate the PHY DUT test samples (LAN#1) and to control the PHYDUT (LAN#2).

One PCB group consists of:

- SF2 STARTER KIT
- PHYDUT
- PHYBASE

The PHYDUT represents a mezzanine based very tiny PCB with one PHY test sample on it.

The SF2 STARTER KIT forms an FPGA based converter between the LAN interface of the EGSE Laptop and the control interface of the PHY test samples. It provides a RJ45 Ethernet LAN Interface for the EGSE and on the other side a MDIO control and status interfaces for the PHY test sample.

The PHYBASE is the carrier PCB, where the other PCBs can be plugged on. In addition to the carrier function, it provides an SF2 STARTER KIT controlled power and temperature interface for the PHYDUT.

Some measurements points for timing characterization are also provided on SF2 STARTER KIT (see page 10 in Appendix 1: PHY Characterization Test Sequence Total Dose).

Due to the mezzanine composition, the PHYDUTs can be simple replaced by the next sample. This approach improves the performance of the test execution.

3.1.2 Samples

Ten ethernet physical layer transceivers (PHY) from 2 different suppliers were tested. In addition, one reference component from both of suppliers which were not irradiated or annealed, were measured simultaneously as the tested component. Types of the components were: Vitesse VSC8501 and Marvell 88E1111.

3.1.3 TID tests

The total ionisation dose (TID) test was carried out at ESA-ESTEC Co-60 Facility in Noordwijk between 21st of February and 7th of March 2016. The irradiation was done in four steps with cumulative doses of 6.5, 13.0, 27.3 and 50.0 krad in silicon using average dose rate of 309.5 rad/h. Appendix 2: "Radiation Summary" summarized the irradiation conditions and other details. The Total Ionising Dose (TID) is given in water and it is converted to TID in silicon using the ratio of mass energy absorption coefficients for about 1.25 MeV gamma rays (Co-60). Ration 0.898 is used in the conversion. (See. https://escies.org/webdocument/showArticle?id=757&groupid=6)

The radiation facility has been reloaded on October 2011 with a 2000 Ci Co-60 gamma source, which activity was 47.06 TBq on 21st of February 2016. The half-life of Co-60 source is 5.25 years. ^{60}Co decays by beta decay to two possible exited states in ^{60}Ni, which then decay to the ground state by emitting 1.1732 MeV and/or 1.3325 MeV gamma-rays.

The layout of the facility is shown in Figure 3-2 below.

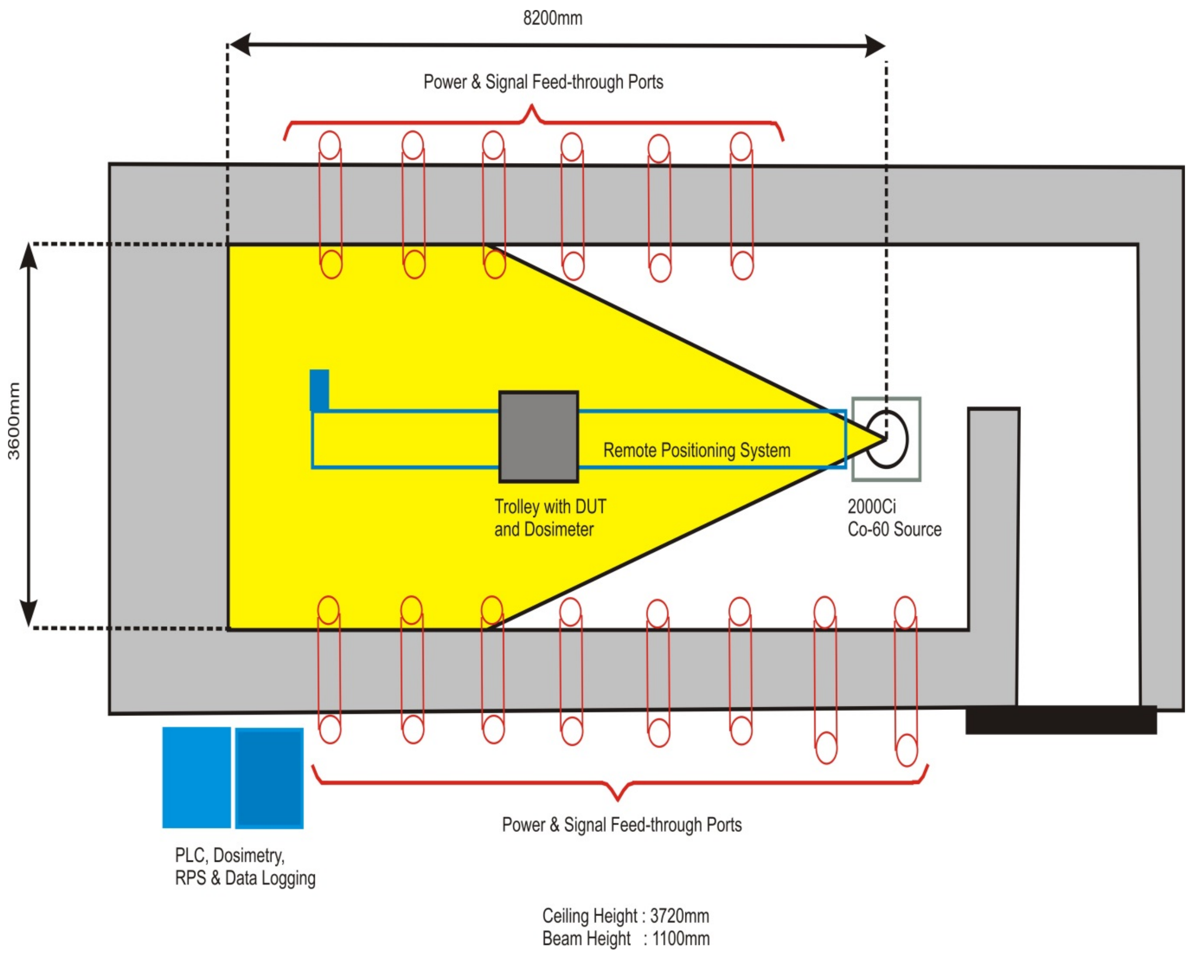


Figure 3-2 Layout of ESA-ESTEC Co-60 Facility in Noordwijk

In all 22 devices, 11 devices from each 2 supplier (Marvell and Vitesse) were tested. One device from both suppliers was selected for reference device, which were not irradiated or annealed. The other devices were irradiated up to 50 krad in silicon in four steps with cumulative doses of 6.5, 13.0, 27.3 and 50 krad, respectively, by using average dose rate of 309.5 rad/h. The function tests of the components were done before irradiation, after each irradiation step and after 163h annealing in 100 degree of Celsius. All 10 components from both suppliers were powered during the irradiation and annealing. Time schedule of the TID test campaign is shown in Table 3-1 Time schedule of the TID test.

Figure 3-3 shows the irradiation configuration at DUT position. More information about the irradiation is given in Appendix 2: “Radiation test summary”.

Test details	Start time	Stop time	Time	Total Ionising Dose (water/silicon) [krad]	Dose Rate (water/silicon) [rad/h]	Cumulative dose (water/silicon) [krad]
Test 0 krad	18.2.2016	19.2.2016				
1st irradiation	22.2.2016 15:33	23.2.2016 12:28	20h 55min	7.239 / 6.50	346.5 / 311.2	7.239 / 6.50
Test 6.5 krad	23.2.2016 12:28	23.2.2016 13:48	1h 20min			
2nd irradiation	23.2.2016 13:48	24.2.2016 10:42	20h 54min	7.239 / 6.50	346.5 / 311.2	14.478 / 13.00

Test 13.0 krad	24.2.2016 10:42	24.2.2016 12:19	1h 29min			
3rd irradiation	24.2.2016 12:19	26.2.2016 10:34	45h 58min*	15.90 / 14.28	346.0 / 310.7	30.382 / 27.28
Test 27.28 krad	26.2.2016 10:34	26.2.2016 11:46	1h 12min			
4th irradiation	26.2.2016 11:46	29.2.2016 13:33	70h 13min	25.30 / 22.72	342.8 / 307.8	55.682 / 50.00
Test 50 krad	29.2.2016 13:33	29.2.2016 15:30	1h 57min			
Annealing 100°C	29.2.2016 15:30	7.3.2016 10:49	163h 19min			
Test	7.3.2016 13:51	7.3 2016 16:50	2h 59min			

* Two short breaks 13 min and 4 min during this run (see. Appendix 2: "Radiation test summary").

Table 3-1 Time schedule of the TID test

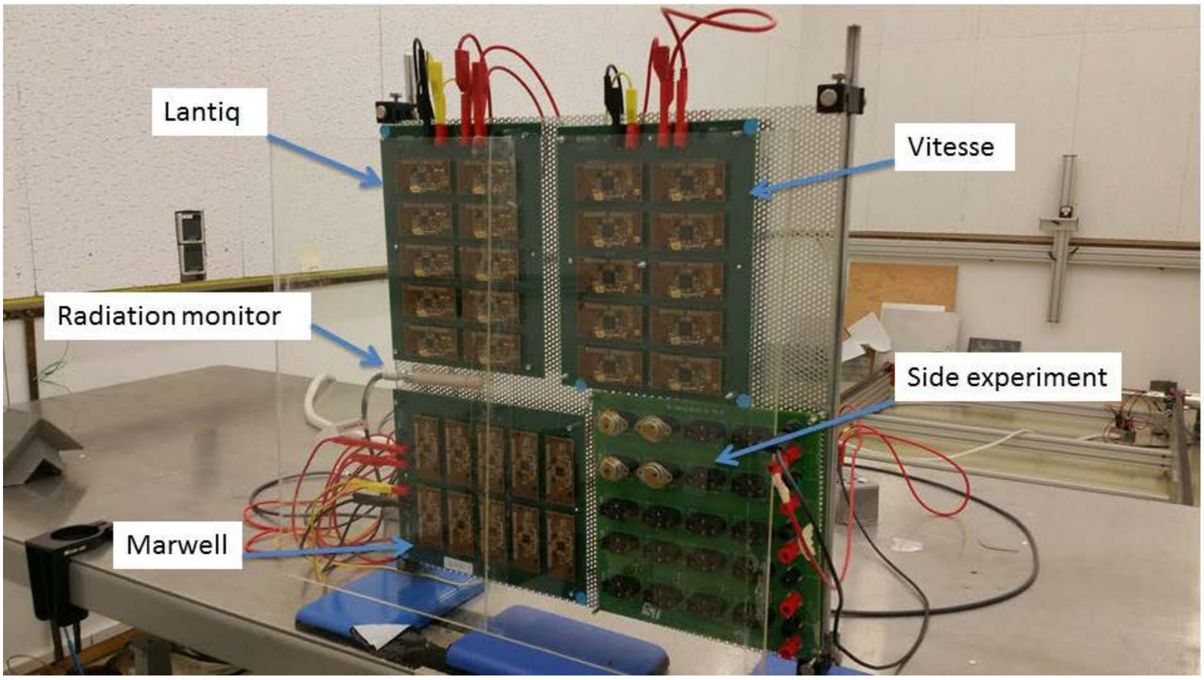


Figure 3-3 Components ready for TID irradiation

3.1.4 TID Results

Test sequence was performed according to detailed introduction given in Appendix 1: "PHY Characterization Test Sequence Total Dose".

During the first pretests in Bremen on 19.2.2016, one Marvell component (#3) was not communicated with test computer at all and it was replaced with other one (#12). After some closer investigation it was noticed that the component itself was working normally when it was pressed against the PCB. It was concluded that, most probably the soldering of the component to the PCB was not perfect.

3.1.4.1 Current consumption and functional results

First the current consumption of 10 DUTs for 1V and 2.5V power voltages was measured (Appendix 1: page 3) before and after individual DUT tests (measurement was done twice between irradiation steps). Figure 3-4 shows the evolution of the current consumption starting from pretests is Bremen 19.2.2016 and ending to the measurement after annealing 7.3.2016.

For Marvell components, the average currents of all 12 measurements were 58.7mA for 1V and 237.2mA for 2.5V with standard deviation of 4.6mA and 2.5mA, respectively. With Marvell it was however noticed a strange behavior quite often when the power was turned on. The current consumption of 1V line was either 50mA or 60mA and for 2.5V about 240mA, 400mA or sometime even 600mA. Reason for this behavior was not completely sure and therefore the current values were booked only went the 2.5V current was showing lower, about 240mV value.

For Vitesse the average currents were 154.9mA for 1V and 68.9mA for 2.5V with standard deviation of 2.7mA and 0.5mA, respectively.

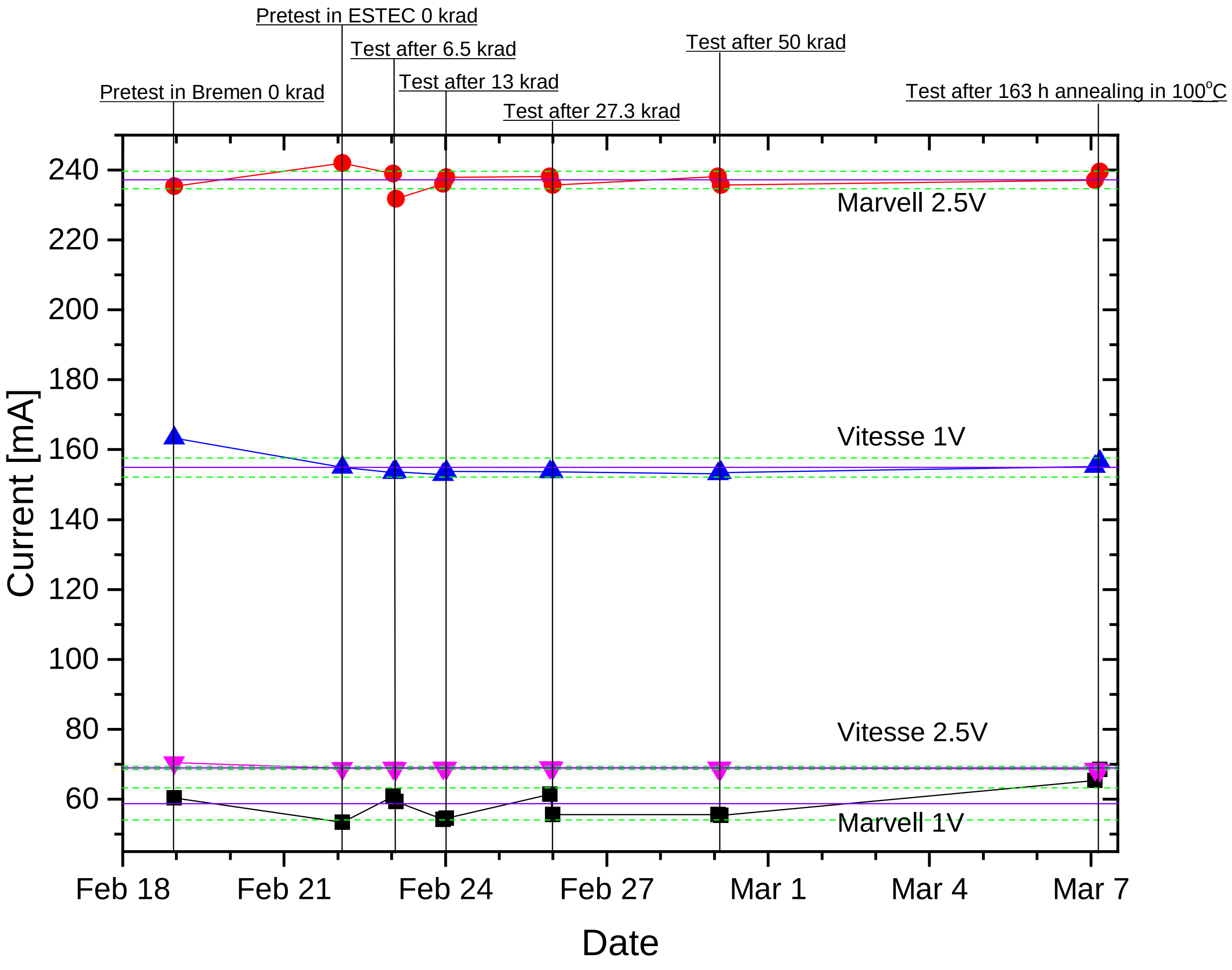


Figure 3-4 Evolution of current consumption of 10 Marvell and 10 Vitesse components over irradiation and annealing. Violet lines are average values and green dashed lines are average value ± standard deviation.

The “Test 4000 packets” is a short test to check the functionality and current consumption of the PHYs for 100Mbps and 1000Mbps mode. This test was done 6 times for each component. First it was done before irradiations, then after each irradiation step and finally after annealing. Test sequence is described detailed in Appendix 1, starting page 5.

In this test, LAN packets generator program Colasoft sent 4000 packets of data to the PHYDUT which sent it to FPGA. FPGA looped data back to PHYDUT which then send it back to the EGSE Laptop. If everything worked correct, LAN data packet counter program Wireshark register 8000 data packets (see Appendix 1: page 8). Only number of sent and received packets was registered. Contents of the packets were not analyzed. At the same time the current consumptions of each PHYDUT for 1 V and 2.5 V power lines were registered.

Table 3-2 shows the results of data packet counter program Wireshark. If all 8000 data packets were registered with Wireshark program and no any problem were observed with the component the cell is marked “OK”. If packets were lost cell is market with red note. Next four tables summarize the power consumption conditions. More details are given in text after tables.

Table 3-2 Results of “Test 4000 packets” for Marvell.

		Marvell components in “4000 packets test”									
	Mbps	#1	#2	#3	#12	#5	#6	#7	#8	#9	#10
Pre test	100	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	1000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
6.5 krad	100	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	1000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
13 krad	100	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	1000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
27.3 krad	100	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	1000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
50 krad	100	OK	OK	OK	2 lost	OK	OK	OK	OK	OK	2 lost
	1000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
annealed	100	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
	1000	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

Table 3-3 Current consumption of Marvell for 1V power line and 100MBps speed.

		Marvell: current consumption for 1V power [mA]									
	Mbps	#1	#2	#3	#12	#5	#6	#7	#8	#9	#10
Pre test	100	24	24	24	24	24	24	24	24	24	24
6.5 krad	100	24	24	24	24	24	24	24	24	24	24
13 krad	100	24	24	24	24	24	24	24	24	24	24
27.3 krad	100	24	24	24	24	24	24	24	24	24	24
50 krad	100	24	24	24	24	24	24	24	24	24	24
annealed	100	24	24	24	24	24	24	24	24	24	24

Table 3-4 Current consumption of Marvell for 2.5V power line and 100MBps speed.

		Marvell: current consumption for 2.5V power [mA]									
	Mbps	#1	#2	#3	#12	#5	#6	#7	#8	#9	#10
Pre test	100	80	80	88	80	80	88	80	88	80	80
6.5 krad	100	80	88	88	88	80	80	80	80	88	80
13 krad	100	80	88	80	80	88	80	80	80	80	80
27.3 krad	100	80	88	80	80	88	80	80	80	80	80
50 krad	100	80	88	88	80	88	88	80	80	88	80
annealed	100	80	88	80	80	88	88	88	80	88	80

Table 3-5 Current consumption of Marvell for 1V power line and 1000Mbps speed.

		Marvell: current consumption for 1V power [mA]									
	Mbps	#1	#2	#3	#12	#5	#6	#7	#8	#9	#10
Pre test	1000	192	192	200	200	192	200	200	200	200	200
6.5 krad	1000	192	192	200	200	192	192	200	200	200	200
13 krad	1000	192	192	200	200	192	200	200	200	200	200

27.3 krad	1000	192	192	200	200	192	200	200	200	200	200
50 krad	1000	192	192	200	200	200	200	200	200	200	200
annealed	1000	192	192	200	200	192	192	200	200	200	200

Table 3-6 Current consumption of Marvell for 2.5V power line and 1000Mbps speed.

		Marvell: current consumption for 2.5V power [mA]									
	Mbps	#1	#2	#3	#12	#5	#6	#7	#8	#9	#10
Pre test	1000	184	184	184	184	184	184	184	184	184	184
6.5 krad	1000	184	184	184	184	184	184	184	184	184	184
13 krad	1000	184	184	184	184	184	184	184	184	184	184
27.3 krad	1000	184	184	184	184	184	184	184	184	184	184
50 krad	1000	184	184	184	184	184	184	184	184	184	184
annealed	1000	184	184	184	184	184	184	184	184	184	184

3.1.4.2 Pretests 0krad

All the components worked correctly. No data packets lost.

The current consumptions at 100Mbps speed were 24mA for 1V and 80mA (#1, #2, #12, #5, #7, #9, #10) or 88mA (#3, #6, #8) 2.5V. At 1000Mbps speed 1V currents were 192mA (#1, #2, #5) or 200mA (#3, #12, #6, #7, #8, #9, #10) and for 2.5V 184mA.

3.1.4.3 Test after 6,5 krad

All the components worked correctly. No data packets lost.

The current consumptions at 100Mbps speed were 24mA for 1V and 80mA (#1, #5, #6, #7, #8, #10) or 88mA (#2, #3, #12, #9) 2.5V. At 1000Mbps speed 1V currents were 192mA (#1, #2, #5, #6) or 200mA (#3, #12, #7, #8, #9, #10) and for 2.5V 184mA.

3.1.4.4 Test after 13 krad

All the components worked correctly. No data packets lost.

The current consumptions at 100Mbps speed were 24mA for 1V and 80mA (#1, #3, #12, #6, #7, #8, #9, #10) or 88mA (#2, #5) 2.5V. At 1000Mbps speed 1V currents were 192mA (#1, #2, #5) or 200mA (#3, #12, #6, #7, #8, #9, #10) and for 2.5V 184mA.

3.1.4.5 Test after 27,3 krad

All the components worked correctly. No data packets lost.

The current consumptions at 100Mbps speed were 24mA for 1V and 80mA (#1, #3, #12, #6, #7, #8, #9, #10) or 88mA (#2, #5) 2.5V. At 1000Mbps speed 1V currents were 192mA (#1, #2, #5) or 200mA (#3, #12, #6, #7, #8, #9, #10) and for 2.5V 184mA.

3.1.4.6 Test after 50 krad

When testing component #1 using 100Mbps the component had to be pressed with finger. Otherwise only 4000 packets were seen. This indicated that there was a problem with the soldering of the component to the PCB. In addition, the test computer did not automatically recognize the correct speed. For the 100Mbps test the computer had to be forced to 100Mbps. Otherwise component #1 was working correct.

Components #2 and #7 lost 1 packet when using 100Mbps. When the test was repeated (2nd and 3rd time) not packets were lost. All the other components were working correct.

The current consumptions at 100Mbps speed for all the components were 64mA and 104mA for 1V and 2.5V powers, respectively. At 1000Mbps speed 1V currents were 112mA (#1, #4, #5, #6, #8, #9) or 120mA (#2, #3, #7, #10) and for 2.5V 160mA.

3.1.4.7 Test after annealing 163 h and 100°C

When testing components #1, #4, #8 and #10 using 100Mbps the component had to be pressed with finger. Otherwise only 4000 packets were seen. This indicated that there was a problem with the soldering of the component to the PCB.

In addition, with component #1 and #9 the test computer did not automatically recognize the correct speed when using 100Mbps. For the test the computer had to be forced to 100Mbps. Otherwise component was working correct.

The current consumptions at 100Mbps speed for all the components were 64mA and 104mA for 1V and 2.5V powers, respectively. At 1000Mbps speed 1V currents were 112mA (#1, #2, #3, #4, #5, #6, #7, #8, #10) or 120mA (#9) and for 2.5V 160mA.

3.1.4.8 Timing characterisation

Testing of timing properties was performed according the introduction given in Appendix 1: "PHY Characterization Test Sequence Total Dose" starting from page 9. The error bars for the average values in the following figures represent confidential interval of one sigma, 68.2%.

3.1.4.8.1 Marvell

First is shown the evolution of timing properties for Marvell components. Figures from Figure 3-5 to Figure 3-8 summarize the behavior of RX clock period and RX clock to Data delay times, respectively, for 100Mbps speed. In pretests, 12.9ns and 33ns delays were measured for components #1 and #2, respectively. Those two values are left out of the scale and average values. No clear changes in timing properties can be observed. Data for Reference device is also shown in figures.

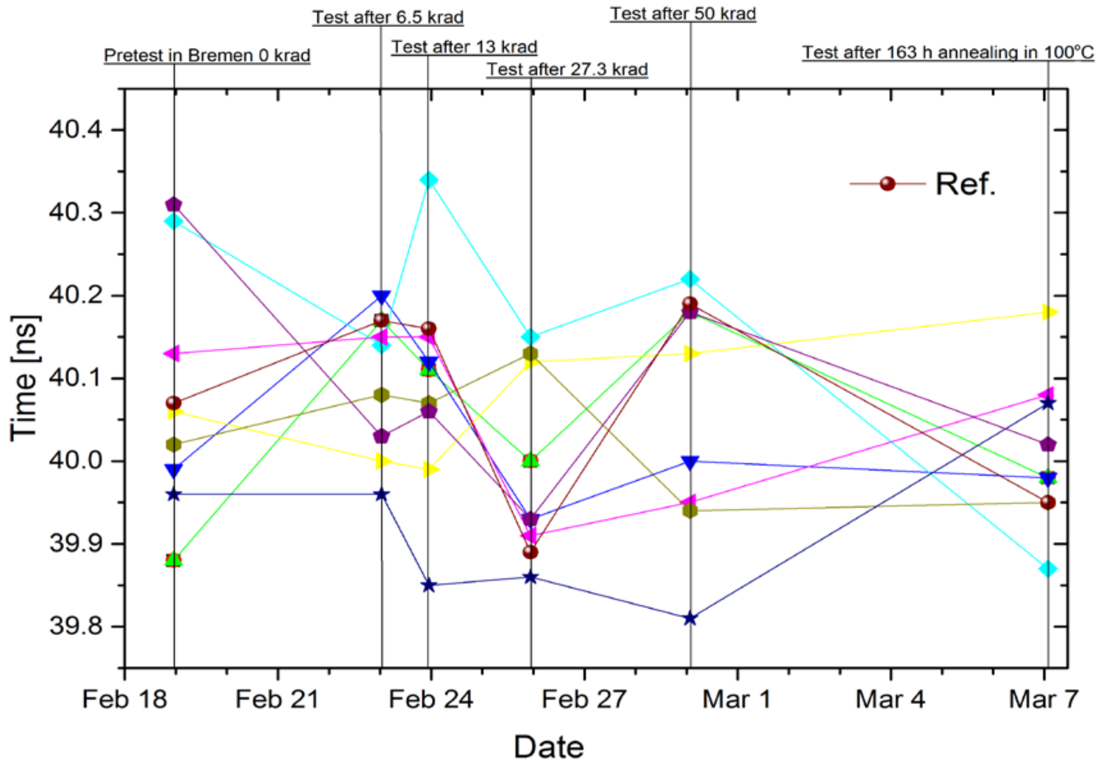


Figure 3-5 RX Clock period Marvell 100MB/s.

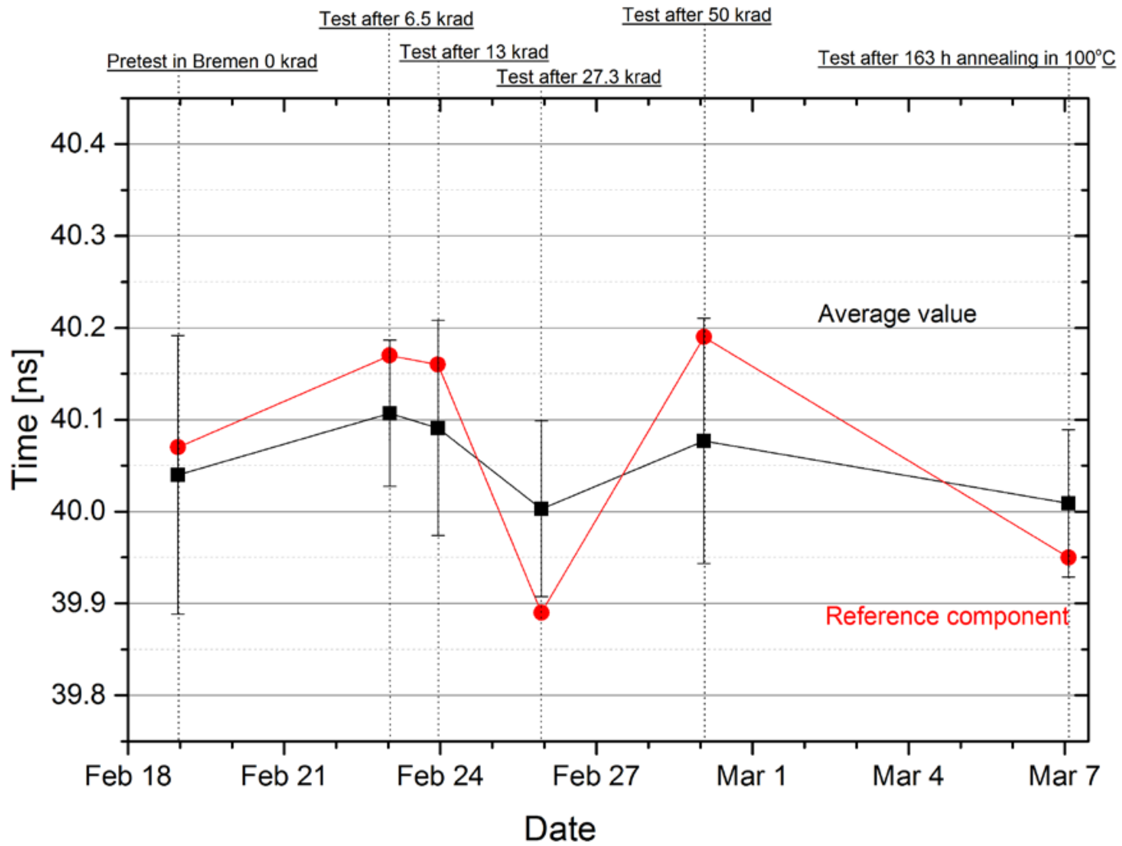


Figure 3-6 Average of RX Clock period for Marvell at 100MB/s compared with reference component.

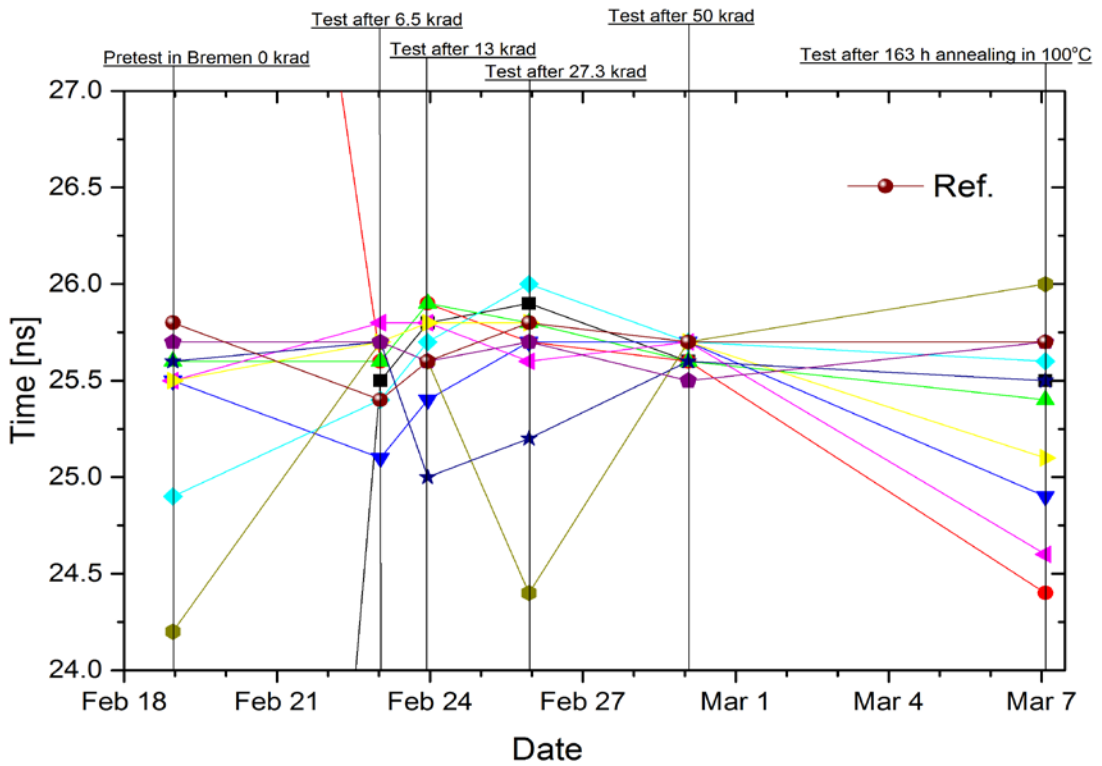


Figure 3-7 RX Clock to Data delay for Marvell 100MBps.

In pretests, 12.9ns and 33ns delays were masured for components #1 and #2, respectively. Those two values are left out of the scale.

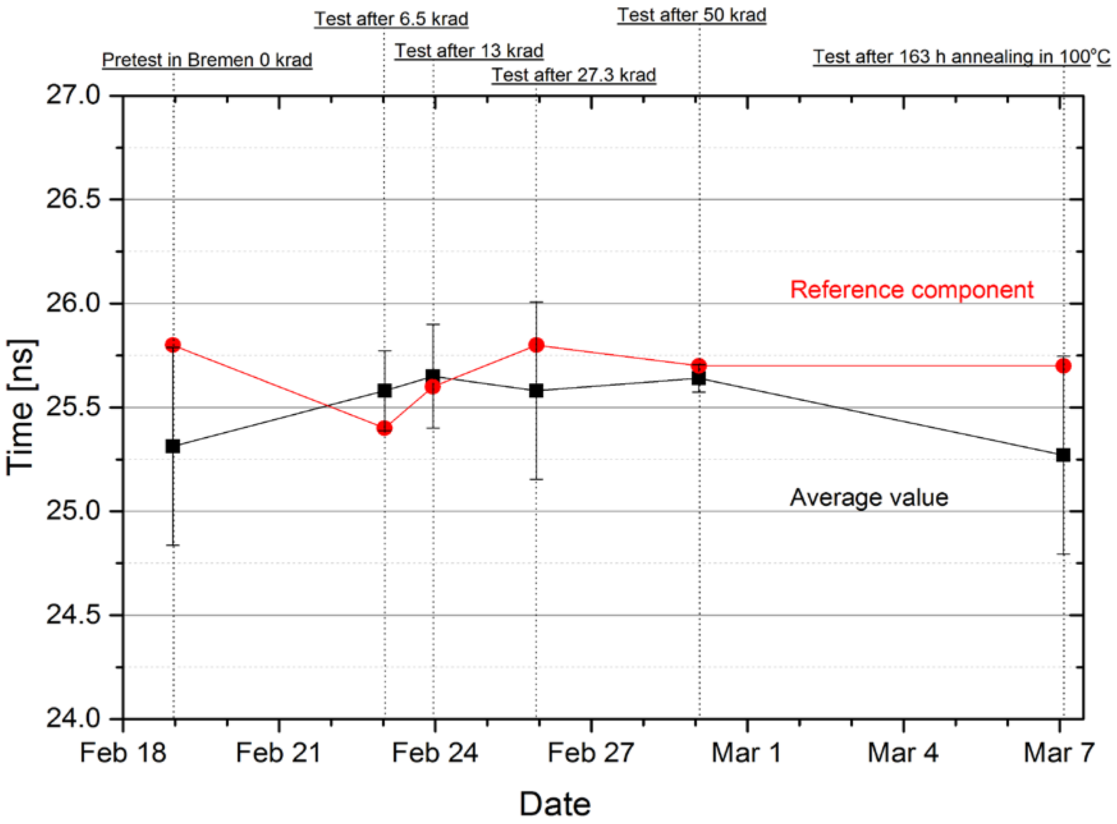


Figure 3-8 Average of RX Clock to Data delay for Marvell at 100MB/s compared with reference component.

Abnormal results of pretestes for components #1 and #2 were left out from the average values.

Then, Figures from Figure 3-9 to Figure 3-12 show the behavior of RX clock period and RX clock to Data delay times, respectively, for 1000Mbps speed. No clear changes in timing properties can be observed. Data for Reference device is also shown in figures.

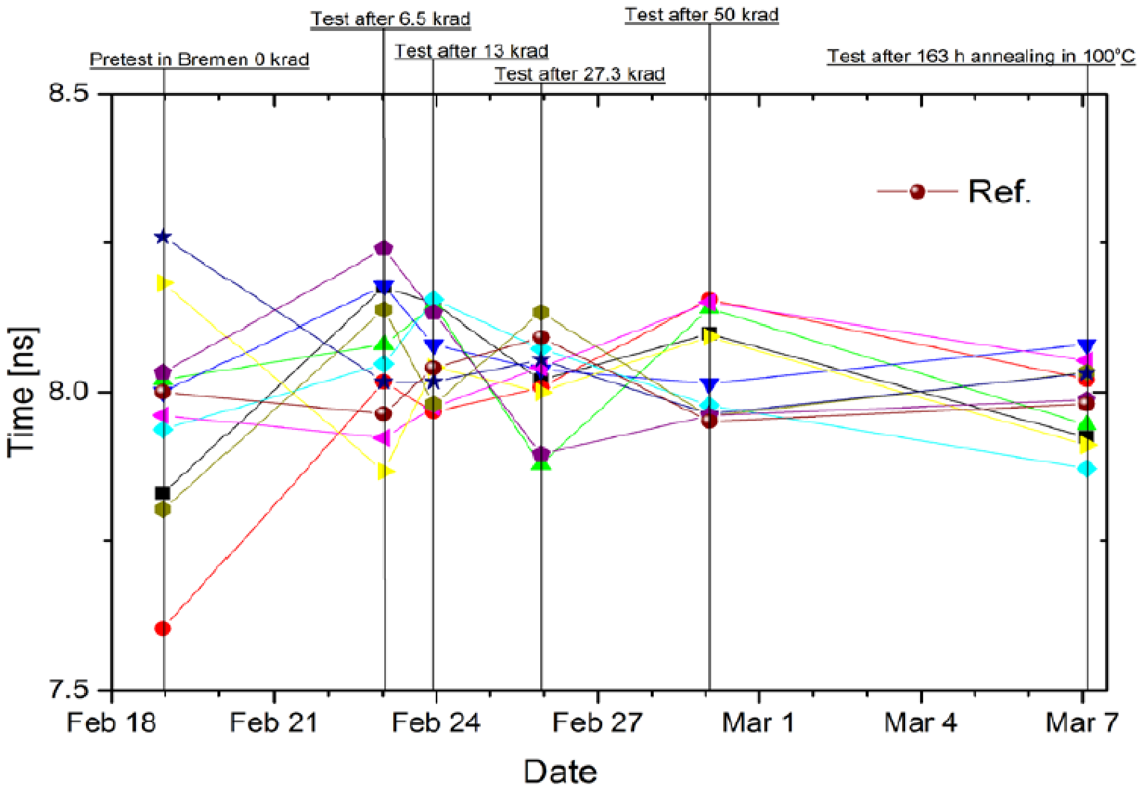


Figure 3-9 RX Clock period Marvell 1000MB/s

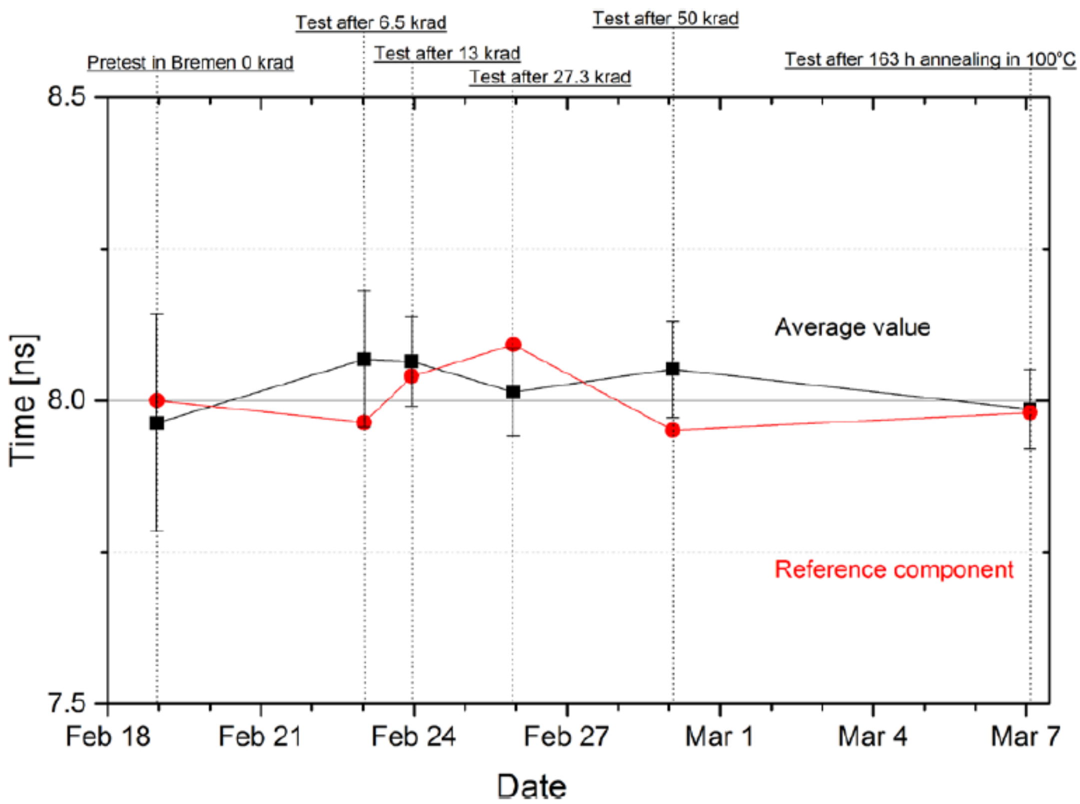


Figure 3-10 Average of RX Clock period for Marvell at 1000MB/s compared with reference component.

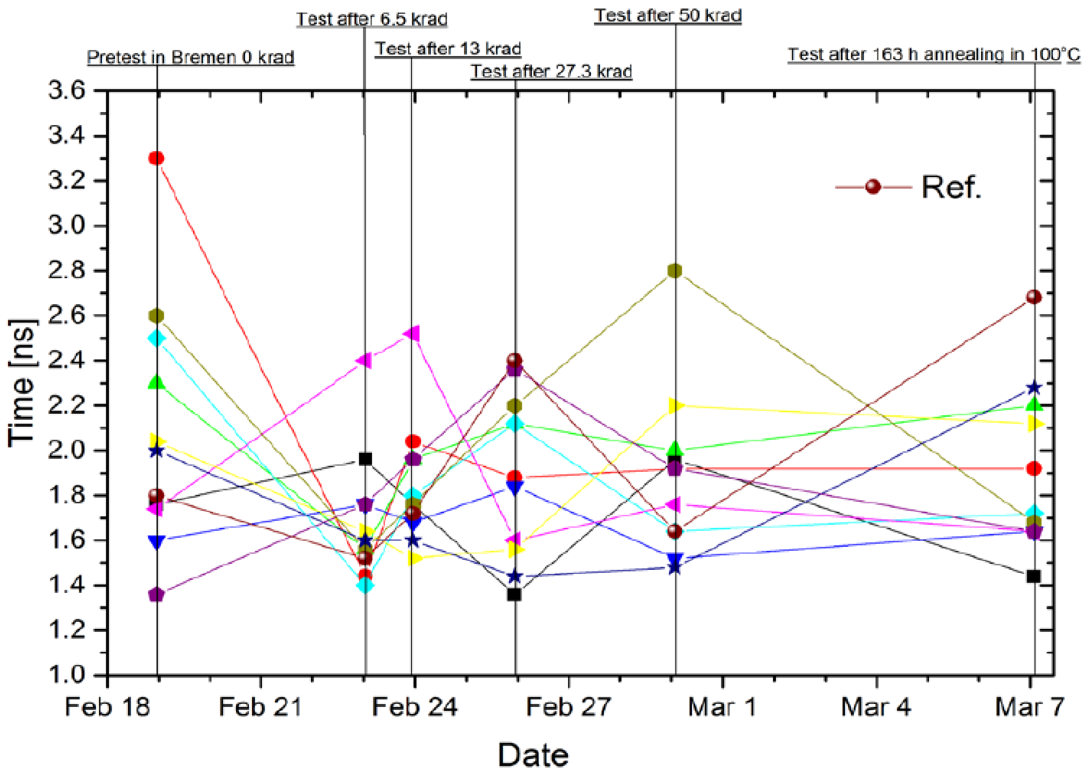


Figure 3-11 RX Clock to Data delay for Marvell 1000MB/s

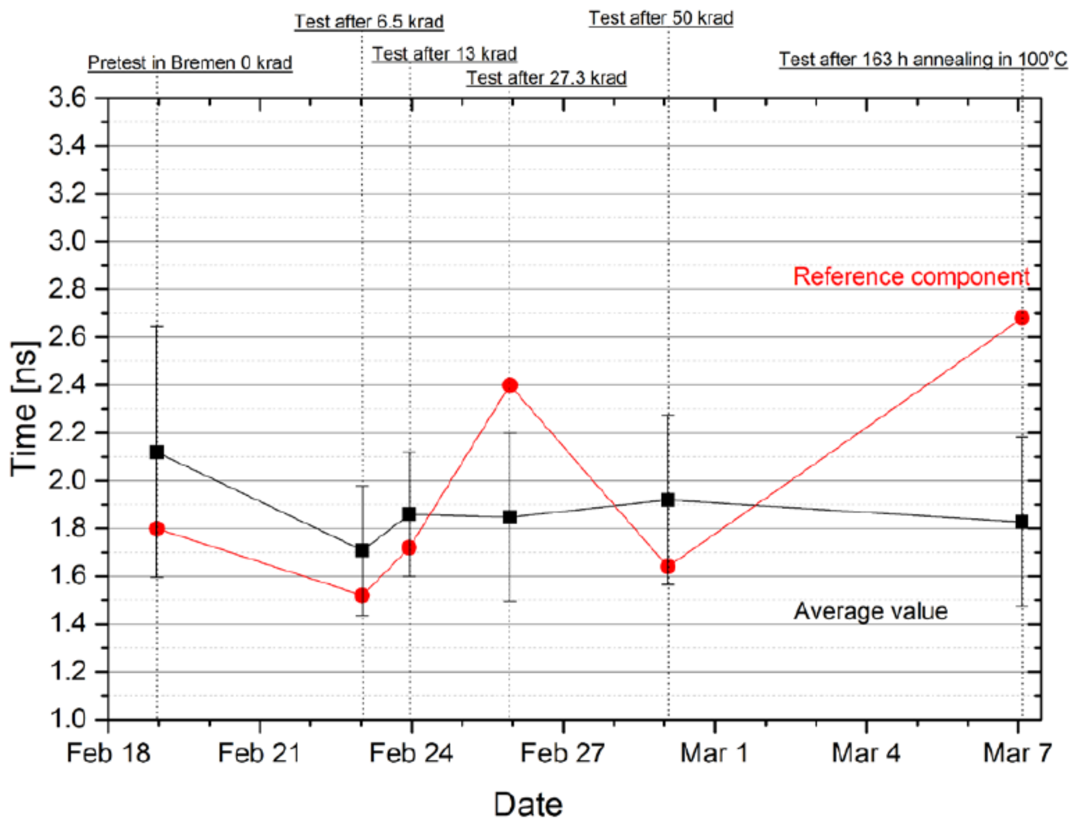


Figure 3-12 Average of RX Clock to Data delay for tested Marvell at 1000MB/s compared with reference component.

3.1.4.8.2 Vitesse

Figures Figure 3-13 to Figure 3-16 show the evolution of RX clock period and RX clock to Data delay times for Vitesse components when 100Mbps speed was used. Data for Reference device is also shown in figures. After annealing 47.82ns and 47.73ns RX clock to Data delay times were measured for component #2 and Refrence component which was not irradiated or annealed. Those values are left out of the scale. No clear changes in timing properties can be observed.

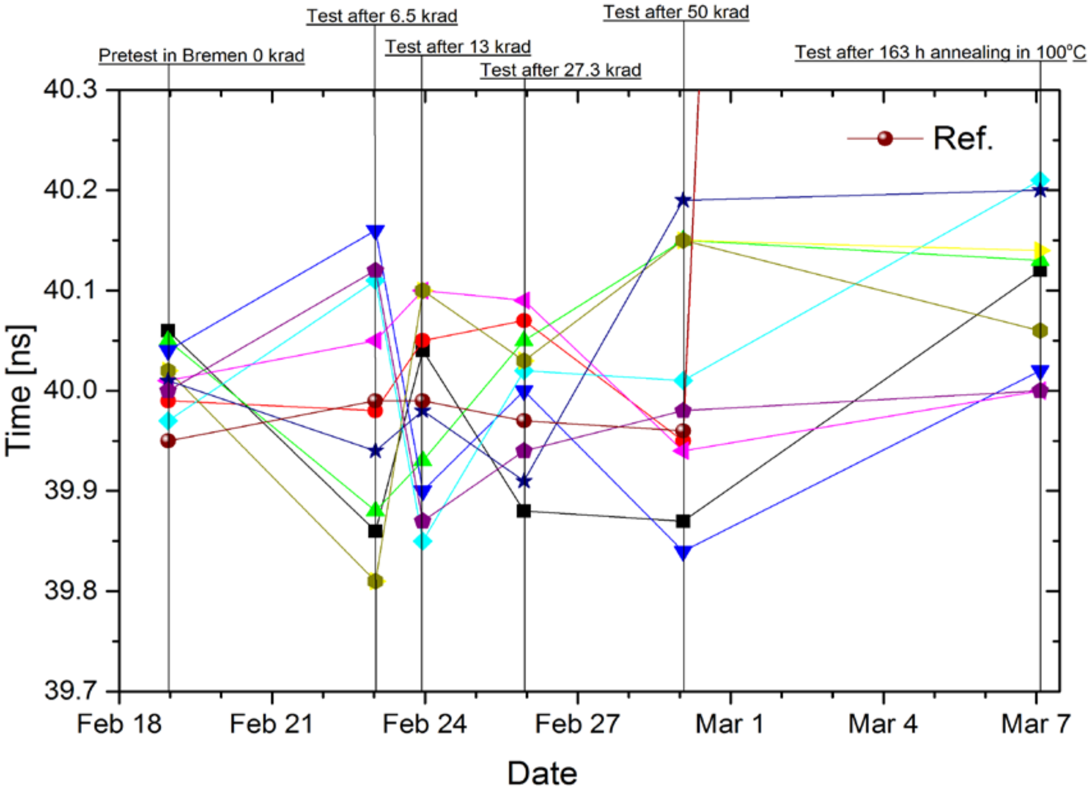


Figure 3-13 RX Clock period for Vitesse 100MB/s.

After annealing 47.82ns and 47.73ns delay was measured for component #2 and Refrence component which was not irradiated or annealed. Those values are out of the scale.

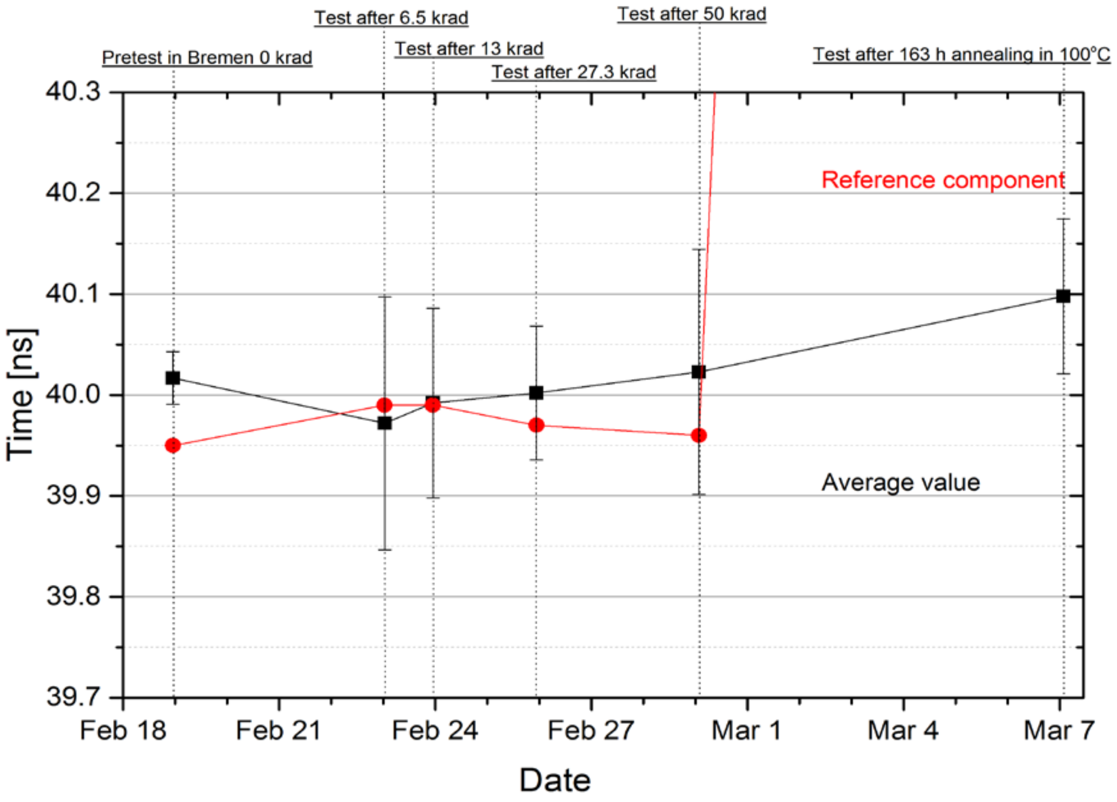


Figure 3-14 Average of RX Clock to Data delay for Vitesse at 100Mbps compared with reference component.

Abnormal results of component #2 after annealing is left out from the average value.

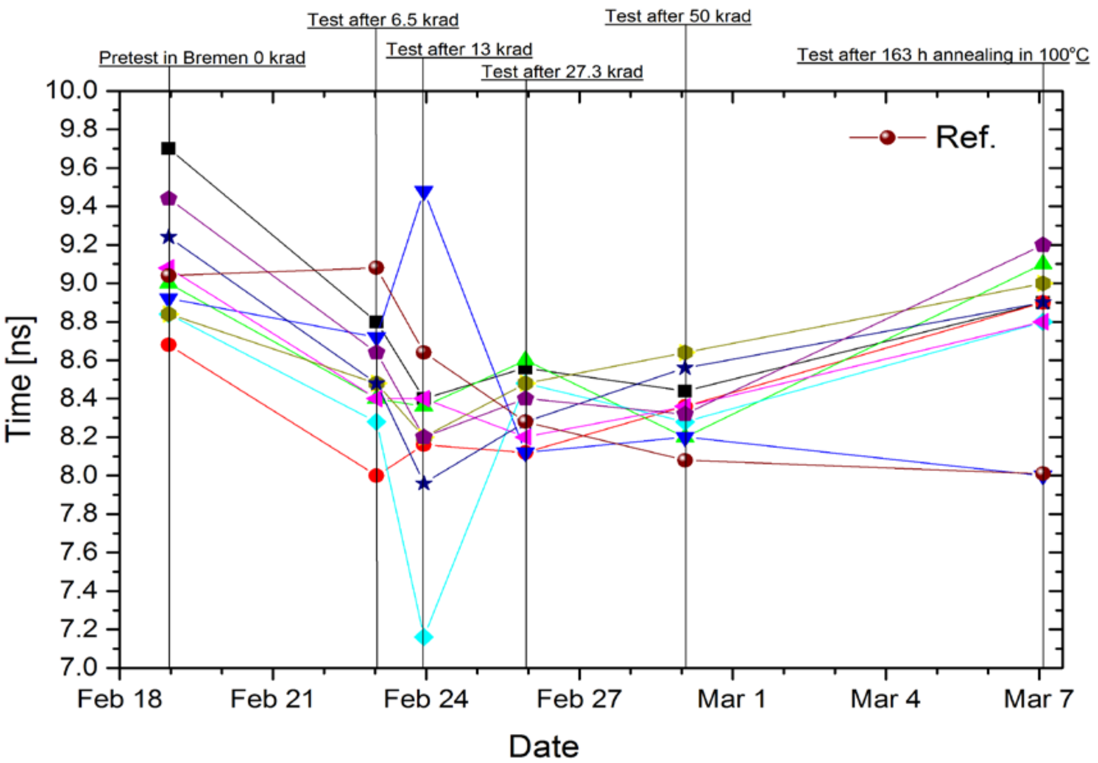


Figure 3-15 RX Clock to Data delay for Vitesse 100MB/s.

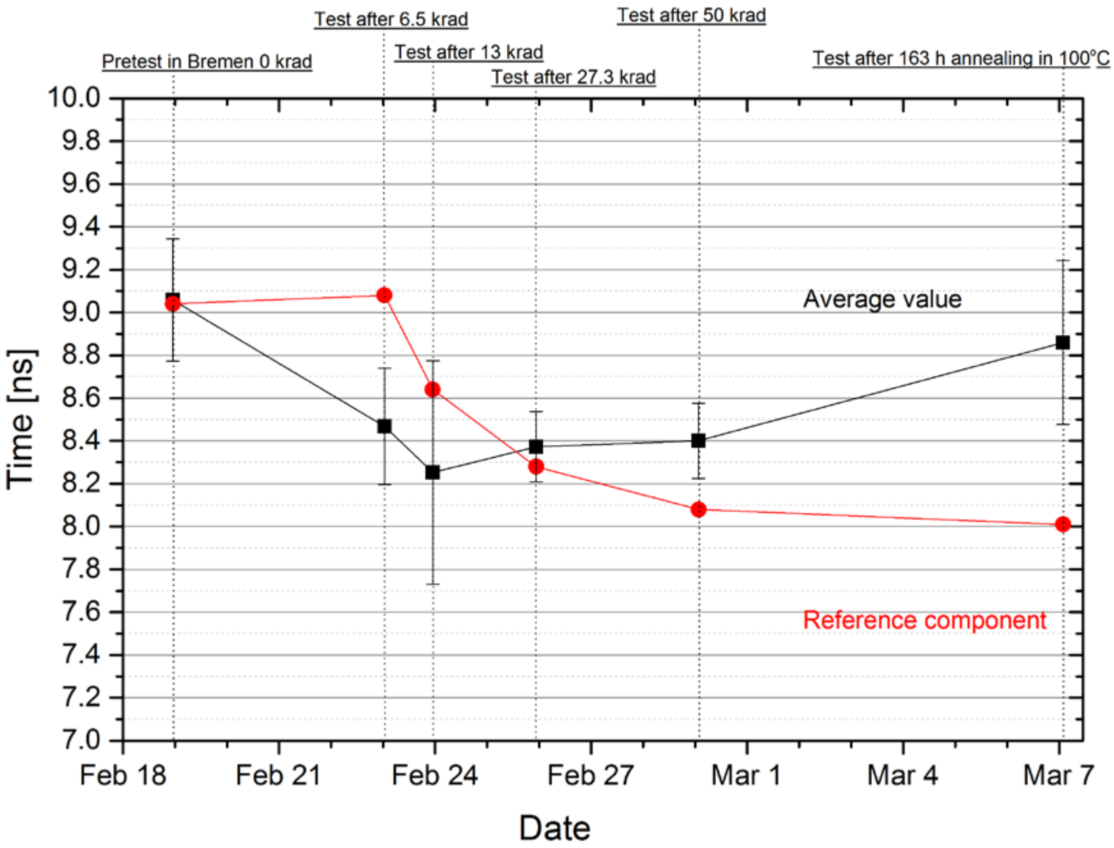


Figure 3-16 Average of RX Clock to Data delay for Vitesse at 100Mbps compared with reference component.

Then same data, but using 1000Mbps speed in figures from Figure 3-17 to Figure 3-20.

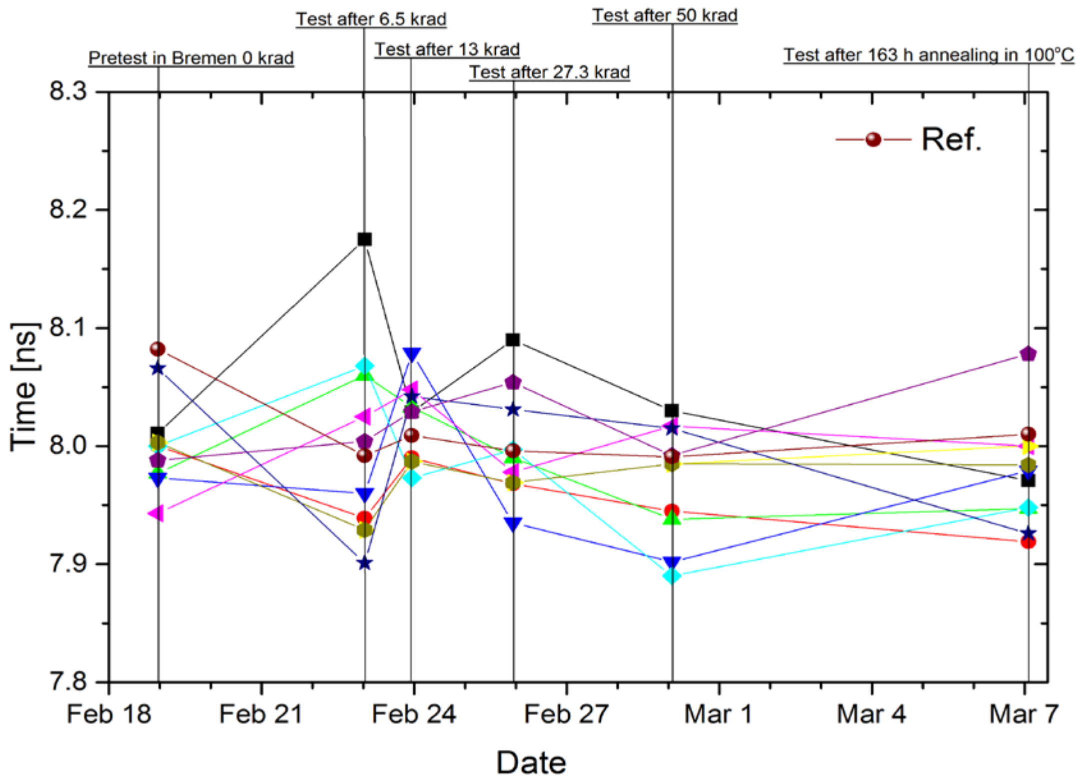


Figure 3-17 RX Clock period for Vitesse 1000Mbps.

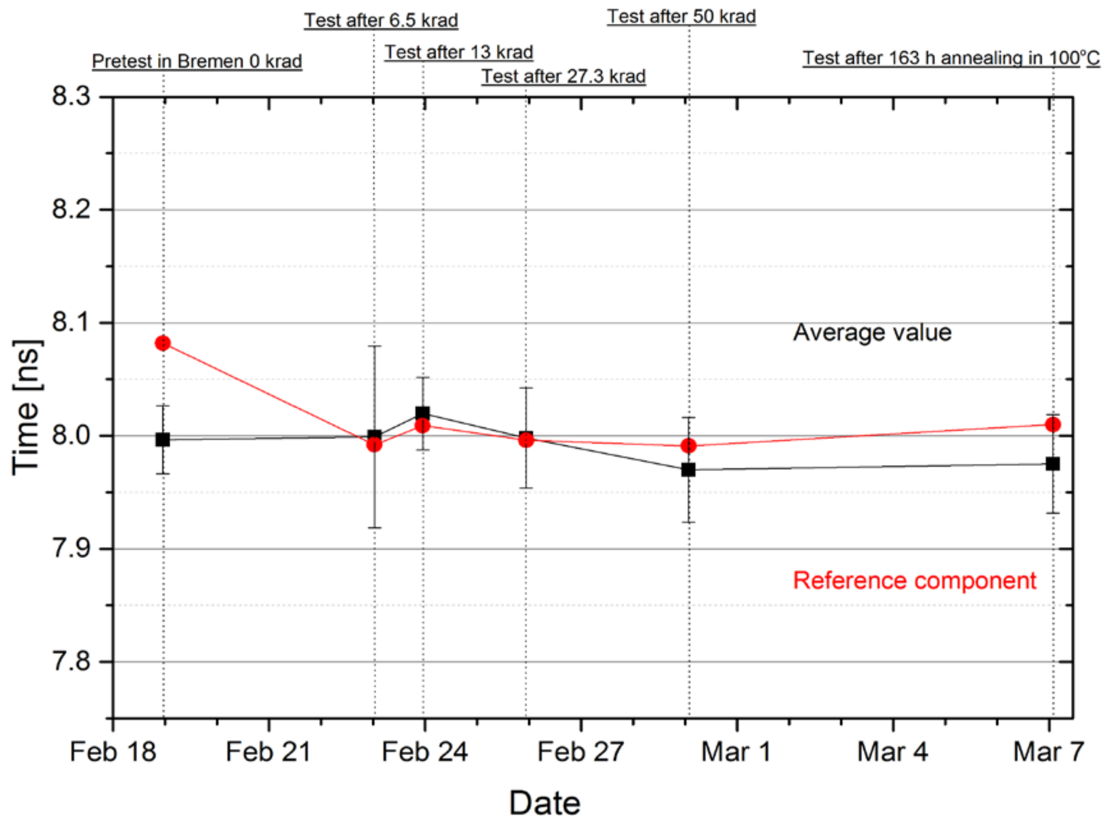


Figure 3-18 Average of RX Clock period for Vitesse component at 1000Mbps compared with reference component.

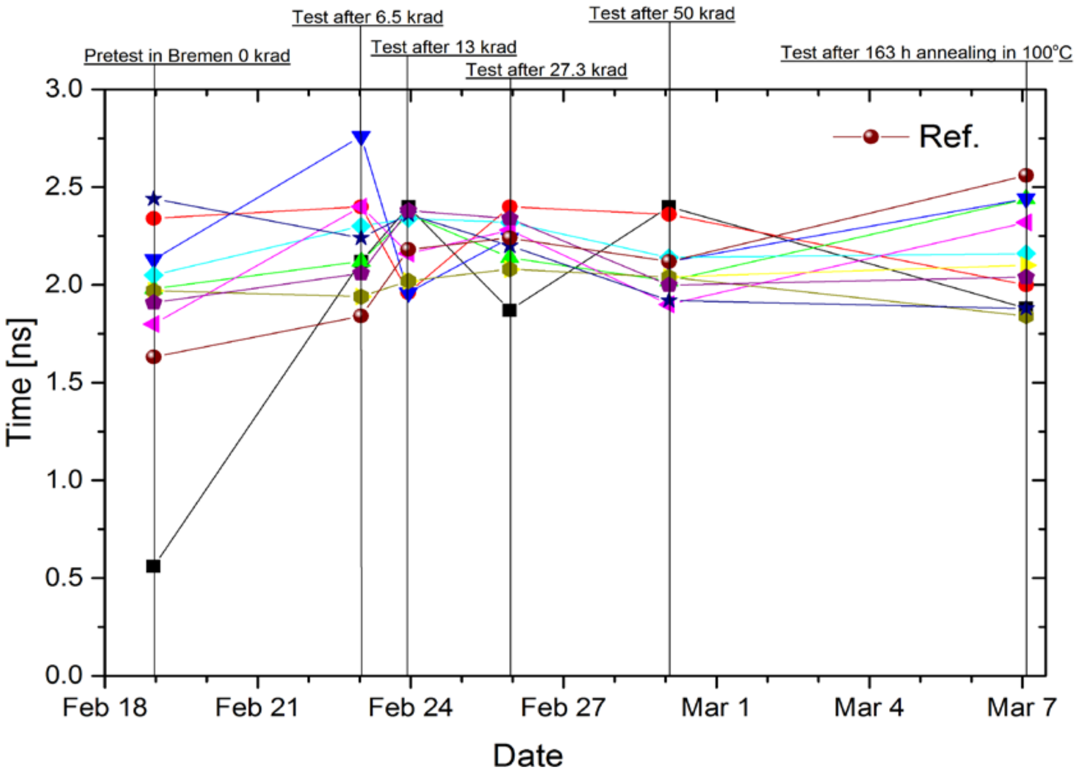


Figure 3-19 RX Clock to Data delay for Vitesse 1000MB/s.

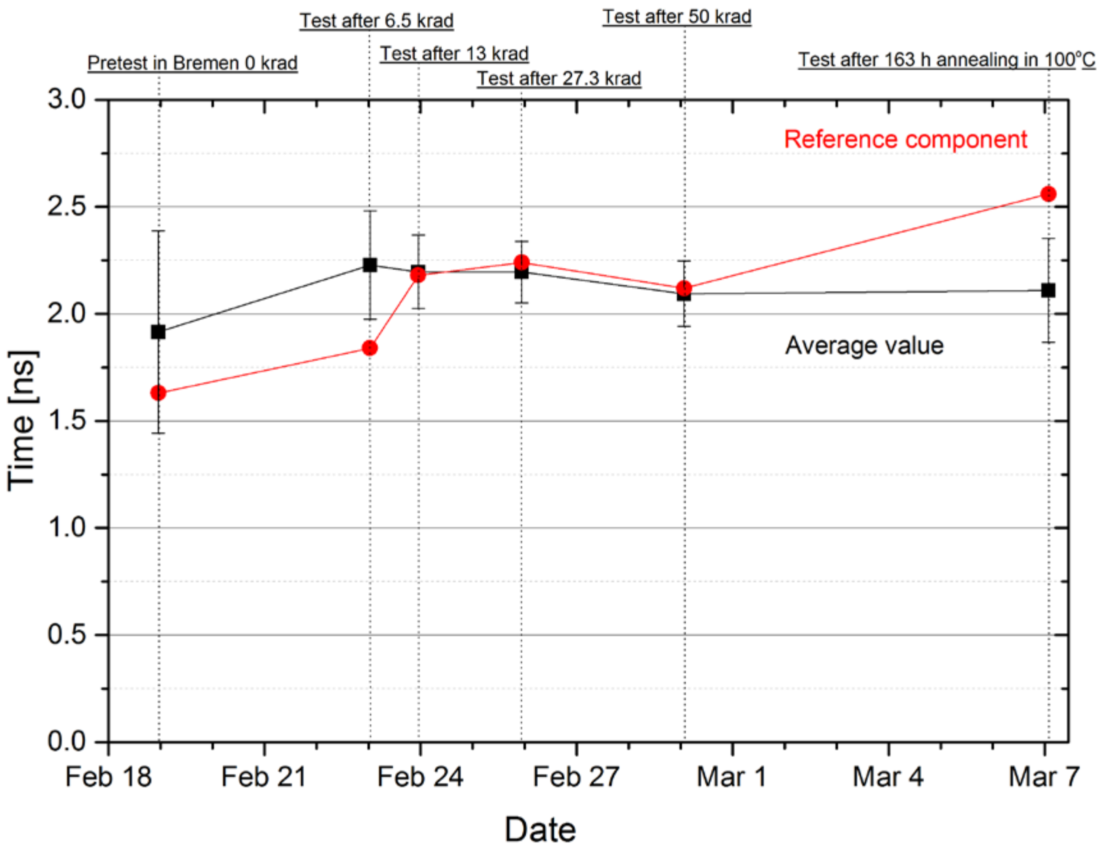


Figure 3-20 Average of RX Clock to Data delay for Vitesse at 1000MB/s compared with reference component.

3.1.5 TID Summary

In all 20 Ethernet PHY transceivers, 10 transceivers from 2 different suppliers were TID tested in ESA-ESTEC Co-60 Facility in Noordwijk. In addition, 1 component from both suppliers was measured as a reference component. The tested components were irradiated up to 50krad (in silicon) with four cumulative steps 6.5, 13, 27.3 and 50krad. After irradiation, components were annealed in 100°C 163 hours.

Components were tested before and after each irradiation steps and annealing. First was tested current consumption of 10 components on PHYTID PCB board. No systematic change in the current consumption was observed.

Then functionality and current consumption of each component was checked in “Test 4000 packets”-test. Only number of sent and received packets was registered. Contents of the packets were not analyzed. At the same time the current consumptions of each PHYDUT for 1 V and 2.5 V power lines were registered. No clear effects of radiation were observed. Sometimes 1 or 2 packets out of 8000 was lost, but it was not possible to conclude was the reason radiation effects or bad solder connections between the component and PCB board. No clear systematics in current consumption of components was observed.

Changes in timing properties of each component were measured according the Appendix 1 starting from page 9. No effects of radiation were observed in RX clock period or RX clock to data delay measurements.

We may conclude that Vitesse and Marvell could be deployed in radiation environments with Total Ionising Doses up to 50 krad(Si), depending on the required application design margins, with no deterioration of the functional and of timing properties.

3.2 Heavy ion testing

3.2.1 RADEF facility

The heavy ion irradiation tests were carried out at RADEF facility at Accelerator laboratory of University of Jyväskylä. The beam lines at RADEF are shown in Figure 3-21. For the test the 9.3MeV/u ion cocktail from the K130-cyclotron was used. The cocktail includes in all 7 ion species listed in table 1. The developments of LET values of the ions as a function of range in silicon are shown in Figure 3-22.

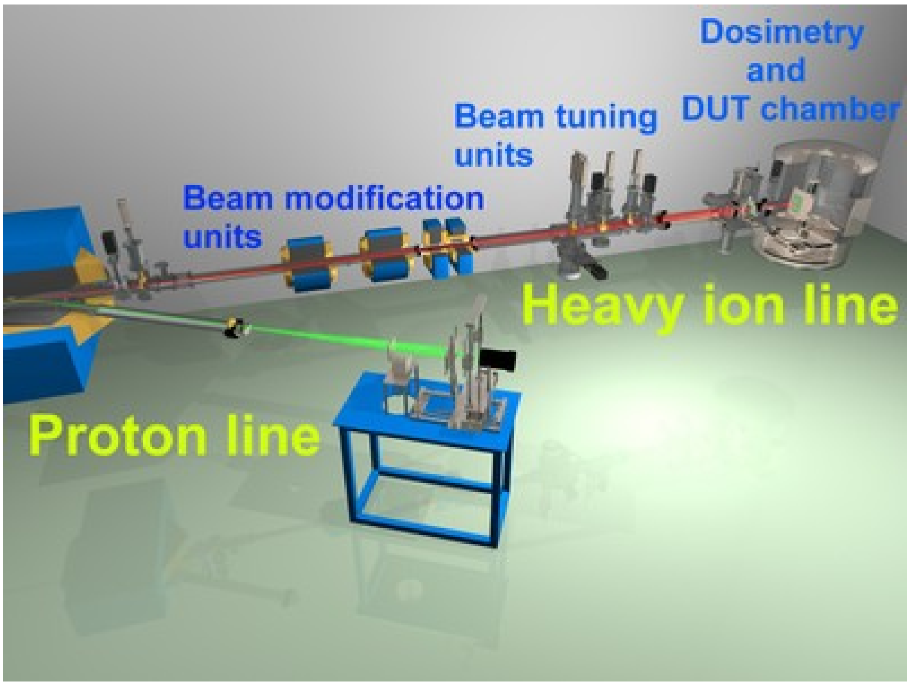


Figure 3-21 Heavy ion and low energy proton beam line with the vacuum chamber at RADEF.

High energy protons are taken to air using the beam line at front.

Table 3-7 Ion species in the 9.3MeV/u cocktail. N, Fe, Kr and Xe

These ions are in the same ion cocktail and the ion change between them can be accomplished within less than 15 min. The same is between Ne and Ar. The changing between ions with different colors in the table takes about 1 hour.

Ion	Energy [MeV]	$LET^{surface}$ [MeV/mg/cm^2]	$LET^{Bragg\ peak}$ [MeV/mg/cm^2]	Range in silicon [µm]
$^{15}N^{+4}$	139	1.8	5.9	202
$^{20}Ne^{+6}$	186	3.6	9.0	146
$^{30}Si^{+8}$	278	6.4	14.0	130
$^{40}Ar^{+12}$	372	10.2	19.6	118
$^{56}Fe^{+15}$	523	18.5	29	97
$^{83}Kr^{+22}$	768	32	41	94
$^{131}Xe^{+35}$	1217	60	69	89

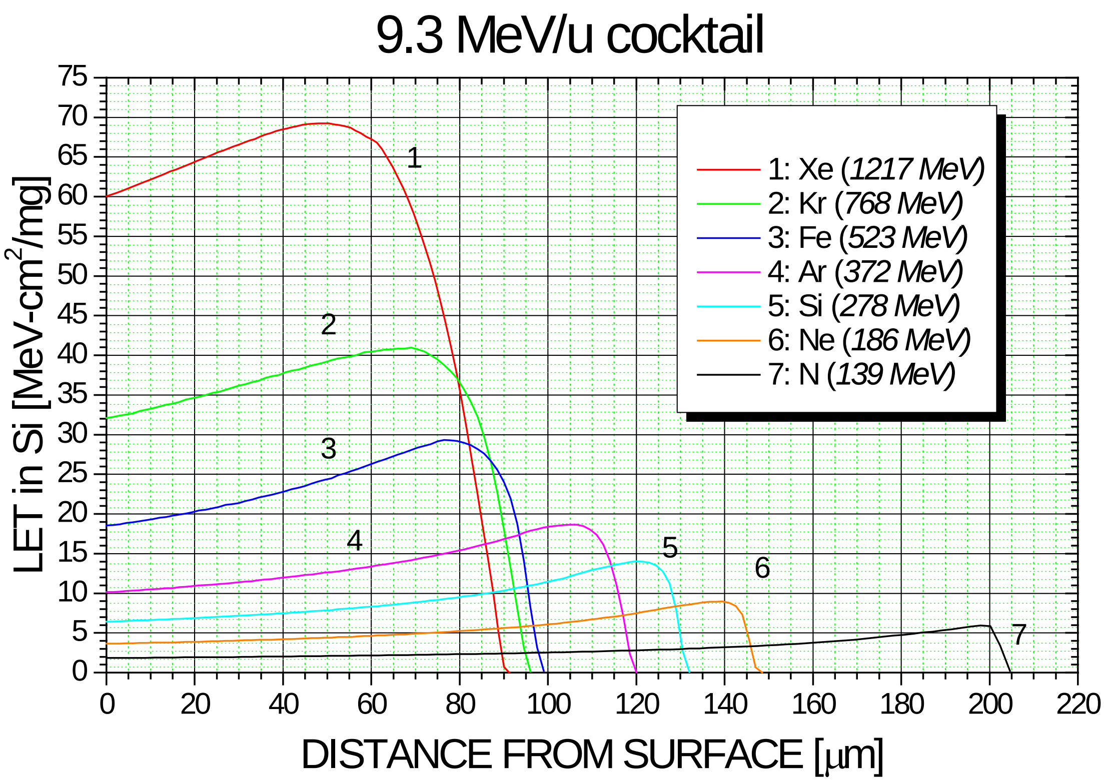


Figure 3-22 LET curves of 9.3 MeV/u cocktail ions in silicon.

The beam homogeneity over about 1.4x1.4 cm^2 collimated beam size that should be large enough for this experiment is better than 10%. The beam flux will be monitored and recorded during the irradiation runs. The accuracy of the beam fluence is better than 10%.

3.2.1.1 Test Setup

Same Setup as in the TID testing was used. More information about the test setup and the test sequence is given in Appendix 2: “PHY Characterization - Heavy Ion and Proton Radiation”.

The main parts of the system are laptop with 2xLAN cables one connected to PHY DUT controller PCB and another directly to PHY DUT. The controller and PHY DUT are connected with a ribbon cable. Test setup can run one test line (one DUT) at the time, so DUTs are tested one by one in front of the beam. To speed up the radiation tests, three PHY DUT controllers are situated on one test plate, allowing three PHY DUT positions as shown in Figure 3-23 These way three components can be tested without breaking the vacuum of the test chamber in heavy ion and low energy proton tests or touching the components in high energy proton tests.

Following pictures show the test motherboards with the components not yet installed.

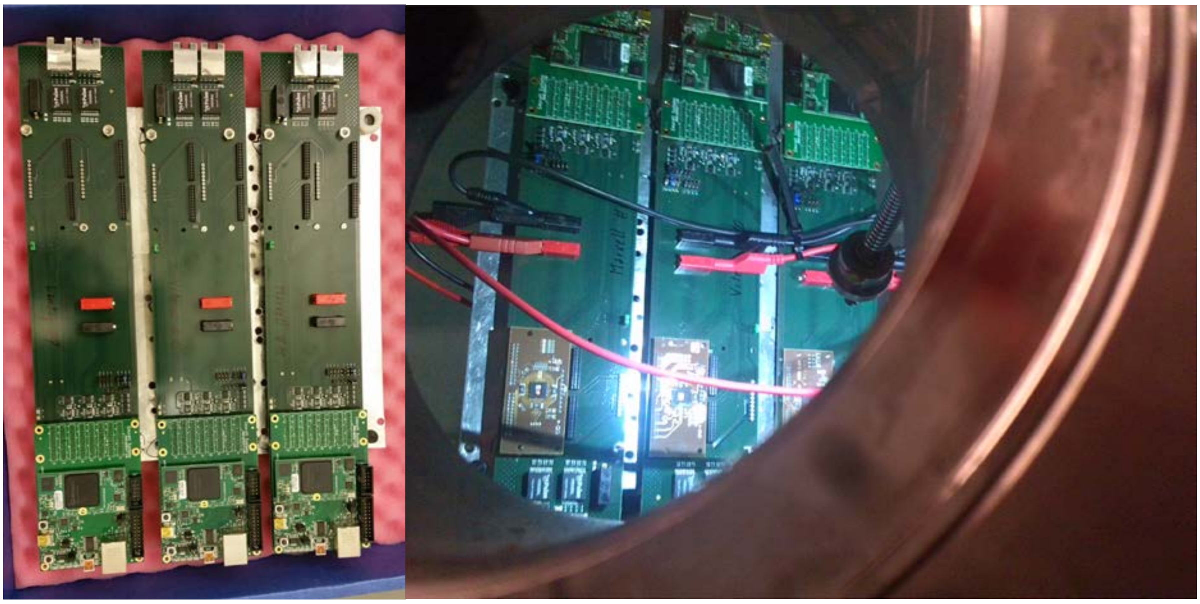


Figure 3-23 Motherboards without the PHYs and with PHYs in the vacuum chamber

3.2.1.2 Samples

Ethernet physical layer transceivers (PHY) from 3 different suppliers were tested. Types of the three components are: Lantiq XWAY PHY11G PEF7072, Vitesse VSC8501 and Marvell 88E1111.

3.2.1.3 Temperature of the samples during the test

For investigating Single Event Latchup Events (SEL) the DUTs temperatures were set to 115°C, while for investigating the Single Event Upsets (SEU) the room temperature has been chosen.

3.2.1.4 Error types

3.2.1.4.1 Single Event Latchup and micro-latchup

The single event latchup (SEL) is triggered when a parasitic NPNP feedback latch structure becomes biased into the on state, as a result of the very dense track of electron-hole pairs created by the heavy-ion interaction with the silicon. The SEL could lead to destructive failure of the tested EEE device.

The architecture of the testing setup was designed with the hindsight of the SEL phenomenon and a latchup protection circuit. For identifying hard latchup events, we designed a fast current control and a fast power switch function. The maximum allowed current would be set by the Labview application into a FPGA register. The FPGA transfers this setting into an Analog Monitoring and Control device AMC7820 from Bur-Brown.

The AMC7820 is now setting the comparator value for the analog comparator by its DAC outputs. As soon as the comparator signals the overcurrent to the FPGA, the FPGA disables the power directly at the LDO regulators enable pins and in parallel drives '0's on the IOs to/from the DUT to discharge it. With this approach, the power will be disabled and the device will be discharged within a few microseconds, which is exactly the time scale of the latch-up process.

Airbus DS has set the threshold (comparator value) to 1000 mA. Current values and latchup events are stored in a log file by the Labview application.

Furthermore, with the aim to monitor the micro-latchup phenomen as well, in order to gain more information on the devices behaviour, whose signature is the increase in the current consumption, on a longer time scale than the hard latchup, an observation function during the experiment was implemented. If the current will rise slightly from the nominal value to a higher value and if the momentary value is below the threshold , then some current bar graphs in the Labview application illustrate this behaviour.

In case for a micro-latchup, the current consumption will be rising and it is now in the operator's responsibility to recognize such micro-latchups and to handle (e.g. switch off manually).

The definition for the micro-latchup event was an increase of the nominal current consumption by 30% which lasts at least 15 s.

3.2.1.4.2 Testing modes: heat off (SEU) and heat on (SEL)

During the heavy ions irradiation it became clear that a large family of Single Event Effects occurred and the test methodology needed to be splitted in two classes of measurements:

1. The heat on mode for SEL testing (it is the worst case scenario for the SEL). Data rate was chosen the highest, thus 1GB/s.

2. The heat off mode for SEE testing since the room temperature is the usual condition for such events. These tests were conducted using both data rates 1Gb/s and 100Mb/s in heavy ion tests and only 1Gb/s data rate in proton tests.

The following types of failures were observed in the heat off mode:

“FILL” = Functional Interrupt, Link Lost = Component stop working and Ethernet connection is lost -> Beam was turned off and component was rebooted. After reboot beam was turned on and measurement was continued. Link connection status was check from Windows network adapter setting window (Network Connections). Link was interpreted lost when red cross top of the network connection icon was seen.

“FINL” = Functional Interrupt, Link NOT Lost = Component stop working but Ethernet connection is still on -> Beam was turned off and component was rebooted. After reboot beam was turned on and measurement was continued. Link connection status was check from Windows network adapter setting window (Network Connections).

“LLR” = Link Lost and Recovered = Component lost Ethernet connection but Recover by itself after few seconds. Link connection status was check from Windows network adapter setting window (Network Connections). Link was interpreted lost when red cross top of the network connection icon was seen.

“Data loss” = the number of lost data packets compared to overall data packets. This was analyzed from the recorded data afterwards. However, once the link was lost and recovered (LLR), the Wireshark did not sense that and continued to count up all packets. Therefore, the method/software is not optimized to exactly quantify the data loss cross-section in presence of link lost, as depending on the delay of an LLR the loss packets can appear higher or lower.

The classification of the SEU phenomena (LLR, FILL, FINL, SEL) had to be indeed based on operator decision and logic. The data packets and housekeeping overview (Temperature, Current packets lost) were recorded to log files.

The following types of failures were observed in the heat on mode:

"Micro-Latch up" = SEL. Operating currents increase more than 30% from the nominal value which did not decrease back down within 15 s. Beam was turned off and component was rebooted. After reboot beam was turned on and measurement was continued. Current consumptions of the components during the Latch-Ups in Heat on mode are presented in Appendix 3: "MicroLatch-Up current consumptions". Latch ups were booked in heat on but also in heat off mode.

"Latch up" Increasing currents exceeding the 1A limit.

3.2.1.5 Determination of package loss

Wireshark network port analyzer was used for logging the network traffic between measurement computer and the PHY DUT. A data packet was considered valid, if the packet was sent through the network adapter of the laptop and the PHY DUT replied by returning the packet to the measurement computer. If the reply form PHY DUT was missing the packet was counted as lost. Also the validity of the data section of the packet was verified, but no corrupted data packets were seen.

Wireshark wrote the packages in consecutive files. After each 100KB of data, a new file was generated. When the PHY DUT needed to be restarted during a run, a new folder for Wireshark data files was made. As a result, for each run 1 to N folders containing the data packet files were obtained. (N is number of system restarts in a run subtracted by one.)

When a measurement was started the beam was switched on after the first data packet file was full, ie. around 600 packets were sent and received. When an error that required restarting the PHY DUT occurred, especially in a case of FINL error, the packets sent after the error but before stopping the system were all lost. Since these would have an impact on data loss calculations, two measures were taken for each of the folders of a single run before calculating the packet loss: 1) The first data packet file recorded before beam was on was ignored. 2) starting from the end of last file, the last good packet was sought and all lost packets received after that were ignored. Therefore, the reported data loss does not include data loss by FINL, FILL and SEL. Also the good packets received before beam was switched on were discarded.

For link loss, some data loss may happen, that was not possible to clear from the log files, but mainly link loss does not cause data loss, as the packets are not sent from the measurement computer, if there is no link to DUT.

3.2.1.6 Test sequence

Detailed introduction about setting up the test setup and programs are given in Appendix 3 "PHY Characterization - Heavy Ion and Proton Radiation". In the Figure 3-24 and Figure 3-25. the general methodology of the test for Heat off and Heat on mode, is presented.

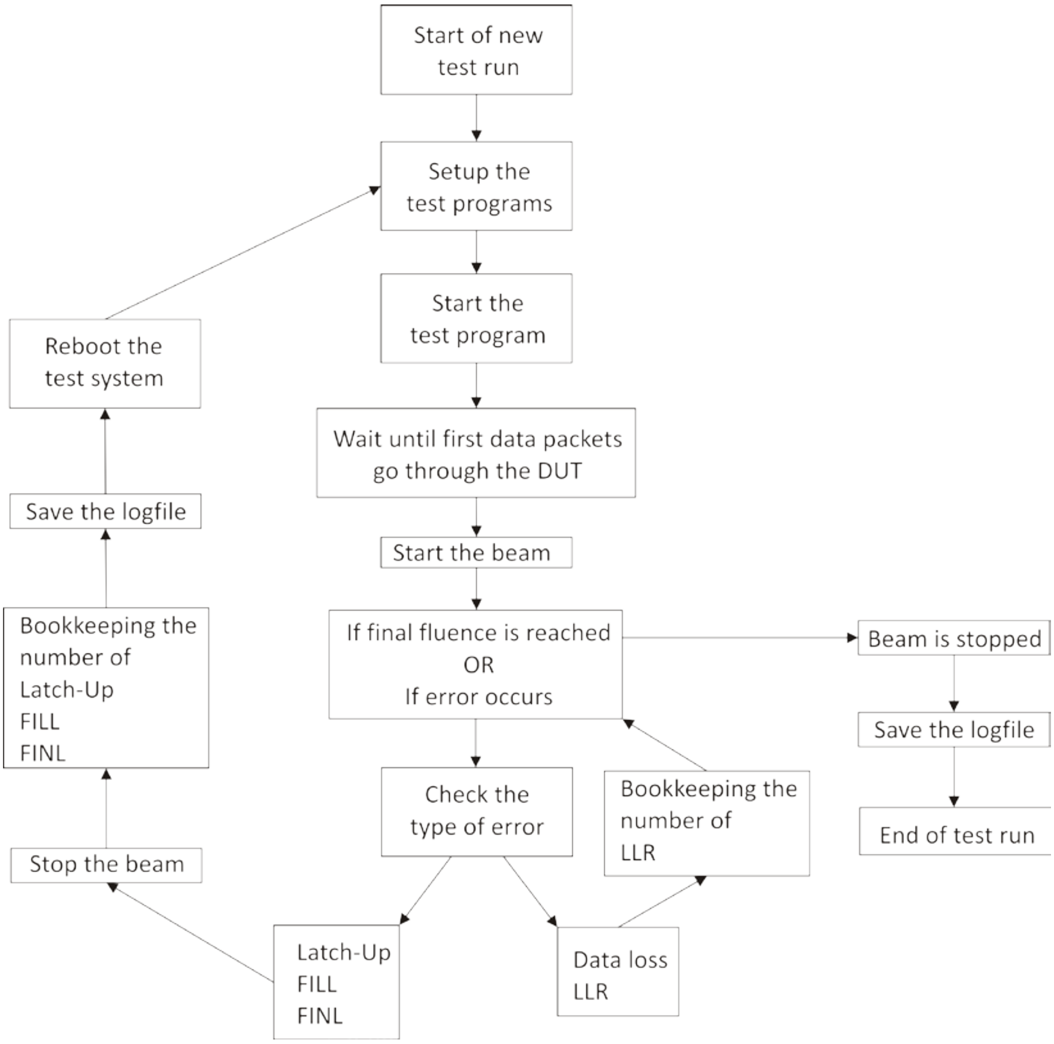


Figure 3-24 Test logic for “Heat off” mode for the SEU events.

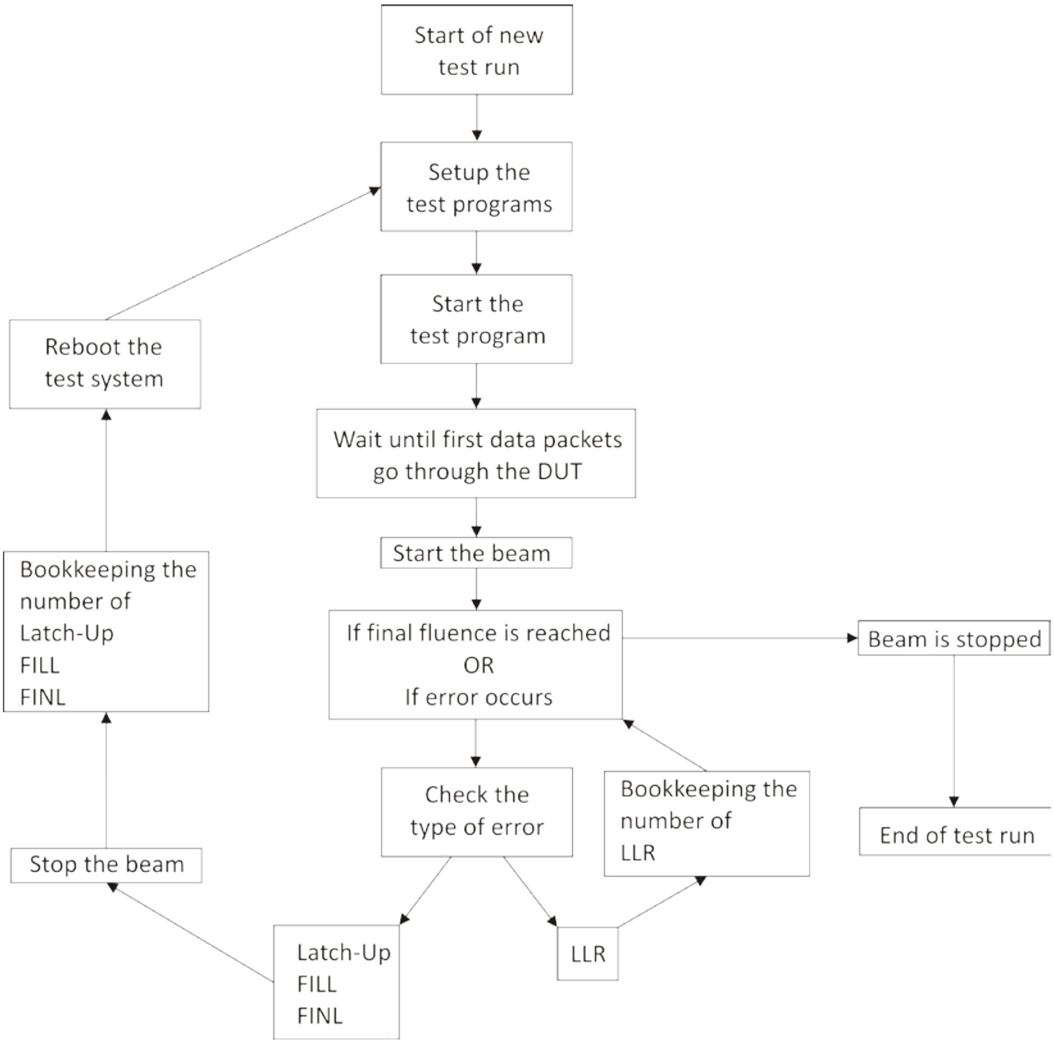


Figure 3-25 Test logic for “Heat on” mode and for the SEL events.

The measurement program software could not be completely optimized to the observation of errors occurred in components because only during the tests the whole spectrum of the SEE emerged. . It mainly showed the status of the component and the identification of the errors mainly based on human eye and interpretation. Book keeping of different errors had to be done by hand. For example, like “Link Lost” event had to be observed from the red cross in Windows operating systems network adapter setting window (Network Connections). It is not sure how fast Windows operating system notices if the network link is lost, and how long the link has to be lost before Windows announce it. Lots of data analysis had to be done after the experiment, like data loss calculation which made the checking of the quality of the data online impossible. All these kind of non-optimized features, in addition on human eye observations complicate the measurements and make them more uncertain.

3.2.1.7 Heavy ion results

First heavy ion tests were performed 16.5-19.5.2016. Due to the fact that components were not tested earlier with heavy ions lots of time was used to learn the behavior of them. Possible error types were tried to be categorized (See “Error types to be search”). In addition, one day of beam time had to cancel due to the main magnet power supply problem in the cyclotron. 3 data points from that data (Ar beam and Marvell #18, #23 and Vitesse #21 components) were taken to the final results.

Main part of the heavy ion irradiations was performed 6.6.-9.6.2016. Five ions N, Ar, Fe, Kr and Xe with LET values of 1.8, 10.2, 18.5, 32 and 60 MeV/mg/cm^2, respectively, were used. During the first measurements, it was noticed that Lantiq components were much more sensitive against heavy ion and proton irradiations than the two other components (Marvell and Vitesse). Based on this observation Lantiq was decided to be excluded from the second heavy ion and proton tests.

The results of the heavy ions tests are shown in figures 6-23 first for Marvell and then for Vitesse. Cross-section of different error events are plotted as a function of LET value. They are calculated for "Data loss" using equation

$$\sigma_{DL} = \frac{\frac{number\ of\ lost\ data\ packages}{number\ of\ all\ data\ packages}}{FLUENCE},$$

and for the other errors (LLR, FILL, FINL, Latch-Up)

$$\sigma_{SEE} = \frac{number\ of\ errors}{FLUENCE},$$

where "FLUENCE" is in ions/cm^2.

Error bars are plotted using 95% confidential interval. If the error bars are not visible in the plot the error is so small that it is covered by the data point.

If certain error events were not seen during a test run the cross-section limit for these errors reached in the run is marked by a bar with downwards arrow and connected to other points with dashed line.

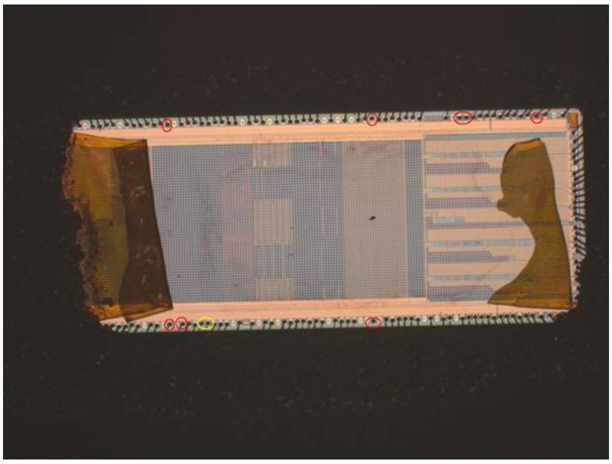
Measured data including used flux, fluence, number of errors and cross-sections are shown for each run in tables 3-7 after the plots in section "5.4 Heavy Ion data run by run". In tables, the number of errors and cross-sections are shown also for heat on mode even these tests were dedicated for searching of "Micro-Latch-Up" events. Heat on mode data is no plotted.

Numbers and cross-section values of "MicroLatch-Up" errors are given in tables 3-7. Those are not plotted due to the low number of events.

Some heavy ion data is shown for Lantiq in tables 8 and 9. With higher LET value ions Kr and Xe Lantiq has a great problem to work.

3.2.1.7.1 Marvell

Etched (opened) components numbers #18, #20 and #23 were used for Marvell. Component number #20 did not work in 100 Mb/s mode and because there were no spare/fresh components left anymore data only for 2 components for 100 Mb/s mode was obtained. It is not clear what exactly did happen with the Marvell 20. It did work for a total of 10 runs, up to an LET of 60 MeVcm2/mg and at some point ceased being functional. The part was sent at ESA request to the ESA Quality Laboratory in November, thus a couple of months following the heavy ion experiment. The picture is shown below.



A number of broken contacts can be seen indicated in red in the picture. Two possible explanations could be found:

1. The electrical contacts were damaged during the experiment and this would be the failure cause.
2. The contacts became damaged by a corrosive on-going process, taking place between the radiation exposure and the moment when it was analyzed by ESA. In this scenario, the cause of failure during the experiment would be indeed radiation. Marvell was exposed to a Total Ionising Dose of 14 krad(Si) during the heavy ion testing, while its counterparts were exposed to more without failing. The TID effect was therefore not the cause, especially because the complementary TID tests showed immunity up to 50 krad(Si). A destructive SEE event would have been a latchup event and the signature would have been observed in the experiment, the current increase and the built-in latch-up protection reaction.

With all the aspects pondered, it is more likely that the failure case was 1 then 2.

The data loss cross-section is presented below.

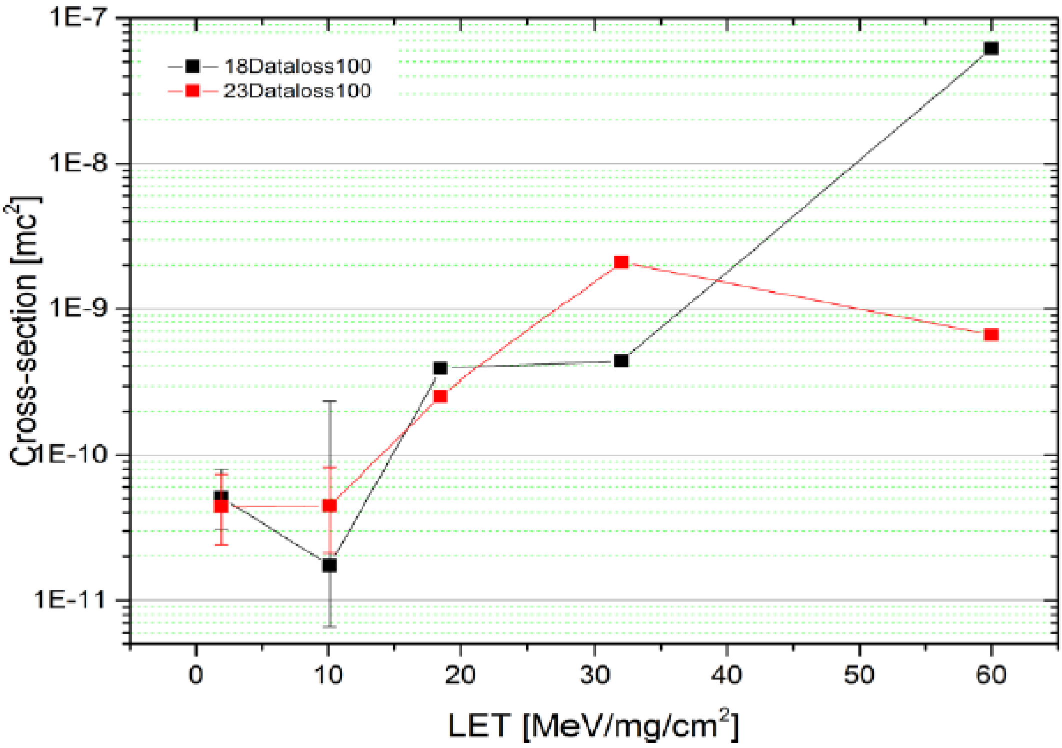


Figure 3-26 Data loss cross-section for Marvell components at 100 Mb/s mode (heat off).

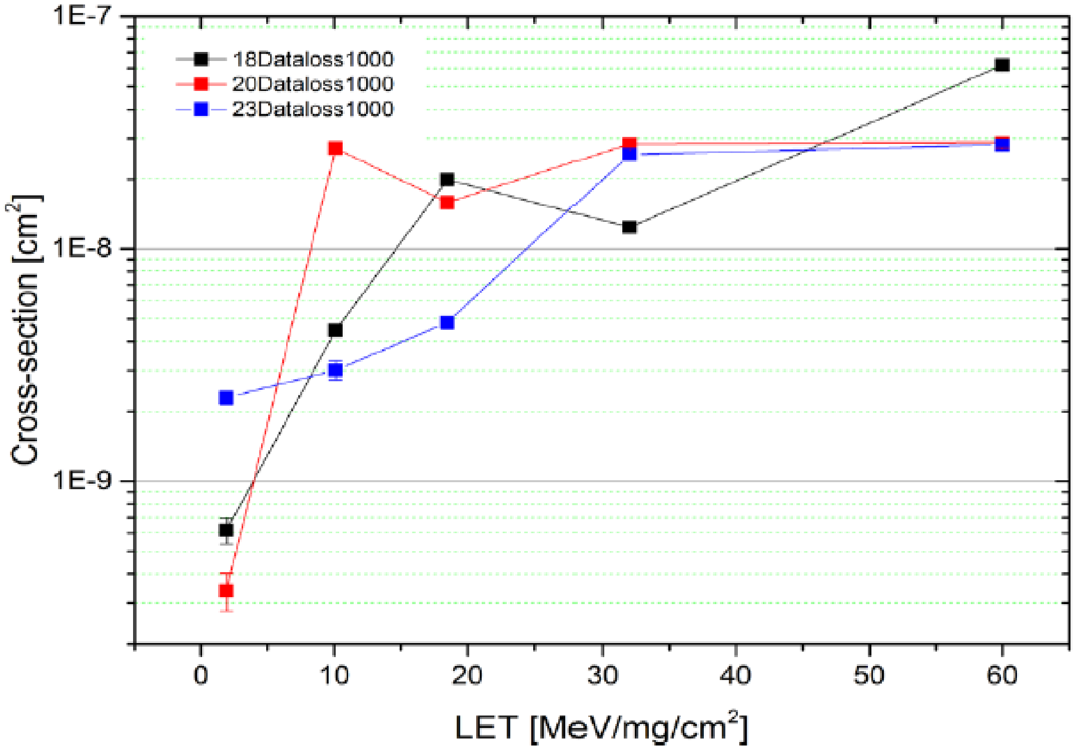


Figure 3-27 Data loss cross-section for Marvell components at 1000 Mb/s mode (heat off).

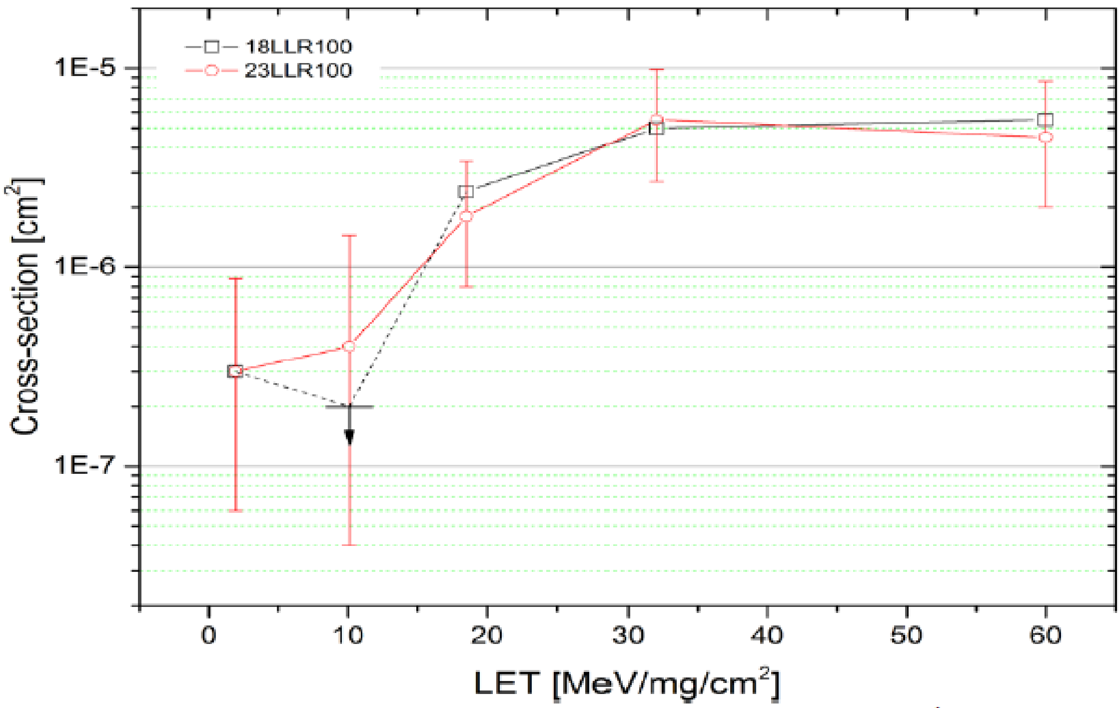


Figure 3-28 Link lost recovery “LLR” cross-section for Marvell components at 100 Mb/s mode (heat off).

No LLR events were seen for component #18 at LET 10.2 MeV/mg/cm^2. The limit of the cross-section reached in the test run is marked with bar and downward arrow.

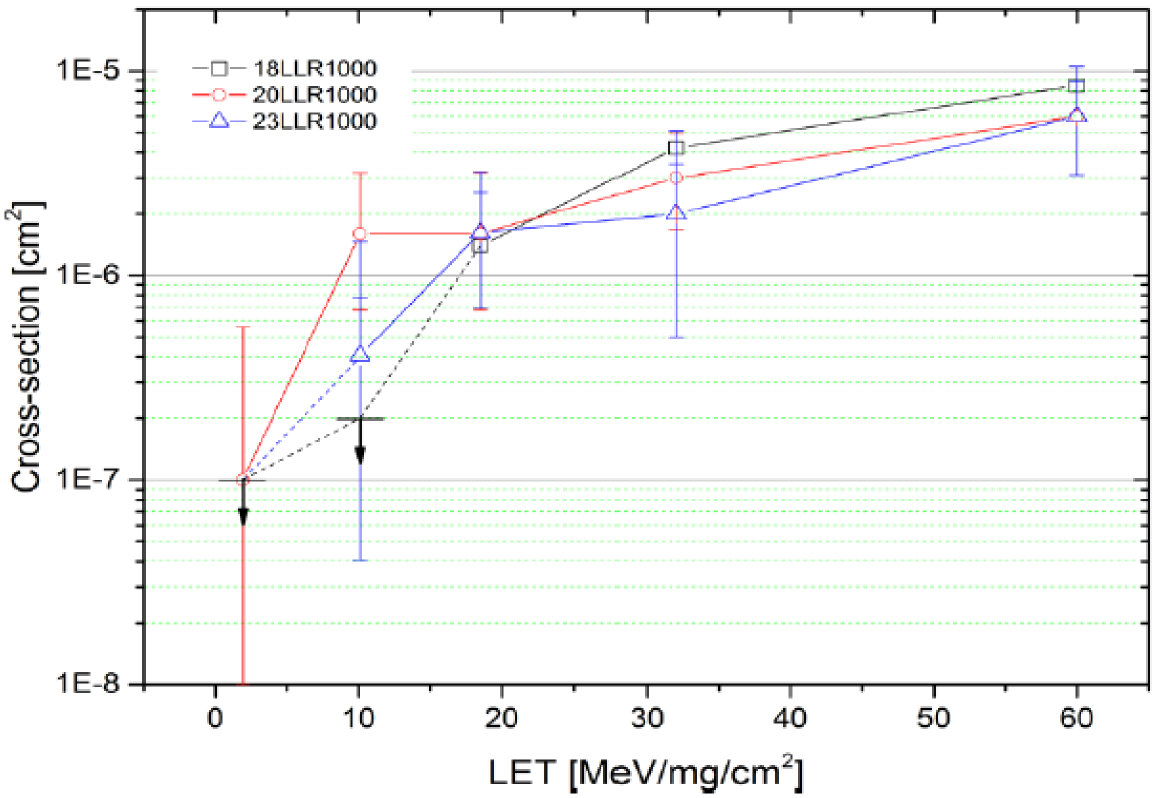


Figure 3-29 Link lost recovery “LLR” cross-section for Marvell components at 1000 Mb/s mode (heat off).

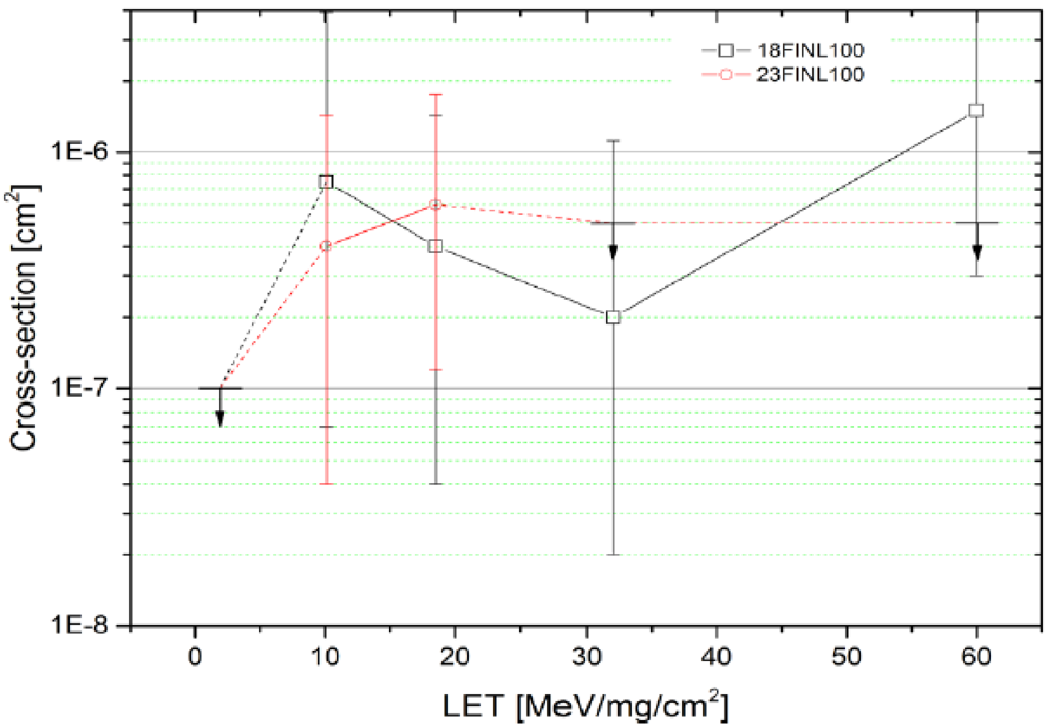


Figure 3-30 “FINL” cross-section for Marvell components at 100 Mb/s mode (heat off).

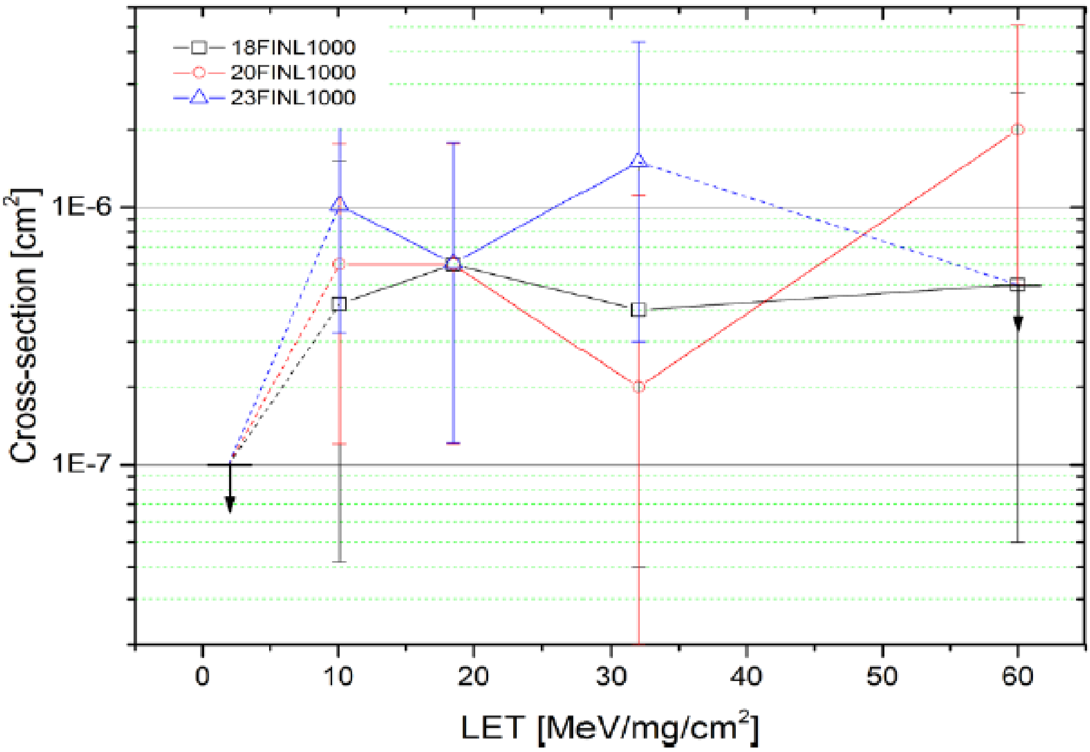


Figure 3-31 Link lost recovery “LLR” cross-section for Marvell components at 1000 Mb/s mode (heat off).

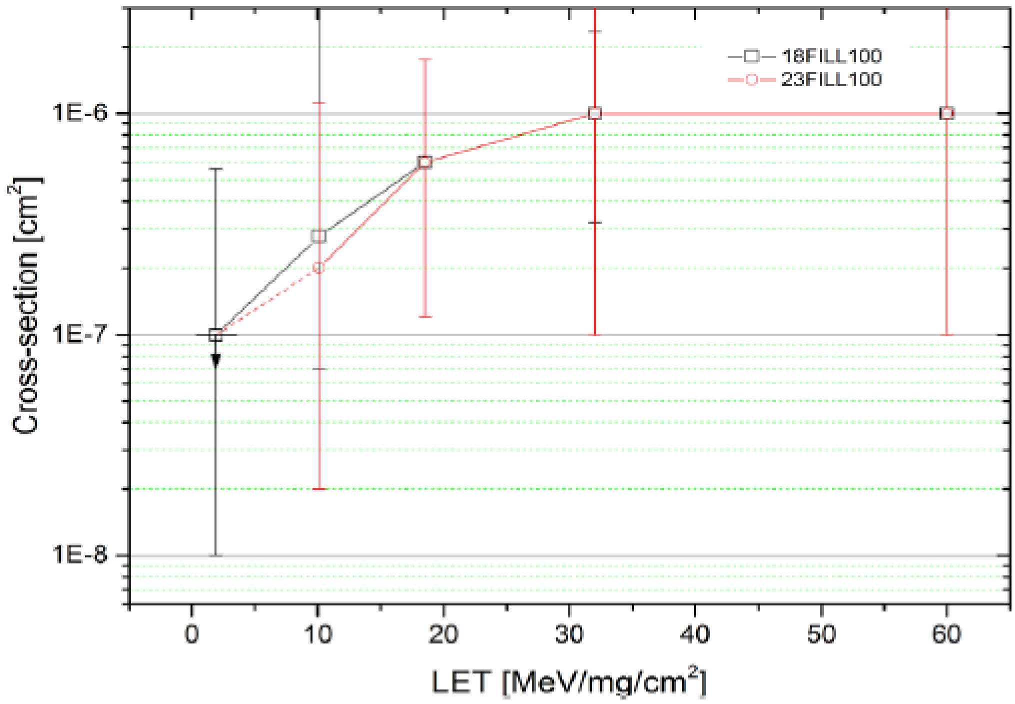


Figure 3-32 FILL cross.section for Marvell at 100MB/s heat off.

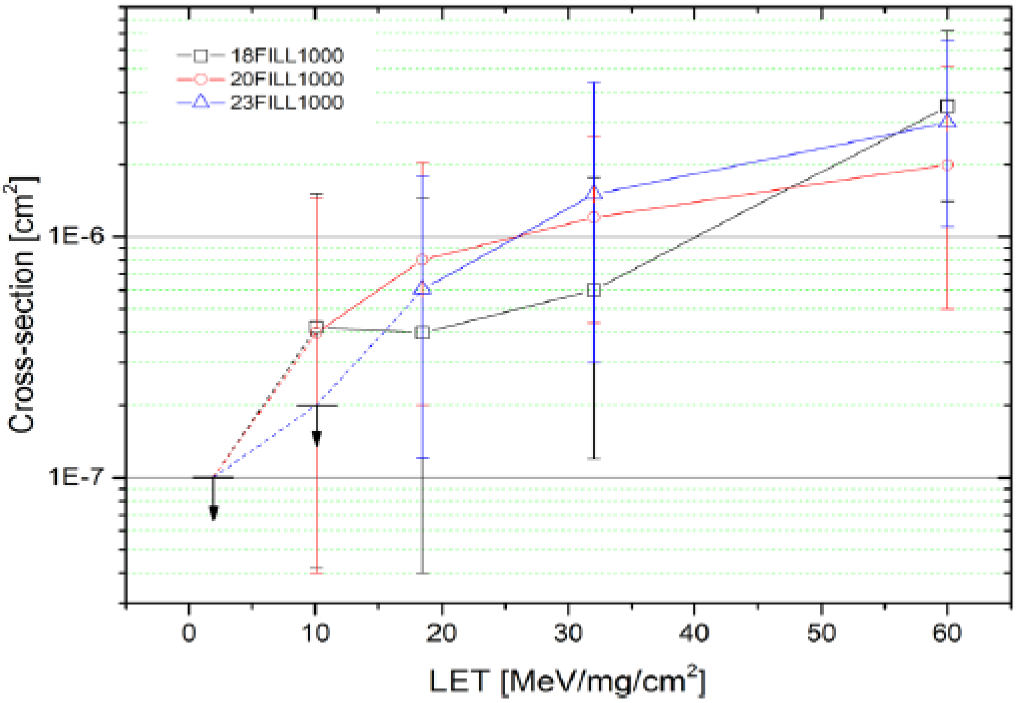


Figure 3-33 FILL cross-section for Marvell at 1Gb/s mode heat off.

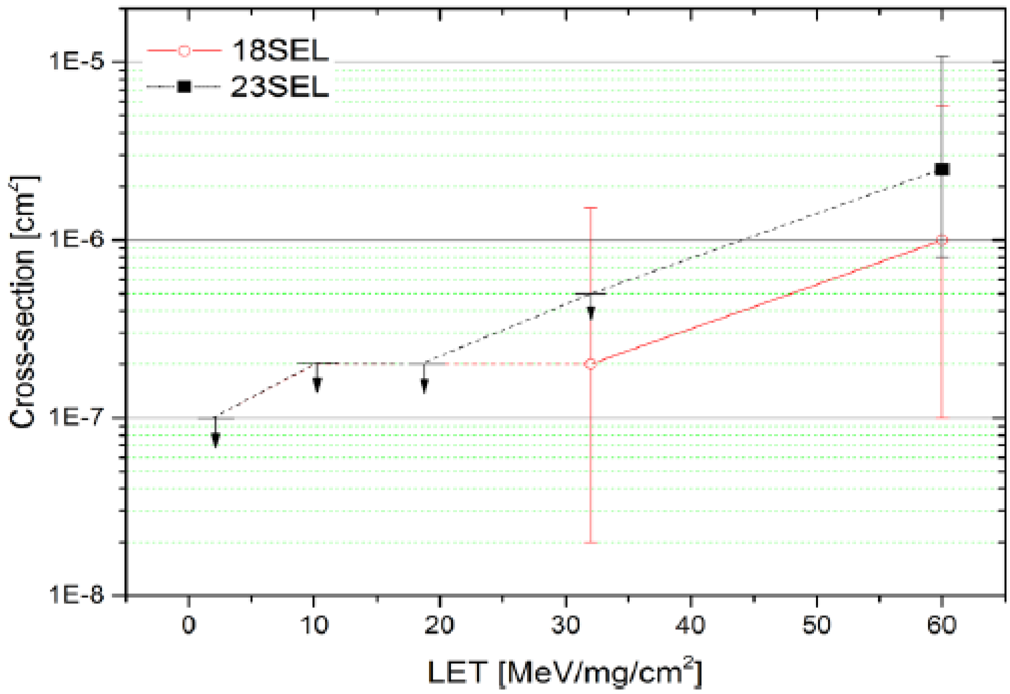


Figure 3-34 Micro-lachup cross-section for Marvell at 1Gb/s and heat on.

3.2.1.7.2 Results for Vitesse

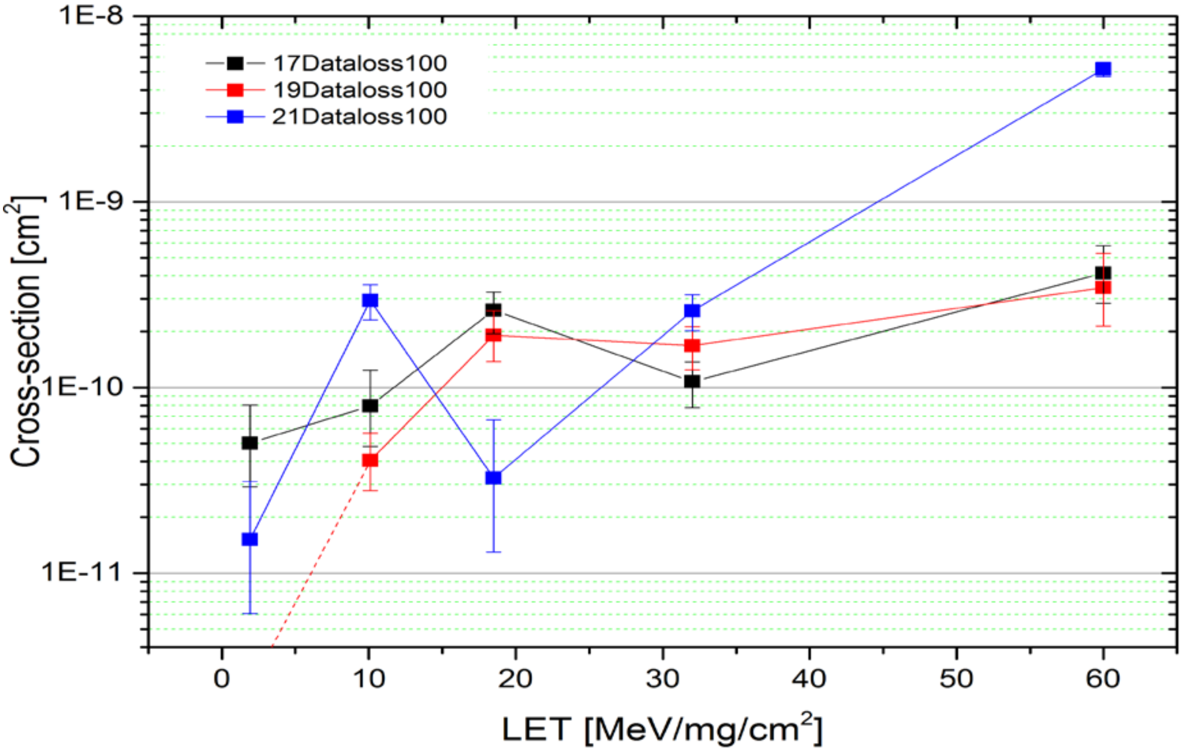


Figure 3-35 “Data loss” cross-section for Vitesse components at 100Mb/s mode (heat off).

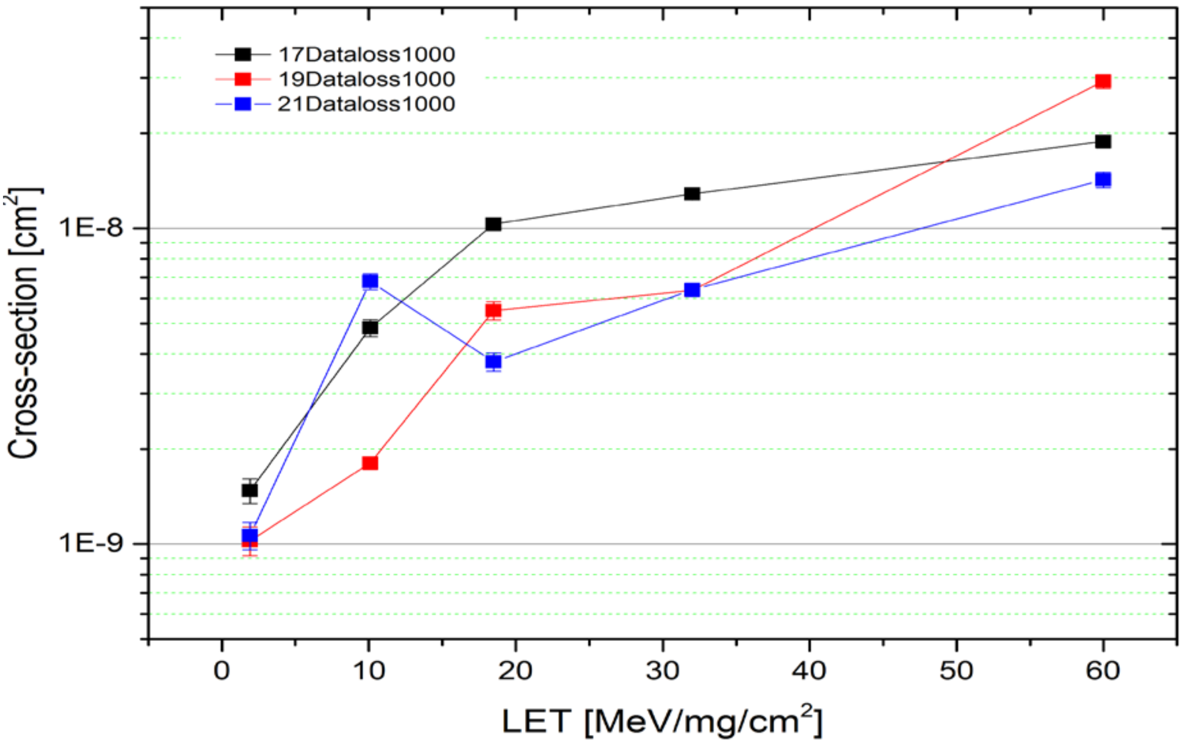


Figure 3-36 ”LLR” cross-section for Vitesse components at 100 Mb/s mode (heat off).

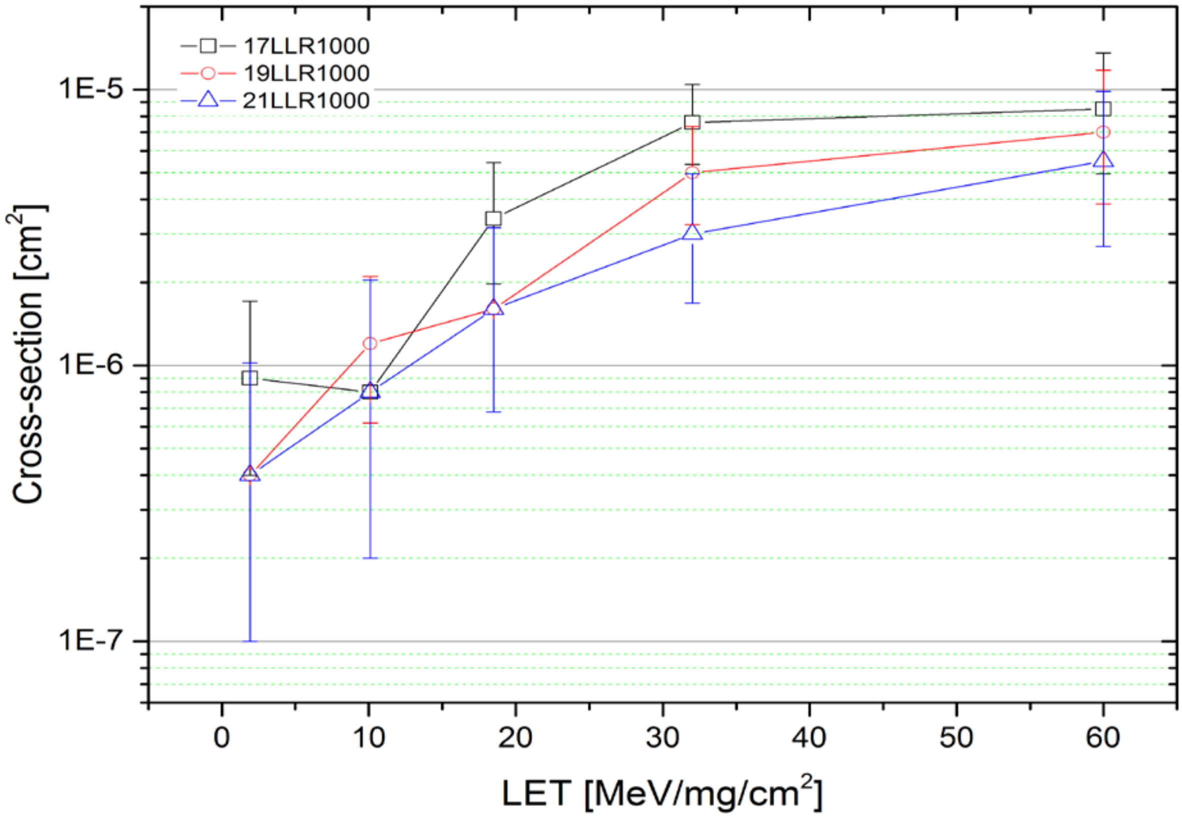


Figure 3-37 ”LLR” cross-section for Vitesse components at 1000 Mb/s mode (heat off).

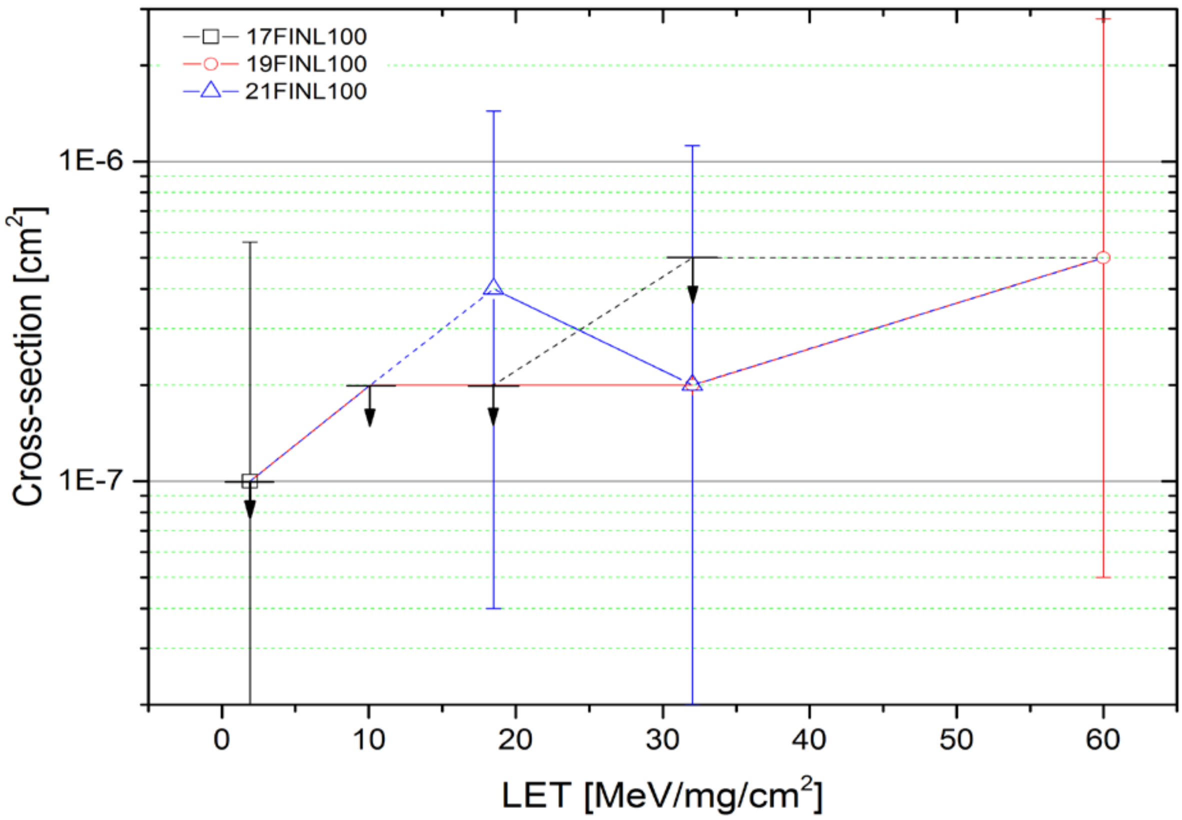


Figure 3-38 ”FINL” cross-section for Vitesse components at 100 Mb/s mode (heat off).

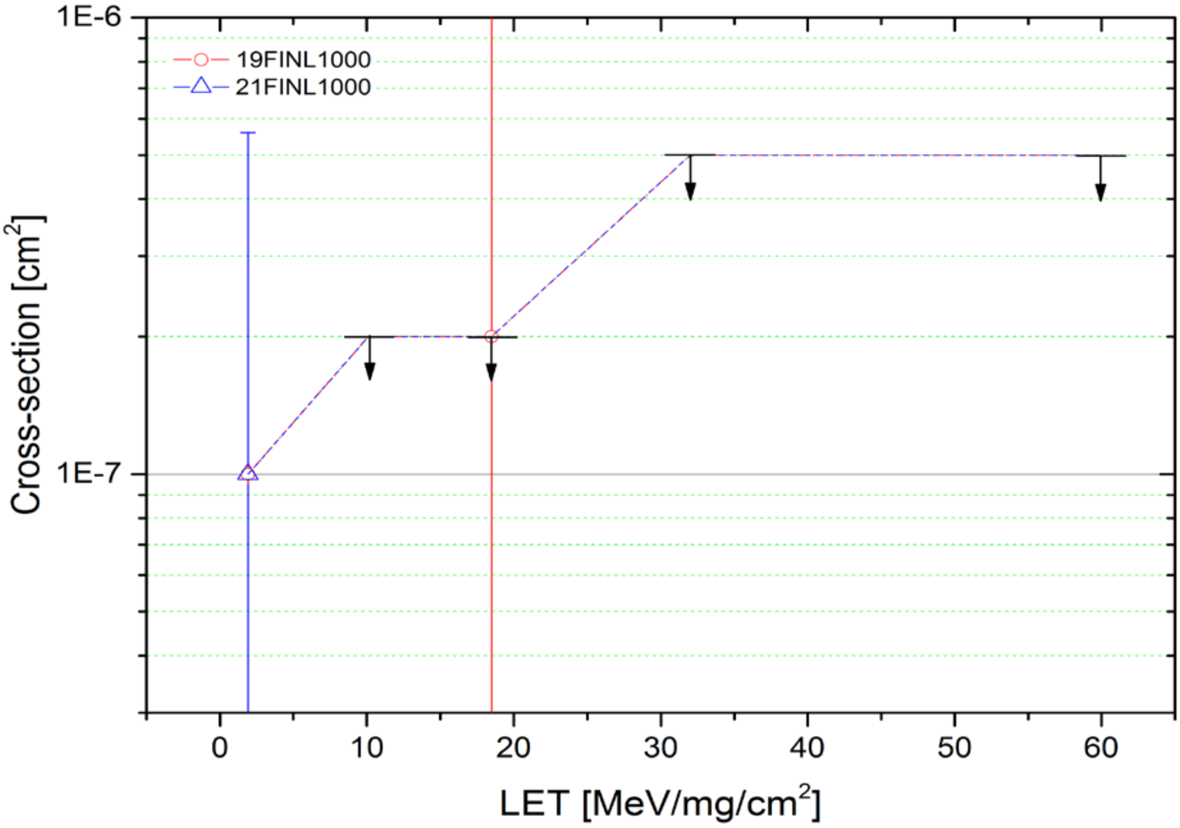


Figure 3-39 ”FINL” cross-section for Vitesse components at 1000 Mb/s mode (heat off).

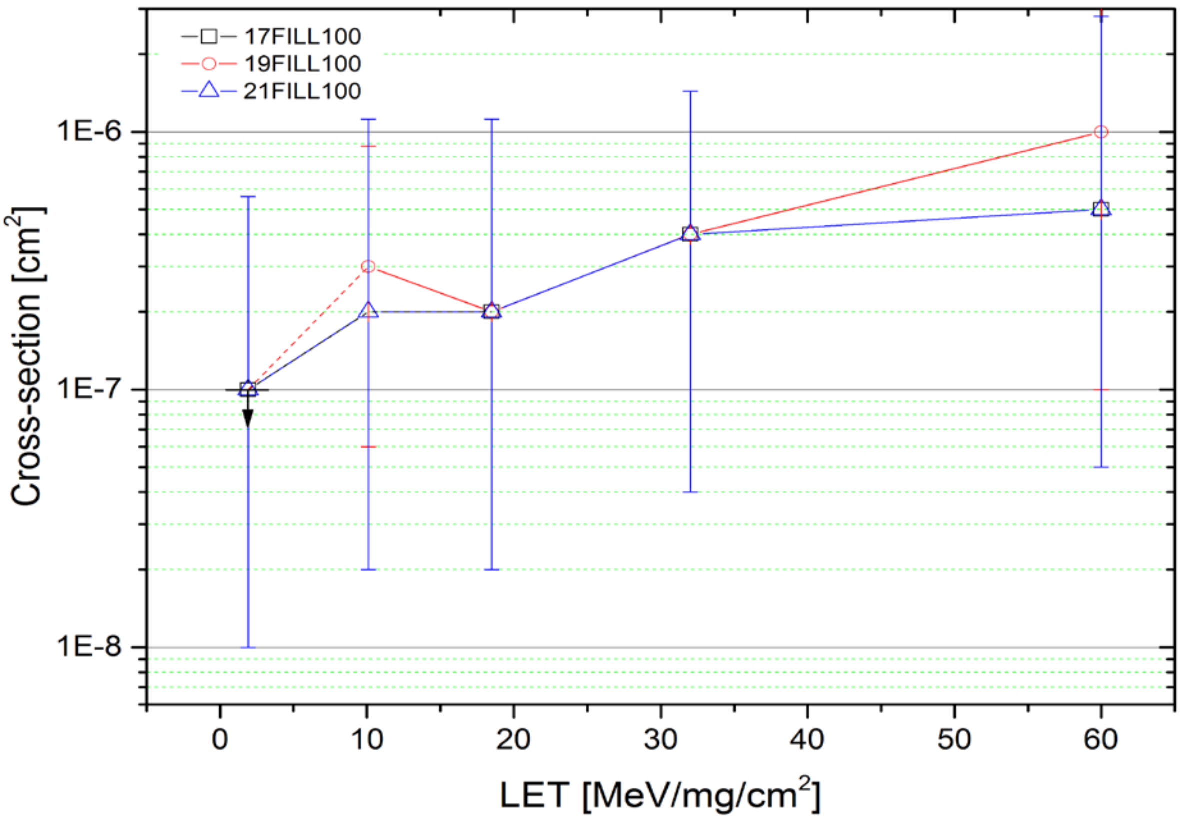


Figure 3-40 ”FILL” cross-section for Vitesse components at 100 Mb/s mode (heat off).

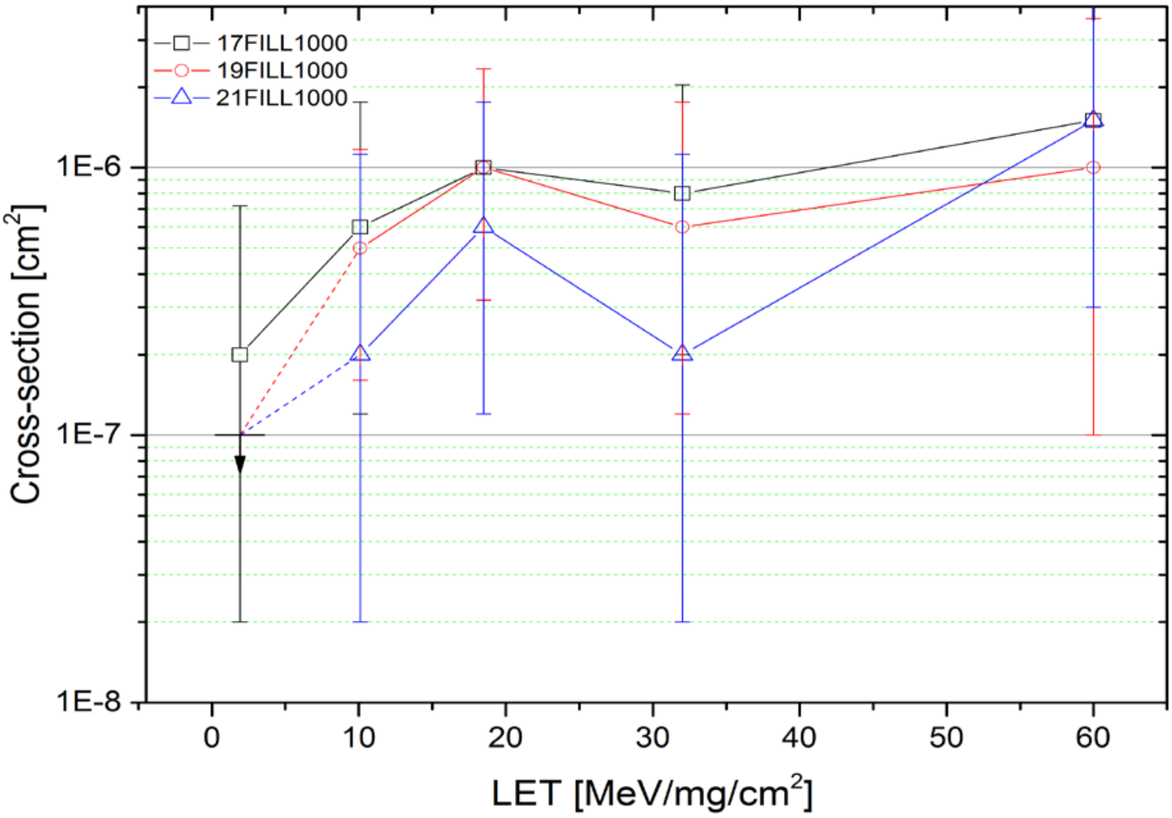


Figure 3-41 ”FILL” cross-section for Vitesse components at 1000 Mb/s mode (heat off).

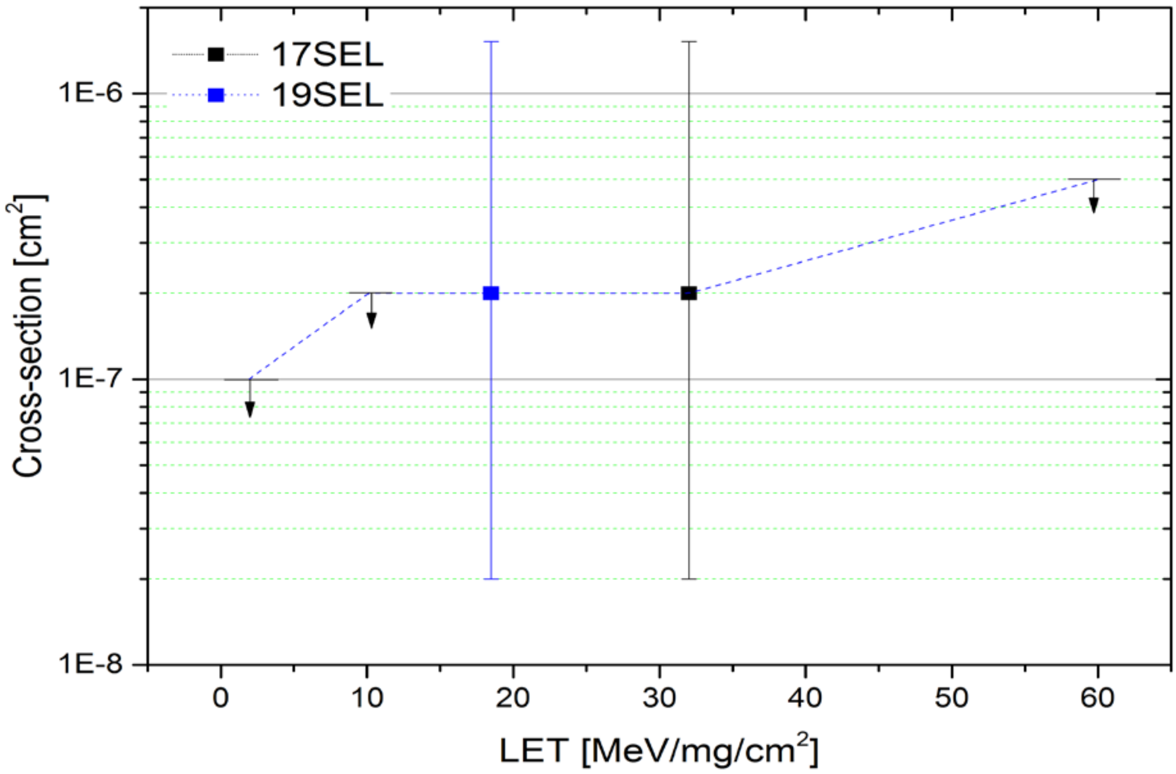


Figure 3-42 MicroLatch-Up” cross-section for Vitesse components at 1000 Mb/s mode (heat on).

3.2.1.7.3 Mean values for data loss cross-section

In figures 24 and 25 the mean values of “Data loss” cross-section for Marvell and Vitesse components are shown along with a Weibull fit. The Weibull fit is done using equation

$F(x) = A(1 - e^{-(s(x-x_c))^W})$.

Values of Weibull fit parameters for “Data loss” cross-sections are shown in Table 2. where A=Sat. Cross-section, x_c=Onset. Fit parameters for other failure modes are given in Appendix 3: “Weibull fit tables and figures”.

The error bars for mean values are plotted simply as the standard error of the mean values from the appropriate figures.

Table 2. Values of the Weibull fit parameters for “Data loss” cross-sections.

DUT Failure mode Data loss	Sat. Cross-section [cm²/byte]	Onset [MeVcm²/mg]	W	S
Marvell 100 MB/s	2,99E-07	-6,10678	3,32291	0,00508
Marvell 1 GB/s	4,57E-06	0,44114	0,82014	5,08E-05
Vitesse 100 MB/s	2,43E-09	-1,82345	1,61891	0,01138
Vitesse 1 GB/s	3,27E-08	-11,63445	1,79512	0,0129

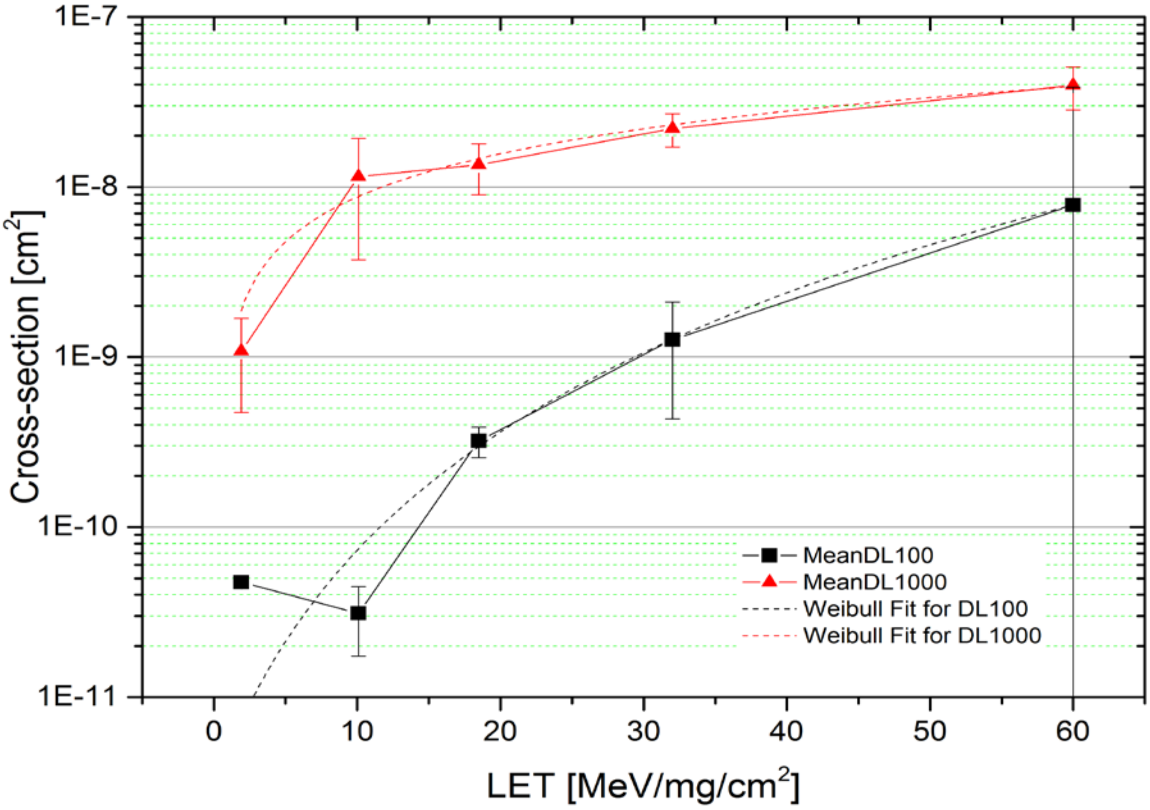


Figure 3-43 Mean value of "Data loss" cross-section as a function of LET for Marvell components (heat off).

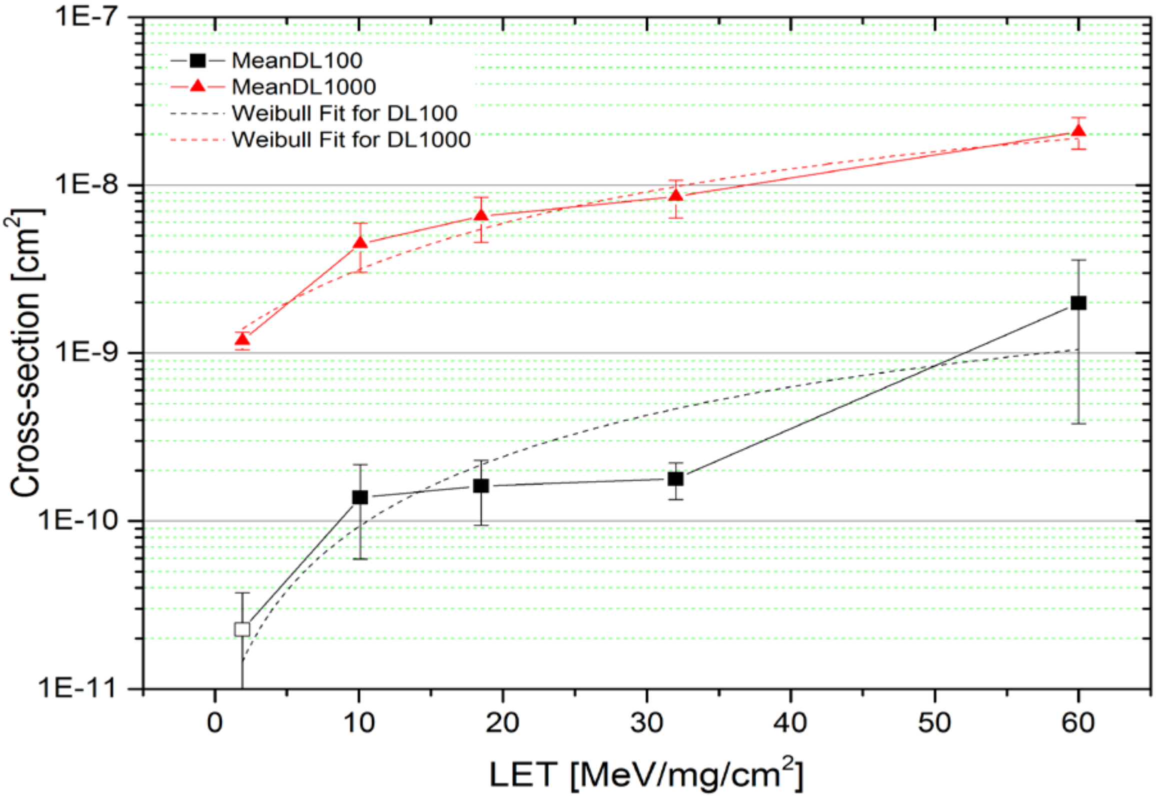


Figure 3-44 Mean value of "Data loss" cross-section as a function of LET for Vitesse components (heat off).

It could be remarked that the saturation cross-sections for Vitesse are smaller than of the counterparts of Marvell. Also, the radiation sensitivity is clearly 10x higher in the 1Gb/s mode than in the 100MB/s.

3.2.1.8 Heavy ion data run by run for Marvell and Vitesse

Nitrogen LET =1.8 MeV/mg/cm²

Heat off 100 Mb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	2.5E4	1E7	2 2E-7	1 1E-7	1 1E-7	1 1E-7	17/33922 5.01E-11
Vitesse 19	2.5E4	1E7	0 <1E-7	0 <1E-7	0 <1E-7	0 <1E-7	0/41865 <2.4E-12
Vitesse 21	2.3E4	1E7	1 1E-7	1 1E-7	0 <1E-7	0 <1E-7	7/46154 1.52E-11
Marvell 18	2.5E4	1E7	3 3E-7	1 1E-7	0 <1E-7	0 <1E-7	19/37244 5.10E-11
Marvell 20	Did not work*						- -
Marvell 23	2.8E4	1E7	3 3E-7	0 <1E-7	0 <1E-7	1 1E-7	14/31811 4.40E-11

Heat off 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	2.5E4	1E7	9 9E-7	2 2E-7	0 <1E-7	0 <1E-7	503/34085 1.48E-9
Vitesse 19	2.5E4	1E7	4 4E-7	0 <1E-7	1 2E-7	0 <1E-7	364/35549 1.02E-9
Vitesse 21	2.5E4	1E7	4 4E-7	0 <1E-7	1 2E-7	0 <1E-7	422/39633 1.06E-9
Marvell 18	2.5E4	1E7	0 <1E-7	0 <1E-7	0 <1E-7	0 <1E-7	245/39779 6.16E-10
Marvell 20	2.5E4	1E7	1	0	2	0	116/34183

			1E-7	<1E-7	2E-7	<1E-7	3.39E-10
Marvell 23	2.4E4	1E7	0 <1E-7	0 <1E-7	0 <1E-7	0 <1E-7	916/39980 2.29E-9

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$
Vitesse 17	2.5E4	1E7	5 5E-7	1 1E-7	0 <1E-7	0 <1E-7
Vitesse 19	2.5E4	1E7	1 1E-7	0 <1E-7	1 1E-7	0 <1E-7
Vitesse 21	2.5E4	1E7	3 3E-7	0 <1E-7	0 <1E-7	0 <1E-7
Marvell 18	2.5E4	1E7	1 1E-7	0 <1E-7	0 <1E-7	0 <1E-7
Marvell 20	2.5E4	1E7	1 1E-7	0 <1E-7	0 <1E-7	0 <1E-7
Marvell 23	2.5E4	1E7	1 1E-7	0 <1E-7	2 2e-7	0 <1E-7

Argon LET =10.2 MeV/mg/cm^2

Heat off 100 Mb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	1E4	5E6	2 4E-7	1 2E-7	1 2E-7	1 2E-7	19/47704 7.97E-11
Vitesse 19	1E4	1E7	0 <1E-7	0 <1E-7	0 <1E-7	0 <1E-7	33/81390 4.05E-11
Vitesse 21*		5E6	0 <2E-7	1 2E-7	0 <2E-7		87/59140 2.94E-10
Marvell 18*		2.86E6	0 <3.5E-7	1 3.5E-7	2 7.0E-7		2/42750 1.74E-11

Marvell 20	Did not work						- -
Marvell 23*		5E6	2 4E-7	1 2E-7	2 4E-7		10/44732 4.47E-11

*Data from the first experiment done 19.5.2016

Heat off 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	1E4	5E6	4 8E-7	3 6E-7	0 <2E-7	0 <2E-7	1032/42691 4.83E-9
Vitesse 19	1E4	1E7	12 1.2E-6	5 5E-7	1 1E-7	0 <1E-7	1847/102322 1.81E-9
Vitesse 21*		5E6	4 8E-7	1 2E-7	0 <2E-7		1228/36180 6.79E-9
Marvell 18*		4.76E6	0 <2.1E-7	2 4.2E-7	2 4.2E-7		1213/57138 4.46E-9
Marvell 20	1E4	5E6	8 1.6E-6	2 4E-7	3 6E-7	0 <2E-7	6805/50182 2.71E-8
Marvell 23*		4.92E6	2 4.07E-7	0 <2.04-7	5 1.02E-6		416/31129 3.01E-9

*Data for the first experiment done 19.5.2016

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$
Vitesse 17	1E4	5E6	11 2.2E-6	0 <2E-7	0 <2E-7	0 <2E-7
Vitesse 19	1-1.7E4	5E6	6 1.2E-6	4 8E-7	0 <2E-7	0 <2E-7
Vitesse 21*	-	-	-	-	-	-
Marvell 18*		5E6				0
Marvell 20	1E4	5E6	8	3	1	0

			1.6E-6	6E-7	2E-7	<2E-7
Marvell 23*		4.91E6				0 <2.04E-7

*Data from the first experiment done 19.5.2016

Iron LET =18.5 MeV/mg/cm^2

Heat off 100 Mb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	6.3E3-1E4	5E6	9 1.8E-6	1 2E-7	0 <2E-7	0 <2E-7	62/47449 2.61E-10
Vitesse 19	1.1E4	5E6	5 1E-6	1 2E-7	0 <2E-7	1 2E-7	42/43854 1.92E-10
Vitesse 21	1E4	5E6	2 4E-7	1 2E-7	2 4E-7	0 <2E-7	7/42999 3.26E-11
Marvell 18	1.1-1.5E4	5E6	12 2.4e-6	3 6E-7	2 4E-7	1 2E-7	55/28457 3.87E-10
Marvell 20	Did not work						- -
Marvell 23	8E3-1E4	5E6	9 1.8E-6	3 6E-7	3 6E-7	0 <2E-7	52/40570 2.56E-10

Heat off 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	1E4	5E6	17 3.4E-6	5 1E-6	0 <2E-7	0 <2E-7	1844/35752 1.03E-8
Vitesse 19	1.1E4	5E6	8 1.6E-6	5 1E-6	1 2E-7	0 <2E-7	900/32815 5.49E-9
Vitesse 21	1E4	5E6	8 1.6E-6	3 6E-7	0 <2E-7	0 <2E-7	912/48314 3.78E-9
Marvell 18	1.1E4	5E6	11 2.2E-6	3 6E-7	3 6E-7	0 <2E-7	3209/32322 1.99E-8

Marvell 20	1E4	4.9E6	8 1.63E-6	4 8.16E-7	3 6.12E-7	0 <2.04E-7	2945/37235 1.58E-8
Marvell 23	8E3	5E6	8 1.6E-6	3 6E-7	3 6E-7	1 2E-7	985/41337 4.82E-9

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$
Vitesse 17	1E4	5E6	4 8E-7	3 6E-7	0 <2E-7	0 <2E-7
Vitesse 19	1.1E4	5E6	17 3.4E-6	0 <2E-7	0 <2E-7	1 2E-7
Vitesse 21	8E3-1E4	5E6	14 2.8E-6	3 6E-7	0 <2E-7	0 <2E-7
Marvell 18	1.1E4	5E6	7 1.4E-6	2 4E-7	3 6E-7	0 <2E-7
Marvell 20	1E4	5E6	3 6E-7	3 6E-7	1 2E-7	0 <2E-7
Marvell 23	8E3- 1.6E4	5E6	12 2.4E-6	4 8E-7	2 4E-7	0 <2E-7

Krypton LET =32.2 MeV/mg/cm²

Heat off 100 Mb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	5-7E3	5E6	8 1.6E-6	2 4E-7	0 <2E-7	4 8E-7	52/96686 1.08E-10
Vitesse 19	6E3-1E4	5E6	9 1.8E-6	2 4E-7	1 2E-7	3 6E-7	59/70079 1.68E-10
Vitesse 21	5E3-1E4	5E6	9 1.8E-6	2 4E-7	1 2E-7	1 2E-7	83/64119 2.59E-10
Marvell 18	5E3	5E6	25 5E-6	5 1E-6	1 2E-7	6 1.2E-6	121/55719 4.34E-10
Marvell 20	Did not work						- -
Marvell 23	4E3	2E6	11 2.2E-6	2 4E-7	0 <2E-7	1 2E-7	197/46897 2.10E-9

Heat off 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	7E3	5E6	38 7.6E-6	4 8E-7	0 <2E-7	0 <2E-7	3385/52704 1.28E-8
Vitesse 19	5E3	5E6	25 5E-6	3 6E-7	0 <2E-7	0 <2E-7	2689/84481 6.37E-9
Vitesse 21	8E3	5E6	15 3E-6	1 2E-7	0 <2E-7	0 <2E-7	1717/53699 6.39E-9
Marvell 18	6E3	5E6	21 4.2E-6	3 6E-7	2 4E-7	0 <2E-7	2290/36993 1.24E-8
Marvell 20	8E3	5E6	15 3E-6	6 1.2E-6	1 2E-7	0 <2E-7	6387/45137 2.83E-8
Marvell 23	4E3	2E6	4 8E-7	3 6E-7	3 6E-7	0 <2E-7	1593/31185 2.55E-8

Heat on 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$
Vitesse 17	8E3	5E6	23 4.6E-6	3 6E-7	0 <2E-7	1 2E-7
Vitesse 19	5E3	5E6	24 4.8E-6	5 1E-6	0 <2E-7	0 <2E-7
Vitesse 21	8E3	5E6	19 3.8E-6	5 1E-6	0 <2E-7	0 <2E-7
Marvell 18	6E3	5E6	22 4.4E-6	9 1.8E-6	2 4E-7	1 2E-7
Marvell 20	6-9E3	5E6	17 3.4E-6	10 2E-6	3 6E-7	0 <2E-7
Marvell 23	4E3	2E6	25 1.2E-6	3 6E-7	1 2E-7	1 2E-7

Xenon LET =60 MeV/mg/cm²

Heat off 100 Mb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	4E3	2E6	6 3E-6	1 5E-7	0 <5E-7	0 <5E-7	33/39977 4.13E-10
Vitesse 19	5-7E3	2E6	3 1.5E-6	2 1E-6	1 5E-7	0 <5E-7	21/30343 3.46E-10
Vitesse 21	4E3	2E6	11 5.5E-6	1 5E-7	0 <5E-7	1 5E-7	502/48387 5.19E-9
Marvell 18	4.7E3	2E6	11 5.5E-6	2 1E-6	3 1.5E-6	1 5E-7	3962/31935 6.20E-8
Marvell 20	Did not work						- -
Marvell 23	4E3	2E6	9	2	0	1	64/48544

			4.5E-6	1E-6	<5E-7	5E-7	6.59E-10

Heat off 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 17	3.5E3	2E6	17 8.5E-6	3 1.5E-6	0 <5E-7	0 <5E-7	1857/49265 1.88E-8
Vitesse 19	6E3	2E6	14 7E-6	2 1E-6	0 <5E-7	0 <5E-7	1611/27554 2.92E-8
Vitesse 21	4E3	2E6	11 5.5E-6	3 1.5E-6	0 <5E-7	0 <5E-7	1286/45074 6.39E-9
Marvell 18	4E3	2E6	17 8.5E-6	7 3.5E-6	1 5E-7	0 <5E-7	4150/33470 6.20E-8
Marvell 20	4E3	2E6	12 6E-6	4 2E-6	4 2E-6	0 <5E-7	1684/29304 2.87e-8
Marvell 23	5E3	2E6	12 6E-6	6 3E-6	0 <5E-7	1 5E-7	1379/24581 2.81E-8

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$
Vitesse 17	3.2E3	2E6	18 9E-6	3 1.5E-6	0 <5E-7	0 <5E-7
Vitesse 19	6E3	2E6	5 2.5E-6	4 2E-6	0 <5E-7	0 <5E-7
Vitesse 21	4E3	2E6	11 5.5E-6	2 1E-6	0 <5E-7	0 <5E-7
Marvell 18	2.5-3.8E3	2E6	28 1.4E-5	13	1 5E-7	2 1E-6
Marvell 20	4E3	2E6	14 7E-6	10 5E-6	1 5E-7	0 <5E-7
Marvell 23	3-5E3	2E6	31	6	0	5

			1.55E-5	3E-6	<5E-7	2.5E-6

3.2.1.8.1 Heavy ion results Lantiq first heavy ion measurement

Argon LET =10.2 MeV/mg/cm^2

Heat off 100 Mb/s	Flux $[1/cm^2/s]$	Fluence $[1/cm^2]$	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Lantiq 16	1E4	1.4E6	0 <7.2E-7	6 4.29E-6	0 <7.2E-7	0 <7.2E-7	0/8554 <8.35E-11
Lantiq 18	1E4	4.73E6	0 <2.16E-7	3 6.34E-7	2 4.32E-7	0 <2.16E-7	1/25655 8.24E-12

Heat off 1 Gb/s	Flux $[1/cm^2/s]$	Fluence $[1/cm^2]$	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Lantiq 16	1E4	8.3E5	0 <1.2E-6	4 4.82E-6	1 1.2E-6	0 <1.2E-6	140/9132 1.85E-8
Lantiq 18	1E4	2.9E6	1 3.45E-7	5 1.72E-6	3 1.03E-6	0 <3.45E7	135/17814 2.61E-9

Heat on 1 Gb/s	Flux $[1/cm^2/s]$	Fluence $[1/cm^2]$	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	Latchup
Lantiq 16	1E4	5E6				0 <2E-7	
Lantiq 18	1E4	4.37E6				0 < 2E-7	1 2.29E-7

It should be mentioned that the only real hard latchup effect seen throughout the whole experimental campaign was with Lantiq 18. The current consumption reached the 1A hard limit threshold and the part could not be recovered by a power cycle. It could have also been an extreme effect of the total ionising dose deterioration.

Iron LET =18.5 MeV/mg/cm²

Heat off 100 Mb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Lantiq 16	7E3	2.17E6	0 <4.61E-7	4 1.84E-6	4 1.84E-6	0 <4.61E-7	1486/9953 6.88E-8

Heat off 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Lantiq 16	8E3	1.07E6	4 3.74E-6	6 5.61E-6	1 9.35E-7	0 <7.2E-7	101/6523 1.45E-8

3.3 Proton irradiation tests

Two components from each 3 supplier were tested with proton using 52 MeV beam energy at the surface of the component. Components were not opened. One etched sample from each 3 supplier was tested with low energy protons at energies of 1.0 and 1.5 MeV. These tests were done on 31.5.2016. In addition, Marvell and Vitesse were tested on 9.6.2016 using 0.7, 1.0 and 1.2 MeV protons. These low energy tests to map the sensitivity of the samples for direct ionization were done in vacuum.

3.3.1 52 MeV proton tests

Two components from each 3 suppliers were tested using 52 MeV proton energy at the surface of the component cover. Components were not opened (not etched). For each component 2 separate runs with heat on and heat off were done using 1Gb/s data rate. The final fluence for each run was 1E11 protons/cm² and flux of 3E8 protons/cm²/s was used. Tests were performed on 31.5.2016.

Only one LLR and one FILL even was seen for Marvell components during 52 MeV tests. No error events were seen for Vitesse. Several error events were seen when Lantiq was tested, as can be seen in table 10. “Data loss” cross-sections are plotted in figure 23 from heat off data.

Data of 52 MeV proton irradiations. Components were unopened.

Heat off 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 23	3E8	1E11	0 <1E-11	0 <1E-11	0 <1E-11	0 <1E-11	2/35991 5.56E-16
Vitesse 26	3E8	1E11	0 <1E-11	0 <1E-11	0 <1E-11	0 <1E-11	168/35086 4.79E-14
Marvell 28	3E8	1E11	1	0	0	0	4922/35082

			1E-11	<1E-11	<1E-11	<1E-11	1.40E-12
Marvell 29	3E8	1E11	0 <1E-11	0 <1E-11	0 <1E-11	0 <1E-11	82/34419 2.38E-14
Lantiq 882	3E8	1E11	0 <1E-11	2 2E-11	3 3E-11	0 <1E-11	82/10437 7.86E-14
Lantiq 884	3E8	1E11	3 3E-11	1 1E-11	5 5E-11	0 <1E-11	275/16610 1.66E-13

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
Vitesse 23	3E8	1E11	0 <1E-11	0 <1E-11	0 <1E-11	0 <1E-11	21/35465 5.92E-15
Vitesse 26	3E8	1E11	0 <1E-11	0 <1E-11	0 <1E-11	0 <1E-11	2/34551 5.79E-14
Marvell 28	3E8	1E11	0 <1E-11	0 <1E-11	0 <1E-11	0 1E-11	77/35128 2.19E-14
Marvell 29	3E8	1E11	0 <1E-11	1 1E-11	0 <1E-11	0 <1E-11	124/42323 2.93E-14
Lantiq 882	3E8	1E11	3 3E-11	5 5E-11	2 2E-11	0 <1E-11	437/15954 2.74E-13
Lantiq 884	3E8	1E11	3 3E-11	0 <1E-11	1 1E-11	0 <1E-11	703/6055 3.45E-12

3.3.2 Low energy proton tests

One etched sample from each 3 supplier was tested with low energy protons at energies of 1.0 and 1.5 MeV on 31.5.2016. In addition, one component from Marvell and Vitesse were tested using 0.7, 1.0 and 1.2 MeV protons on 9.5.2016. These low energy proton tests to map the sensitivity of the samples for direct ionization were done in vacuum. Results are collected in the following tables.

Results of the low energy proton tests for Vitesse 18

Heat off 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
0.7 MeV	7.2E5	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	0/143961 <6.95E-15
*1.0 MeV	1.1E7	2.02E9	0 <5E-10	0 <5E-10	0 <5E-10	0 <5E-10	0/19067 <2.60E-14
1.0 MeV	2E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	0/53226 <1.88E-14
1.2 MeV	1.8E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	0/53316 <1.88E-14
*1.5 MeV	5.5E6	2E9	0 <5E-10	0 <5E-10	0 <5E-10	0 <5E-10	0/35686 <1.40E-14

*Data from the first experiment done 31.5.2016

Heat on 1 Gb/s	Flux [1/cm²/s]	Fluence [1/cm²]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
0.7 MeV	7.2E5	8.4E8	1 1.19E-9	0 <1.19E-9	0 <1.19E-9	0 <1.19E-9	111/120230 1.1E-12
*1.0 MeV	1.52E7	2.04E9	0 <5E-10	0 <5E-10	0 <5E-10	0 <5E-10	132/14590 4.43E-12
1.0 MeV	2E6	1E9	1 1E-9	0 <1E-9	0 <1E-9	0 <1E-9	113/51542 2.19E-12
1.2 MeV	2E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	110/51604 2.13E-12
*1.5 MeV	5.5E6	2E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	0/36099 <1.39E-14

*Data from the first experiment done 31.5.2016

Results of the low energy proton tests for Marvell 19

Heat off 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch-Up}$	lost/all $\sigma_{Data\ loss}$
0.7 MeV	7.6E5	5E8	0 <2E-9	0 <2E-9	0 <2E-9	0 <2E-9	53/74411 1.42E-12
*1.0 MeV	1.12E7	2.03E9	0 <4.9E-10	0 <4.9E-10	0 <4.9E-10	0 <4.9E-10	7/19295 1.79E-13
1.0 MeV	1.4-1.8E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	6/73340 8.18E-14
1.2 MeV	1.9E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	4/51938 1.75E-13
*1.5 MeV	4-6E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	4/22904 1.79E-13

*Data from the first experiment done 31.5.2016

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch-Up}$	lost/all $\sigma_{Data\ loss}$
0.7 MeV	7.6E5	5E8	0 <2E-9	0 <2E-9	0 <2E-9	0 <2E-9	56/68705 1.63E-12
*1.0 MeV	1.11E7	2.03E9	0 <4.9E-10	0 <4.9E-10	0 <4.9E-10	0 <4.9E-10	8/19517 2.02E-13
1.0 MeV	1.8E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	6/57709 1.04E-13
1.2 MeV	1.9E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	2/54029 3.70E-14
*1.5 MeV	5E5-4E6	1E9	0 <1E-9	0 <1E-9	0 <1E-9	0 <1E-9	6/97968 6.12E-14

*Data from the first experiment done 31.5.2016

Results of the low energy proton tests for Lantiq 20

Heat off 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
*1.0 MeV	1.5E7	2.04E9	0 <4.9E-10	0 <4.9E-10	0 <4.9E-10	0 <4.9E-10	98/14838 3.24E-12
*1.5 MeV	5.7E6	2E9	0 <5E-10	1 5E-10	3 1.5E-9	0 <5E-10	534/15357 1.74E-11

*Data from the first experiment done 31.5.2016

Heat on 1 Gb/s	Flux [1/cm^2/s]	Fluence [1/cm^2]	LLR σ_{LLR}	FILL σ_{FILL}	FINL σ_{FINL}	Micro Latch-Up $\sigma_{Latch\text{-}Up}$	lost/all $\sigma_{Data\ loss}$
*1.0 MeV	1.47E7	2.04E9	1 4.9E-10	2 9.8E-10	1 4.9E-10	0 <4.9E-10	8/19517 2.02E-13
*1.5 MeV	5.75E6	2E9	0 <5E-10	3 1.5E-9	1 5E-10	0 <5E-10	6/97968 6.12E-14

*Data from the first experiment done 31.5.2016

3.3.2.1 "Data loss" cross-section plots for proton tests

The "Data loss" cross-section as a function of proton energy are plotted for Marvell in Figure 3-45 and for Vitesse in Figure 3-46 , respectively.

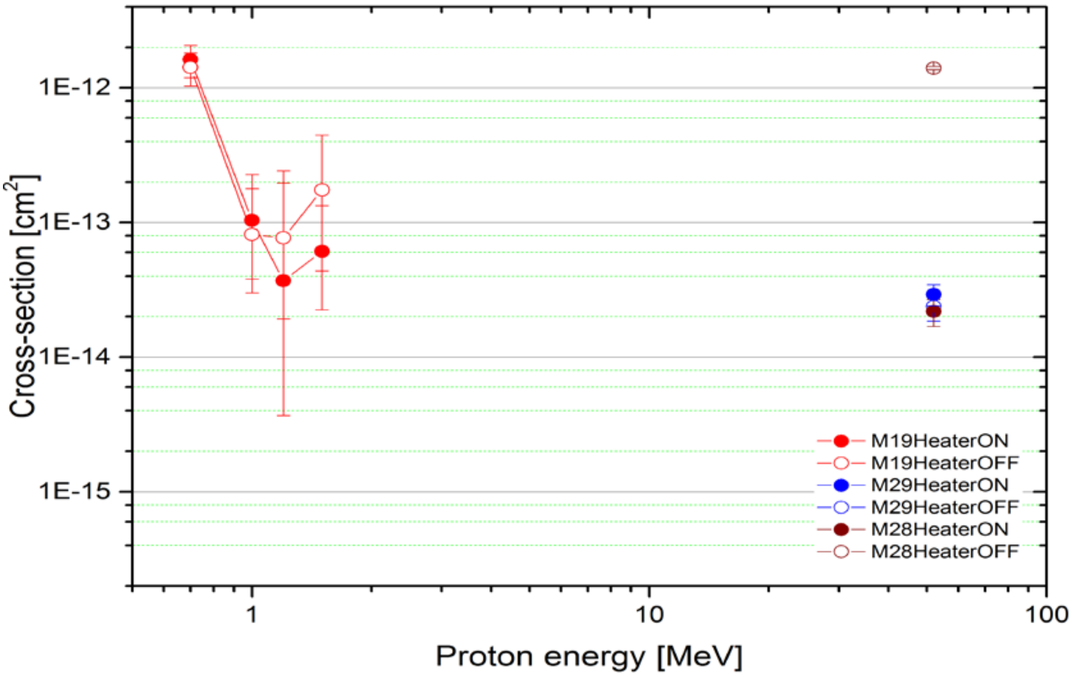


Figure 3-45 "Data loss" cross-sections for Marvell components in proton irradiations.

Point for component 28 with heat off differs from the other 52 MeV points two orders of magnitudes. When analyzing the data it was noticed that component has had some problems during last 2 min of the 6 min long irradiation. During that last 2 min it lost half of the data packets. Reason for this is not known.

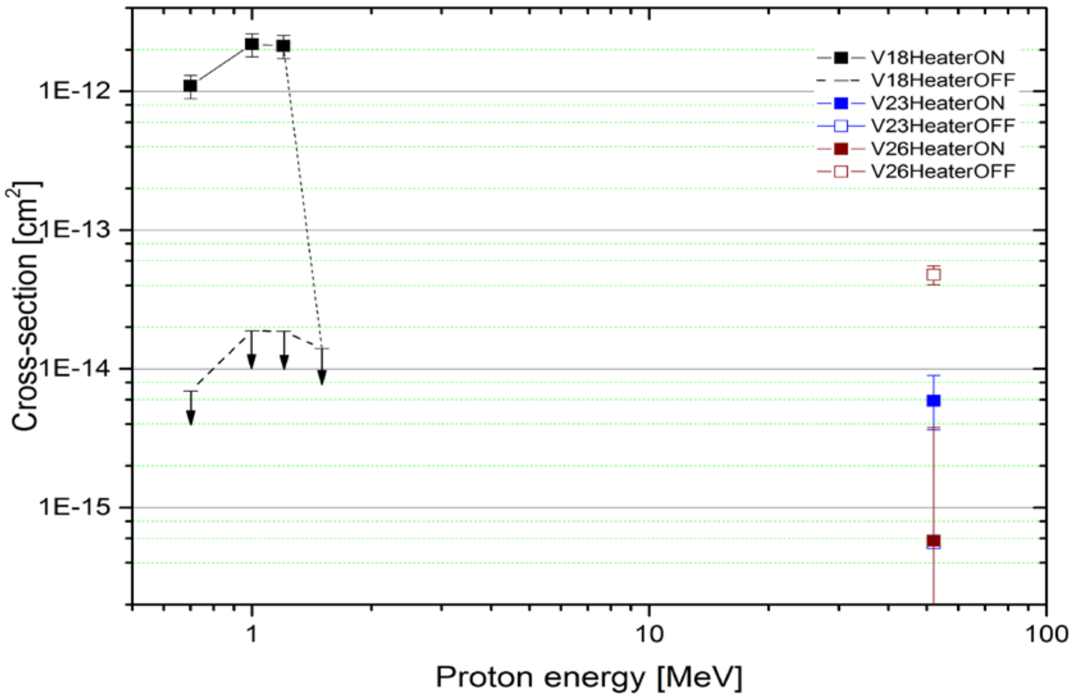


Figure 3-46 "Data loss" cross-sections for Vitesse components in proton irradiations.

No “Data loss” was observed for Vitesse 18 component when heat was off. The highest observation limits of the measurement are marked line symbols with downward arrows.

3.3.3 Conclusion Radiation Experiments

During the first heavy ion and proton tests 16.5-19.5.2016 and 31.5.2016 it came clear that Lantiq components were much more sensitive than Marvell and Vitesse. Due to high error rates of Lantiq, runs took much longer time than with other two devices. Also with Lantiq one device underwent a latchup phenomenon and could not be functional again. Therefore, it was decided to leave Lantiq out from the second irradiation tests 6.-9.2016. This decision speeded up the experiment and more data was obtained for Marvell and Vitesse.

A good set of experimental nuclear data could be obtained for Marvell and Vitesse parts.

The Single Event Upsets observed during the experiments were divided into five event categories:

-**data loss** -whenever a package would not be sent back by the PHY. No mitigation possible. For critical applications hot redundancy recommended.

-**microlatchup**- defined when the current increase exceeded 30% of the nominal current consumption described in the data sheet and the current increase would last at least 15 s. This definition may seem conservative, however it is useful to have detected this phenomenon and know that the devices manifest this current increase.

-functional interrupts with link loss- defined when the PHYs do not transmit packages any longer and the Ethernet connection would be lost. Mitigation: Reset/reboot of the device.

-**functional interrupts with no link loss**- defined when the PHYs do not transmit packages any longer and the Ethernet connection would be still on. Mitigation: Reset/reboot of the device.

-**link lost and recovered**-defined when the PHYs loose the Ethernet connection and recovered. No mitigation needed since the link would be established within seconds.

All the experimental cross-sections were mapped as a function of LETs.

The data loss experimental cross-sections were quantified for a range of LETs up to 60 MeVcm2/mg. The onset of the data loss takes place at low LET levels of 10 MeV/(cm2 mg) for both parts, but the saturation is reached at very low levels in the E-9-E-8 cm2 range. The value at the saturation being small, the mission error rate is expected to be small as well. Systematically, it was observed that the data loss sensitivity is a factor of 10 to 100 higher at 1Gbs compared to the 100 MBs, for both Marvell and Vitesse. The value of the cross-sections for Vitesse were smaller compared to that of Marvell, which points out at a higher robustness for Vitesse. Below, the error rates are calculated for the data loss SEU type for a heavy ion environment which is specific to that of the International Space Station, in a nominal heavy ion scenario with 2.7 mm Al shielding.

DUT Failure mode: data loss	Error rate per day
Marvell Dataloss 100 MB/s	7.4E-9
Marvell Dataloss 1000 MB/s	6.6E-6
Vitesse Dataloss 100 MB/s	4.8E-10
Vitesse Dataloss 1000 MB/s	9E-7

For critical missions, it is therefore recommended to deploy Vitesse devices which have the lowest data loss error rates and the lowest functional interrupts. No destructive events were detected in both components.

The functional interrupts could be an issue for systems which deploy either Marvell or Vitesse, which require high-availability, since for this SEU events the cross-sections were in the 1E-6-1E-7 cm2 range which would translate into a higher error rate per day than the data loss.

As far as the protons data are concerned, we might have seen a upraise in the data loss cross-sections at low protons energy, which could be a signature of the direct ionisation. However, the cross-sections are really small, and for the low energy protons there is minimum of shielding available in each avionic box.

All in all, a set of experimental nuclear data for Marvell and Vitesse could be gained and an insight into the failure types which may be encountered in a mission dominated by the heavy ions. The better component turned to be Vitesse, followed by Marvell. The Lantiq chips which we have tested could not be recommended, due to their latchup effect encountered and higher SEU sensitivity overall.

4. Environmental testing

In the following, we will focus on the description of the seven environmental tests which have to be conducted in the framework of this contract: ESD, thermal, vacuum, life, flammability, outgassing and off gassing for manned space.

4.1 Electrostatic discharge

4.1.1 Facility and general information

The electrostatic discharge test location took place in Airbus DS Bremen, in the certified EMI laboratory. The test was conducted as explained in the Test procedure for radiated discharge.

The test setup for radiated arc susceptibility is shown in the following Figure 4-1.

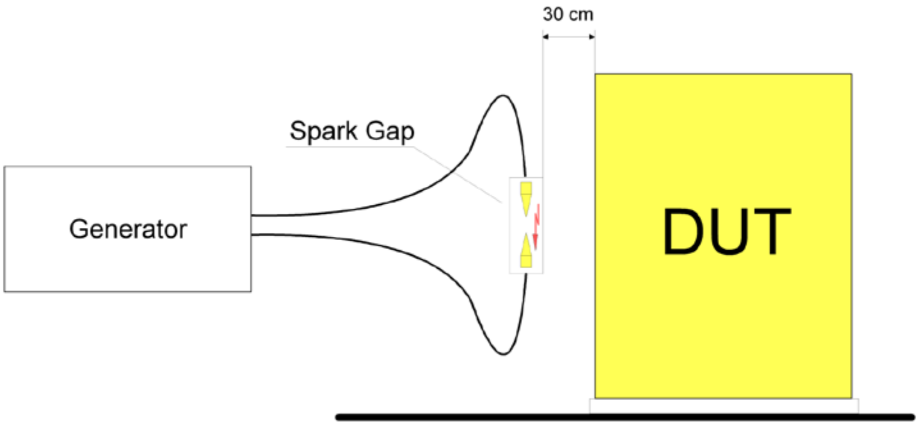


Figure 4-1 Test Setup for radiated arc discharge susceptibility.

Pictures from the test are attached below.

The generator produced a pulse with a pulse repletion rate of 1 Hz, 5 Hz and 10 Hz.

The maximum voltage shall be as indicated per data sheet of the PHY DUTs, 2000 V for each device. The test duration shall be at least 5 minutes per position.

Susceptibilities and anomalies that are not in conformance with contractual requirements are not acceptable. However, all susceptibilities and anomalies observed during conduct of the test shall be documented. When susceptibility indications are noted in EUT operation, a threshold level shall be determined where the susceptible condition is no longer present.

We tested three of each DUTS:

Vitesse #12, #13, and #18

Lantiq #18, #19, and #20

Marvel #13, #11, and #23

The tests were functional tests, at ESD Radiated Spark of 1, 5 and 10 Hz respectively.

The devices transmitted all the packets, with the exception of Lantiq which lost few 1max 20 packets). Lantiq has been always a slightly difficult candidate, and the packets losses were also observed during the dry run thus they are not in correlation with the ESD test.

The log books are attached below.

Logbook of PHYDUT PCBs
PHY characterization ESD Test
Airbus DS Bremen

PHYDUT PCB: Vitesse #13	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Ruttelmann	Plettner	Plettner	Plettner
Date/Time	05.04.2016 11 51	05.04.2016 16 12	05.04.2016 16 15	05.04.2016 16 20
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 64 mA 3) 104 mA	1) OK 8000 2) 64 mA 3) 104 mA	1) OK 8000 2) 64 mA 3) 104 mA	1) OK 8000 2) 64 mA 3) 104 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 112 mA 3) 160 mA	1) OK 8000 2) 112 mA 3) 160 mA	1) OK 8000 2) 112 mA 3) 160 mA	1) OK 7990 2) 112 mA 3) 160 mA

Logbook of PHYDUT PCBs
PHY characterization ESD Test
Airbus DS Bremen

PHYDUT PCB: Vitesse # 12	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Buttelmann	"	Plttner	Plttner
Date/Time	05.04.2016 11 48	05.04.2016 15 35	05.04.2016 15 40	05.04.2016 15 45
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 64 mA 3) 104 mA	1) OK 8000 2) 64 mA 3) 104 mA	1) OK 8000 2) 64 mA 3) 104 mA	1) OK 8000 2) 64 mA 3) 104 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 112 mA 3) 160 mA	1) OK 8000 2) 112 mA 3) 160 mA	1) OK 8000 2) 112 mA 3) 160 mA	1) OK 8000 2) 112 mA 3) 160 mA

Logbook of PHYDUT PCBs
PHY characterization ESD Test
Airbus DS Bremen

PHYDUT PCB: Lantiq #18	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Buttelmann	Plttner	Plttner	Plttner
Date/Time	05.04.2016 12 10	05.04.2016 14 20	05.04.2016 14 26	05.04.2016 14 31
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 7999 2) 48 mA 3) 48 mA	1) OK 7999 2) 48 mA 3) 48 mA	1) OK 7999 2) 48 mA 3) 48 mA	1) OK 7999 2) 48 mA 3) 48 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 7990 2) 248 mA 3) 80 mA	1) 7990 2) 248 mA 3) 80 mA	1) OK 7998 2) 248 mA 3) 80 mA	1) OK 8000 2) 248 mA 3) 80 mA

Logbook of PHYDUT PCBs PHY characterization ESD Test Airbus DS Bremen				
PHYDUT PCB: Lantiq #19	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Buttelmann	"	"	"
Date/Time	05.04.2016 12 16	" 13 55	" 14 05	" 14 10
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 48mA 3) 56mA	1) OK 8000 2) 48mA 3) 51 mA	1) OK 8000 2) 48mA 3) 56mA	1) OK 8000 2) 48mA 3) 56mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 7983 2) 240mA 3) 80mA	1) OK 7999 2) 240mA 3) 80mA	1) OK 7989 2) 240mA 3) 80mA	1) OK 7990 2) 240mA 3) 80mA

Logbook of PHYDUT PCBs PHY characterization ESD Test Airbus DS Bremen				
PHYDUT PCB: Lantiq #20	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Buttelmann	"	"	"
Date/Time	05.04.2016 12 30	" 13 40	" 13 47	" 13 52
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 48mA 3) 56mA	1) OK 8000 2) 48mA 3) 48mA	1) OK 8000 2) 48mA 3) 56mA	1) OK 8000 2) 48mA 3) 56mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 7994 2) 240mA 3) 80mA	1) OK 7998 2) 240mA 3) 72mA	1) OK 8000 2) 240mA 3) 72mA	1) OK 7998 2) 248mA 3) 72 mA

Logbook of PHYDUT PCBs PHY characterization ESD Test Airbus DS Bremen				
PHYDUT PCB: Marvel #13	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Duttelmann	"	"	"
Date/Time	05.04.2016 11 40	" 15 18	" 15 23	" 15 29
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 32 mA 3) 88 mA	1) OK 8000 2) 32 mA 3) 88 mA	1) OK 8000 2) 32 mA 3) 88 mA	1) OK 8000 2) 32 mA 3) 88 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA

Logbook of PHYDUT PCBs PHY characterization ESD Test Airbus DS Bremen				
PHYDUT PCB: Marvel #11	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Duttelmann	"	"	"
Date/Time	05.04.2016 11 37	05.04.2016 15 00	" 15 06	" 15 11
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 24 mA 3) 88 mA	1) OK 8000 2) 24 mA 3) 88 mA	1) OK 8000 2) 24 mA 3) 88 mA	1) OK 8000 2) 24 mA 3) 88 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK 8000 2) 192 mA 3) 192 mA	1) OK 8000 2) 192 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA

Logbook of PHYDUT PCBs PHY characterization ESD Test Airbus DS Bremen				
PHYDUT PCB: Marvel #23	Before RUN	ESD Radiated Spark RUN 1 Hz	ESD Radiated Spark RUN 5 Hz	ESD Radiated Spark RUN 10 Hz
Test Conductor Name	Buttelmann	"	"	"
Date/Time	05.04.2016 11 30	05.04.2016 14 43	" 14 49	" 14 54
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK: 8000 2) 24 mA 3) 88 mA	1) OK 8000 2) 24 mA 3) 88 mA	1) OK 8000 2) 24 mA 3) 88 mA	1) OK 8000 2) 24 mA 3) 88 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) OK: 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA	1) OK 8000 2) 200 mA 3) 192 mA

Thus, the conclusion is that all parts are fully functional during the ESD radiated spark testing.

4.2 Thermal cycle testing

4.2.1 Test conditions

The test location site was be Bremen Airbus Defense and Space environmental laboratory in an environmental chamber with application of a cryomat to control the cold plate temperature, which is part of the liquid cooling loop.

During this test, a number of 100 thermal cycles with temperature ranging from -55°C to 125°C was be applied to the PHY parts. The test is intended to determine the capability of an equipment to be stored or operated at low or very low temperatures or alternatively at very high temperatures, to mimic the influence of the thermally harsh space environment.

The devices, 9 in total were subjected to 100 thermal cycles with the gradients presented below.

The applied thermal cycle is presented in Figure 4-2.

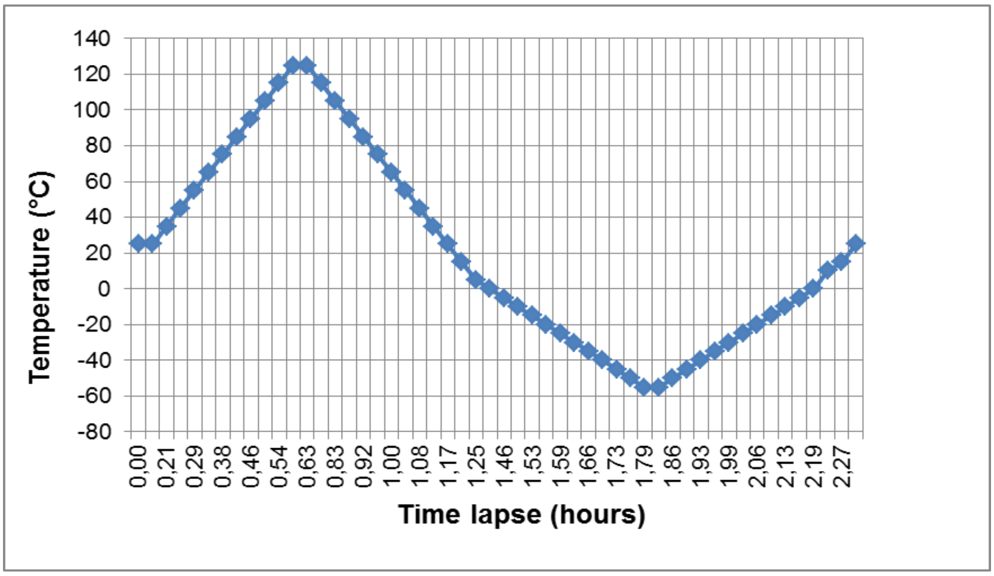


Figure 4-2 The applied temperature gradient.

No effects of this environmental stress could be seen in the devices:

- Changes in the mechanical characteristics of the materials
- Changes and deformations due to overall or differential expansions/compressions and appearance of thermal stresses as well as bindings, fatigue strengths
- Changes in the electrical performance, problems by starting the devices

The results are shown in the following table:

Supplier	**DUT#1** **Functional /Non functional** **100/1000 MB/s**	**DUT#2** **Functional/ Non functional** **100/1000 MB/s**	**DUT#3** **Functional/ Non functional** **100/1000 MB/s**
Marvel	yes	yes	yes
Vitesse	Yes but higher current consumption	Yes but higher current consumption	Yes but higher current consumption
Lantiq	NOK- link could not be established	OK	yes

The log books from the experiment can be found below.

Logbook of PHYDUT PCBs PHY characterization Thermal Cycles Test Airbus DS in Bremen		
PHYDUT PCB: LANTIQ #11	Before RUN	After RUN
Test Conductor Name	Lutz Buttelmann	"
Date/Time	07.03.2016 / 12:51	11.04.2016 / 12¹⁰
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 48 mA 3) 48 mA	1) OK 8000 2) 48 mA 3) 48 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 264 mA 3) 80 mA	1) OK 8000 2) 256 mA 3) 72 mA
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	./.	./.

Logbook of PHYDUT PCBs PHY characterization Thermal Cycles Test Airbus DS in Bremen		
PHYDUT PCB: LANTIQ #12	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 12:56	11.04.2016 / 12¹²
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 56 mA 3) 56 mA	1) 0 NOT OK ← 2) 48 mA 3) 48 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 264 mA 3) 80 mA	1) 0 NOT OK ← 2) 256 mA 3) 64 mA
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	./.	→ Links 100/1000 were established but no Packets are looped back ? PCB Malfunction ?

Logbook of PHYDUT PCBs
PHY characterization Thermal Cycles Test
Airbus DS in Bremen

PHYDUT PCB: LANTIQ #13	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 12:59	11.04.2016 12 20
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 48 mA 3) 56 mA	1) OK 8000 2) 48 mA 3) 48 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 272 mA 3) 96 mA	1) OK 8000 2) 256 mA 3) 72 mA
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	/	/

Logbook of PHYDUT PCBs
PHY characterization Thermal Cycles Test
Airbus DS in Bremen

PHYDUT PCB: VITESSE #14	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 13:15	11.04.2016 12 30
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 80 mA 3) 80 mA	1) OK 8000 2) 72 mA 3) 104 mA *1 ← !
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 136 mA 3) 120 mA	1) OK 8000 2) 128 mA 3) 160 mA *1 ← !
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	/	*1: higher (20mA) ⇕ (40mA)

Logbook of PHYDUT PCBs
PHY characterization Thermal Cycles Test
Airbus DS in Bremen

PHYDUT PCB: VITESSE #15	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 13:18	11.04.2016 12 35
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 80 mA 3) 80 mA	1) OK 8000 2) 72 mA 3) 104 mA *1 ←
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 136 mA 3) 120 mA	1) OK 8000 2) 128 mA 3) 160 mA *1 ←
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	/	*1 higher

Logbook of PHYDUT PCBs PHY characterization Thermal Cycles Test Airbus DS in Bremen		
PHYDUT PCB: VITESSE # 24	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 13:20	11.04.2016 12 40
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 80 mA 3) 80 mA	1) OK 8000 2) 72 mA 3) 104 mA *1 ←
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 7999 OK 2) 136 mA 3) 128 mA	1) OK 8000 *2 ← 2) ~~28~~ 128 mA 3) 160 mA *1 ←
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	✓	*1 higher *2 IC needs to be push down on PCB => PCB Malfunction

Logbook of PHYDUT PCBs
PHY characterization Thermal Cycles Test
Airbus DS in Bremen

PHYDUT PCB: MARVEL #16	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 13:35	11.04.2016 12 59
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 24 mA 3) 80 mA	1) OK 8000 2) 24 mA 3) 88 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 208 mA 3) 184 mA	1) OK 8000 2) 200 mA 3) 192 mA
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	/.	/.

Logbook of PHYDUT PCBs
PHY characterization Thermal Cycles Test
Airbus DS in Bremen

PHYDUT PCB: MARVEL #15	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 13:30	11.04.2016 12 47
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 24 mA 3) 80 mA	1) OK 8000 2) 24 mA 3) 88 mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 216 mA 3) 184 mA	1) OK 8000 2) 208 mA 3) 192 mA
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	/	Colasoft crashed -> restart OK

Logbook of PHYDUT PCBs PHY characterization Thermal Cycles Test Airbus DS in Bremen		
PHYDUT PCB: MARVEL #17	Before RUN	After RUN
Test Conductor Name	Lutz	"
Date/Time	07.03.2016 13:40	11.04.2016 12 55
Test 4000 packets: 1) Speed 100 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 24mA 3) 80 mA	1) OK 8000 2) 24mA 3) 88mA
Test 4000 packets: 1) Speed 1000 [OK/Not OK] 2) Current 1v [mA] 3) Current 2,5v [mA]	1) 8000 OK 2) 224mA 3) 184 mA	1) OK 8000 2) 208mA 3) 184mA
Remarks: NOTE Test 4000 packets is executed according the TID Radiation test sequence	/	/

4.3 Vacuum testing

4.3.1 Test conditions

The test location site was Bremen Airbus Defense and Space environmental laboratory. This test is intended to check the ability of equipment to operate during and/or after a holding time under rarefied atmosphere conditions. The test consists in applying an extreme small pressure combined with a thermal environment during a given period of time.

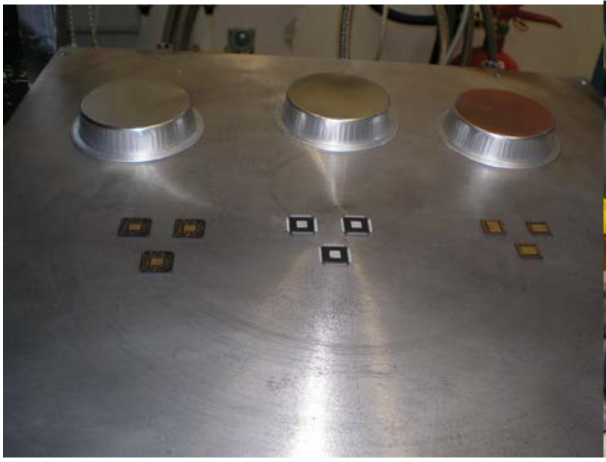
The effects of vacuum might appear in the form of:

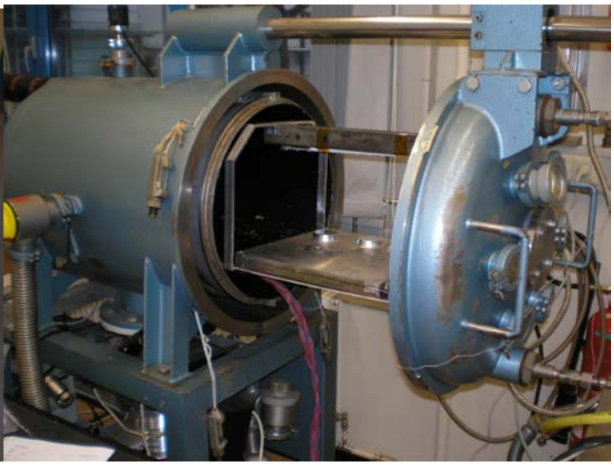
- Mechanical deformations of parts with the possible appearance of jamming, cracks
- Tightness losses, leaks
- A reduced effectiveness of the cooling system, with higher risk of local heating

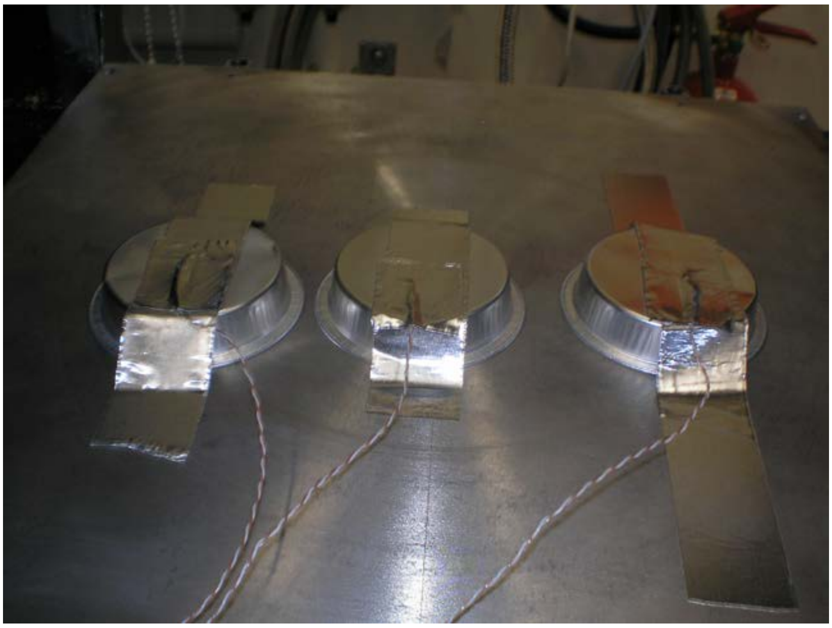
The temperature uncertainty may reach +/- 2°C and the tolerance on pressure amounts to +/- 10%. The pressure level which we envision is 10^{-6} mbar. The thermal flux envisioned for this experiment is fixed at 55°C. The holding time in vacuum shall be several (8) hours.

The devices were visually inspected before and after the holding time in vacuum, and all changes will be recorded.

Picture from the experiment can be seen below:







The devices under test were placed and fixed in a vacuum chamber. The temperature was checked by using three thermocouplers of Type I IEC 584-3mod DIN 43722.

The vacuum chamber was closed, and it was started the pumping. After the pressure reached 5E-4 mbar, the temperature of the hot plate was set to 60°C.

The experiment was running over nicht and the pressure was monitored. The data is presented below. No indication of an outgassing could be seen in the pressure curve.

After the test, the probes were visually inspected by a microscope with a magnyfing lense of 5x.

No mechanical deformations could be seen.

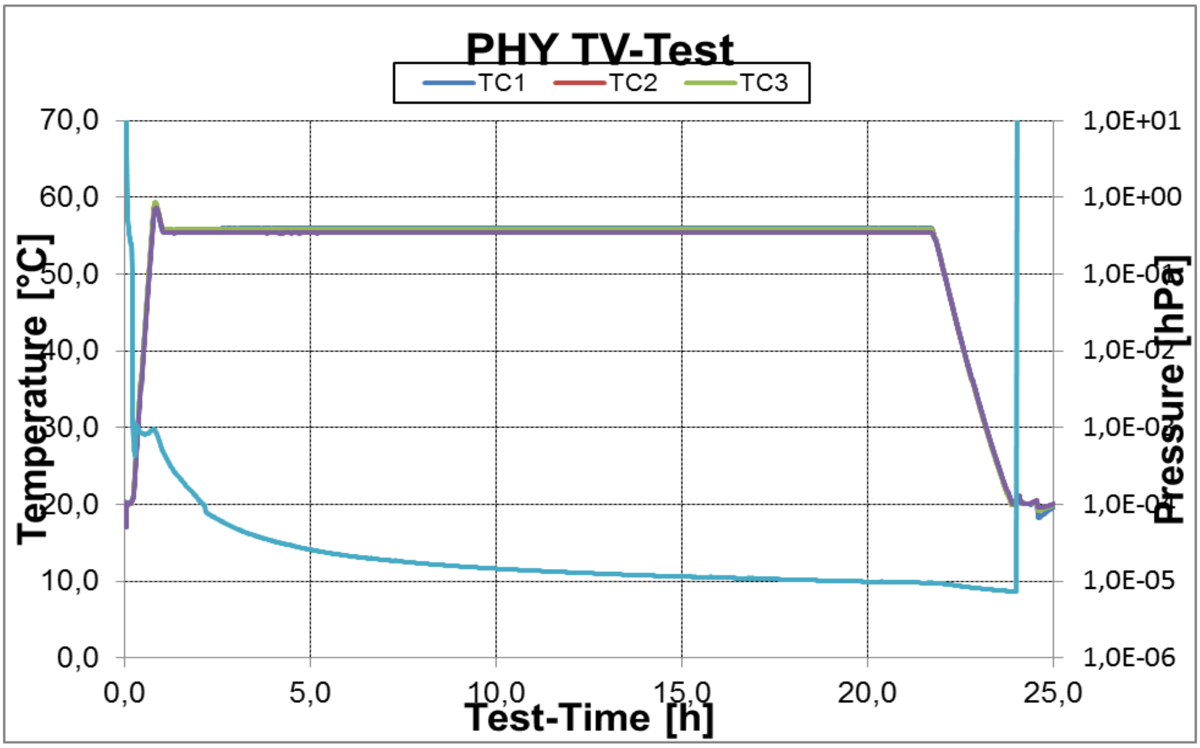


Figure 4-3 The vacuum test data.

The results are reported in the following form:

Supplier	DUT#1 Mechanical deformations/ Comments	DUT#2 Mechanical deformations/ Comments	DUT#3 Mechanical defor-mations/ Comments
Marvel	No deformations	No deformations	No deformations
Vitesse	No deformations	No deformations	No deformations
Lantiq	No deformations	No deformations	No deformations

The test results certify that all the devices could be used in vacuum.

4.4 Life testing

4.4.1 Test conditions

The test location site was the electronic laboratory of Bremen Airbus Defense and Space, which is temperature controlled. This experiment is intended to check the ability of the PHY transceivers to withstand an extreme hard environment. The requirements set forth in SOW are that the PHY DUT will be bias and heated to 125°C for 1000 hours.

The 1000h Life Temperature test was carried out at Airbus DS in Bremen between 7^{st} of April and 25^{th} of Mai 2016.

This test is intended to check the ability of the PHY transceivers to withstand an extreme hard environment. The requirements set forth in SOW are that the PHY DUT will be bias and heated to 125°C for 1000 hours.

For the calibration of the integrated heater, we measured the temperature on the top of the packages and use this results for the heater control of the PHYDUTs.

Previously performed dry runs of the test samples illustrated that the devices should be heated up to 115°C maximum (measured at top of package!). Higher temperatures forced the samples to lost packets. Thus, in the Life test all samples were heated at 115°C and all samples were fully functional.

A set of key parameters were measured with an oscilloscope or automatically by the EGSE. The were recorded to find out eventual drift of signals and current consumption. In addition to the current consumtion of the samples we identified a set of parameters for measurement (Figure 2) which were already used in the TID test (see Appendix 1: “PHY Characterization Test Sequence Total Dose”):

1. RX Clock period (100 and 1000BaseT)
2. Data to Clock delay (100 and 1000BaseT)

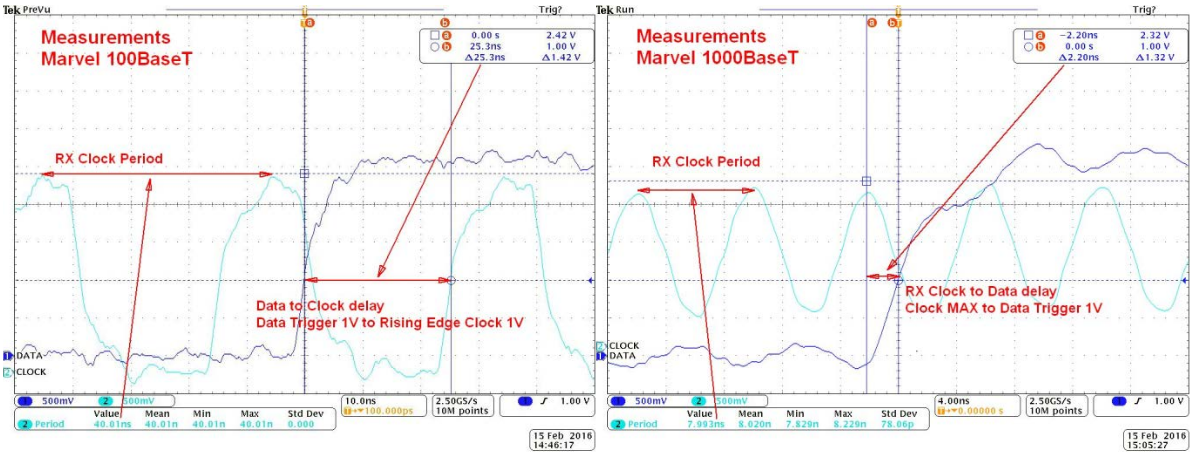


Figure 4-4 Measurements key parameters of test samples, here for Marvell

In addition to the measurements above and we made functional tests for each sample according Appendix 1: “PHY Characterization Test Sequence Total Dose”. We reuse the "Test 4000 Packets" procedure of the TID test to perform functional tests with 100BaseT and 1000BaseT.

After each test execution we switched the speed from 100 to 1000 or vice versa. This guaranties a good coverage of both speeds while the long term Life tests.

A photo of the test setup is shown in Figure below.

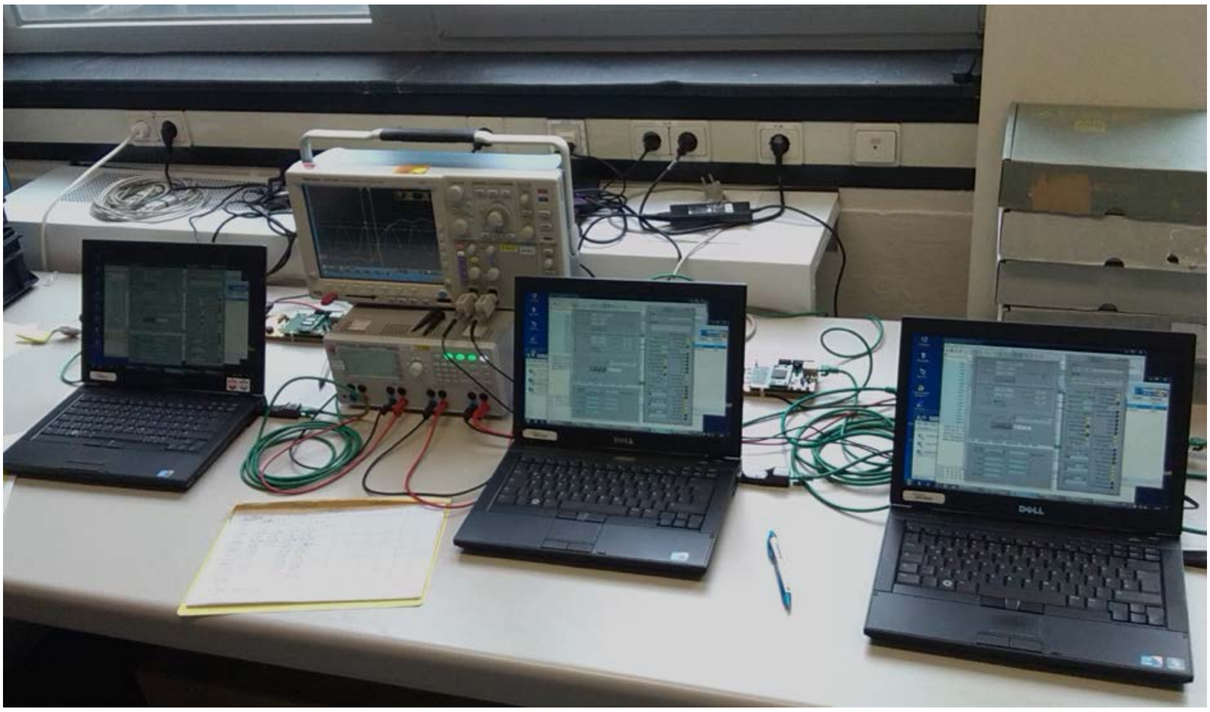


Figure 4-5 Test configuration of Airbus DS Life Temperature Test in Bremen.

In all 3 devices were tested, one of each manufacturer. The time lapse of the life test is set to 41 days, which is approximately 6 weeks or 1000h. The measured parameters will be saved and stored once per working day. During the week-ends the equipment will be maintained under bias and under temperature stress.

Table 4-1 Time schedule of the Life Temperature test.

Device	Start time	Stop time	Time	Remarks
Marvell	07.04.2016	17.05.2016	1000h	Heater works fine.
Lantiq	07.04.2016	19.05.2016	1000h	Integrated Heater defect at 20.04.2016, re-placed by external heater. => Needs test extension of 41h.
Vitesse	15.04.2016	25.05.2016	1000h	First integrated Heater defect at 15.04.2016, replaced by spare sample. Second heater defect at 27.04.2016, replaced by external heater. => Overall test extension of 8 days.

4.4.2 Lifetime Results

Measurements and functional tests were performed according to detailed introduction given in Appendix 1: “PHY Characterization Test Sequence Total Dose” of the TID test.

4.4.2.1 Marvell: "Test 4000 packets"

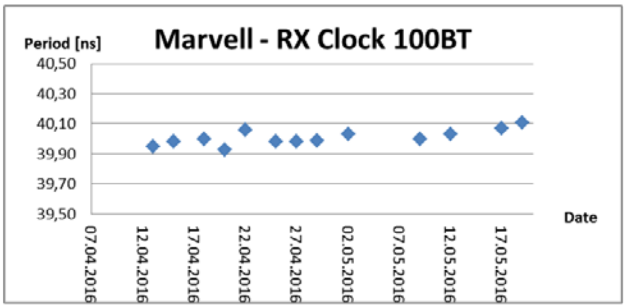
The "Test 4000 packets" is a short test to check the functionality and current consumption of the PHYs for 100Mbps and 1000Mbps mode. This test was done 6 times for each component. First it was done before irradiations, then after each irradiation step and finally after annealing. Test sequence is described detailed in Appendix 1, starting page 5.

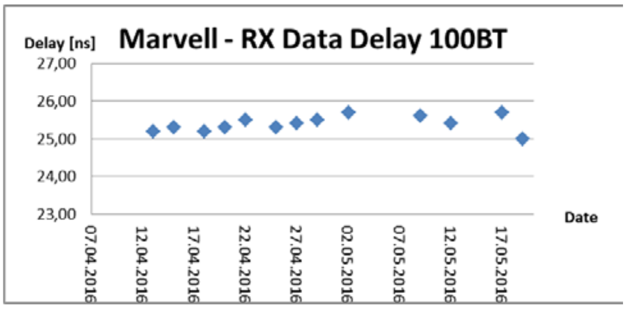
In this test, LAN packets generator program Colasoft sent 4000 packets of data to the PHYDUT which sent it to FPGA. FPGA looped data back to PHYDUT which then send it back to the EGSE Laptop. If everything worked correct, LAN data packet counter program Wireshark register 8000 data packets (see Appendix 1: page 8). Only number of sent and received packets was registered. Contents of the packets were not analyzed. At the same time the current consumptions of each PHYDUT for 1 V and 2.5 V power lines were registered.

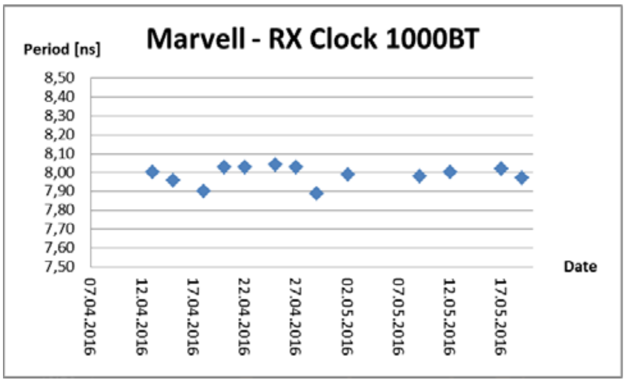
Marvell Date	Current [mA] 1V@100BT	Current [mA] 2,5V@100BT	RX Clock [ns] 100BT	RX Data [ns] 100BT	Current [mA] 1V@1000BT	Current [mA] 2,5V@1000BT	RX Clock [ns] 1000BT	RX Data [ns] 1000BT	Remarks
07.04.2016	48	88			232	192			Initial Temperature 80°C, not 115°C
08.04.2016	48	80			240	192			
11.04.2016	48	88			232	192			
12.04.2016	144	88			344	184			Increase Temperature 124°C, not 115°C
13.04.2016	136	88	39,95	25,20	328	184	8,00	1,85	
14.04.2016	144	88			344	184			
15.04.2016	152	88	39,98	25,30	344	184	7,96	1,48	
18.04.2016	128	88	40,00	25,20	320	192	7,90	1,96	Set Temperature to 119°C (integrated heater)
19.04.2016	120	88			304	192			
20.04.2016	120	88	39,93	25,30	304	192	8,03	1,64	
21.04.2016	112	88			328	192			
22.04.2016	136	88	40,06	25,50	320	192	8,03	1,96	
25.04.2016	120	88	39,98	25,30	320	192	8,04	1,92	
27.04.2016	136	88	39,98	25,40	304	184	8,03	2,12	
28.04.2016	136	88			312	192			
29.04.2016	136	88	39,99	25,50	320	192	7,89	1,56	
02.05.2016	120	88	40,03	25,70	312	184	7,99	2,00	
04.05.2016	136	88			304	192			
09.05.2016	128	88	40,00	25,60	304	192	7,98	1,72	
11.05.2016	112	88			320	184			
12.05.2016	104	88	40,03	25,40	328	184	8,00	1,88	
13.05.2016	128	88			320	192			
17.05.2016	120	88	40,07	25,70	320	192	8,02	2,00	
18.05.2016	120	88			312	192			
19.05.2016	120	88	40,11	25,00	320	192	7,97	1,88	
20.05.2016	112	88			312	184			

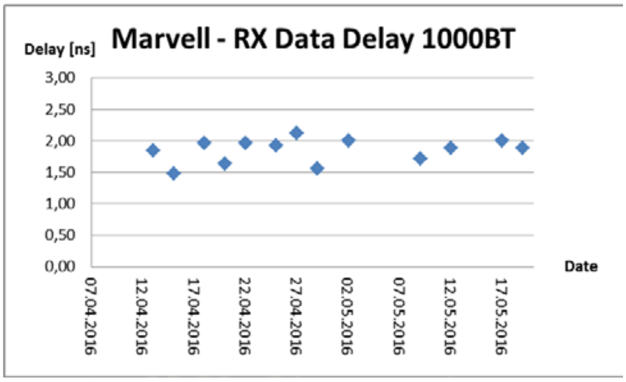
Testing of timing properties was performed according the introduction given in Appendix 1: "PHY Characterization Test Sequence Total Dose" starting from page 9.

First is shown the evolution of timing properties for Marvell components. Figures from 5 to 8 summarize the behavior of RX clock period and RX clock to Data delay times, respectively, for 100Mbps speed. In pretests, 12.9ns and 33ns delays were masured for components #1 and #2, respectively. Those two values are left out of the scale and average values. No clear changes in timing properties can be observed. Data for Reference device is also shown in figures.



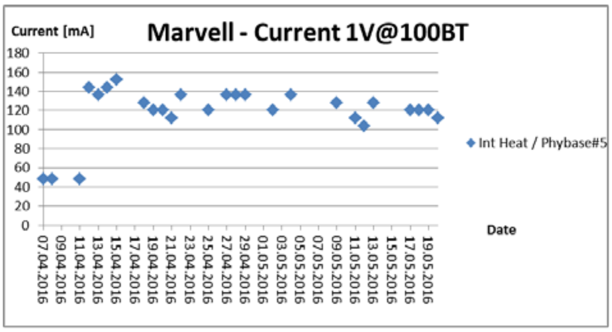


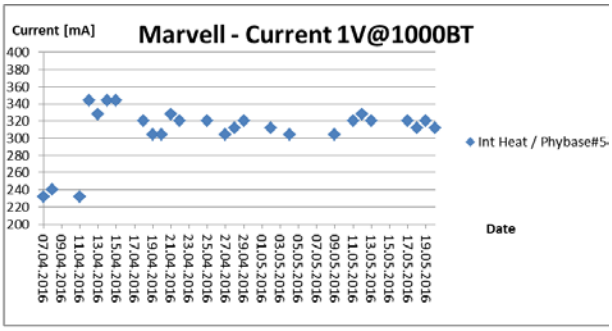


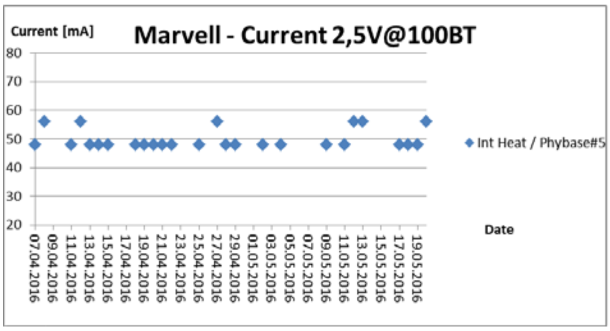


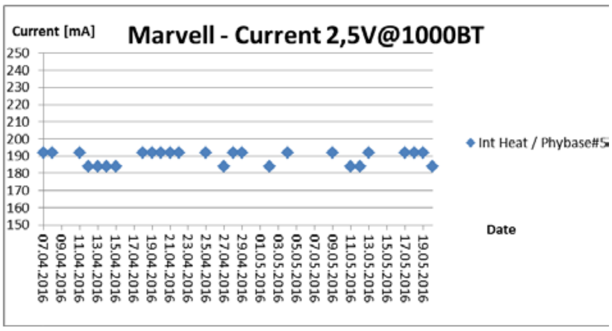
4.4.2.2 Marvell Current Consumption

For Marvell components, the average currents of all 12 measurements were 58.7mA for 1V and 237.2mA for 2.5V with standard deviation of 4.6mA and 2.5mA, respectively. With Marvell it was however noticed a strange behavior quite often when the power was turned on. The current consumption of 1V line was either 50mA or 60mA and for 2.5V about 240mA, 400mA or sometime even 600mA. Reason for this behavior was not completely sure and therefore the current values were booked only went the 2.5V current was showing lower, about 240mV value.





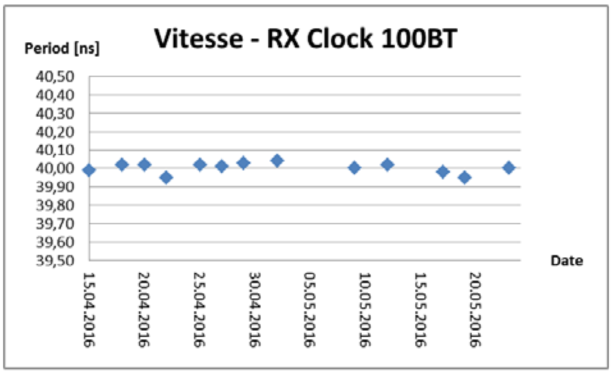


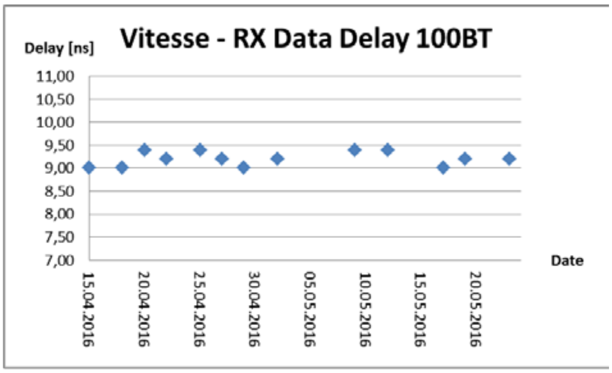


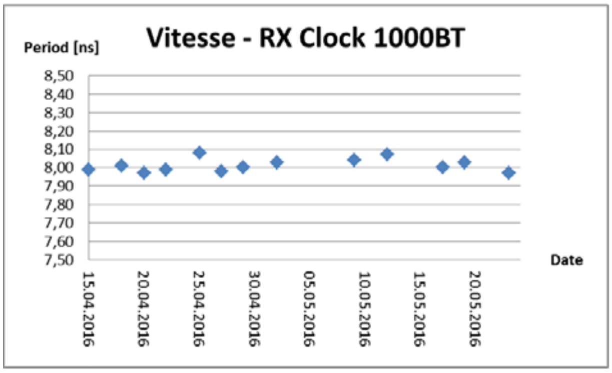
4.4.2.3 Vitesse Measurements

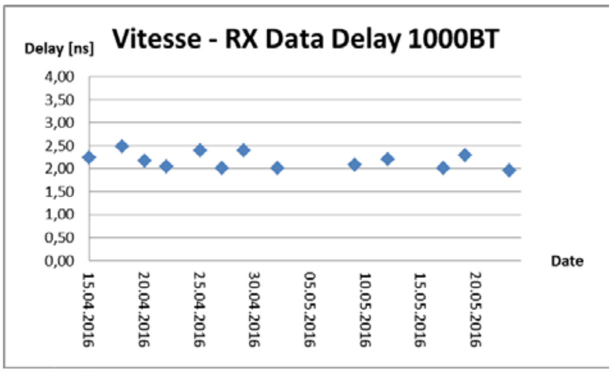
Vitesse Date	Current [mA] 1V@100BT	Current [mA] 2,5V@100BT	RX Clock [ns] 100BT	RX Data [ns] 100BT	Current [mA] 1V@1000BT	Current [mA] 2,5V@1000BT	RX Clock [ns] 1000BT	RX Data [ns] 1000BT	Remarks
15.04.2016	160	104	39,99	9,00	208	160	7,99	2,24	Temperature was 125°C, not 115°C
18.04.2016	144	104	40,02	9,00	208	160	8,01	2,48	Set Temperature to 115°C (integrated heater)
19.04.2016	136	104			208	160			
20.04.2016	136	104	40,02	9,40	208	160	7,97	2,16	
21.04.2016	136	104			200	160			
22.04.2016	136	104	39,95	9,20	200	160	7,99	2,04	
25.04.2016	144	104	40,02	9,40	192	160	8,08	2,40	
27.04.2016	88	104	40,01	9,20	144	160	7,98	2,00	Replace integrated with external Heater (115°C)
28.04.2016	88	104			144	160			
29.04.2016	80	104	40,03	9,00	144	160	8,00	2,40	
02.05.2016	80	80	40,04	9,20	136	120	8,03	2,00	Replace PHYBASE #4 with PHYBASE #3, PHYBASE #4 was needed for HI test in Finland
04.05.2016	80	80			136	120			
09.05.2016	80	80	40,00	9,40	136	120	8,04	2,08	
11.05.2016	80	80			136	120			
12.05.2016	80	80	40,02	9,40	136	128	8,07	2,20	
13.05.2016	80	80			136	128			
17.05.2016	80	80	39,98	9,00	136	120	8,00	2,00	
18.05.2016	80	80			136	120			
19.05.2016	80	80	39,95	9,20	136	120	8,03	2,28	
20.05.2016	80	80			136	120			
23.05.2016	80	80	40,00	9,20	136	128	7,97	1,96	
24.05.2016	72	80			128	120			

4.4.2.3.1 Vitesse Timing

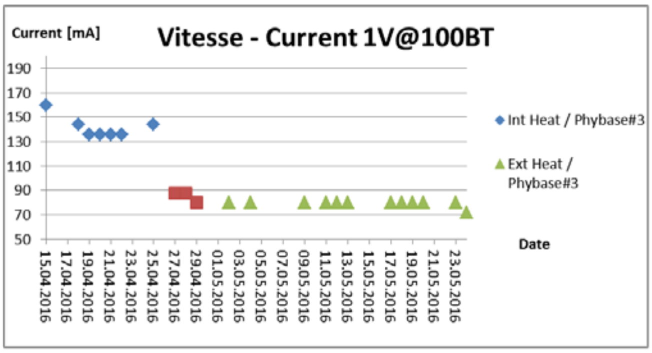


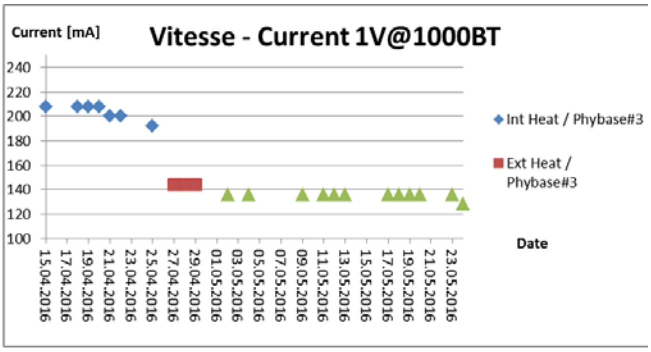


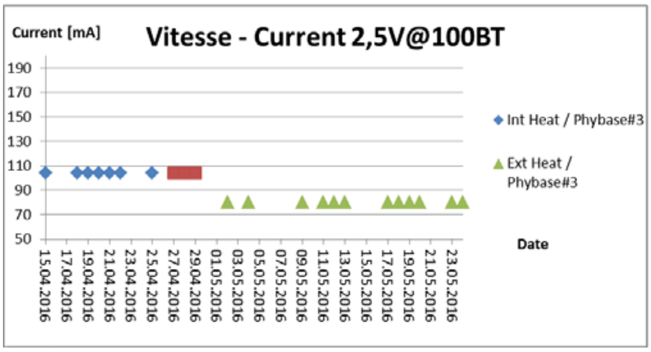


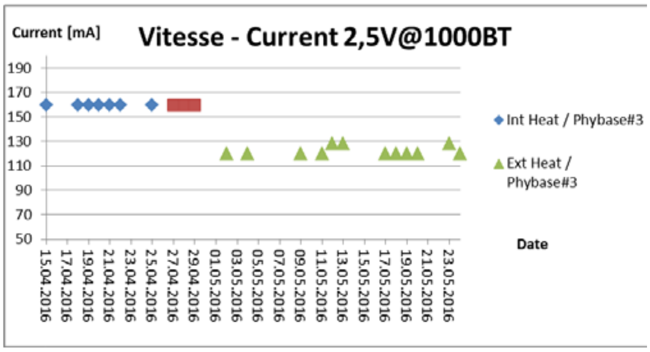


4.4.2.3.2 Vitesse Current Consumption





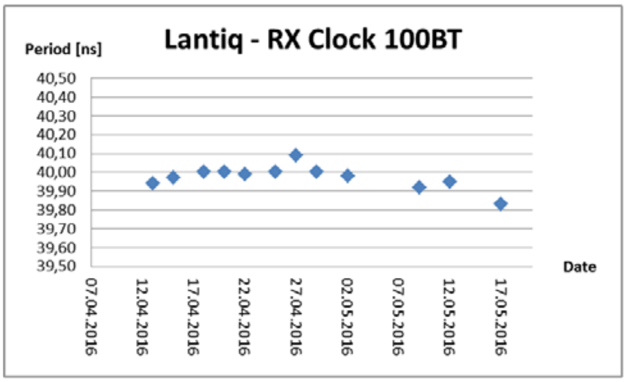


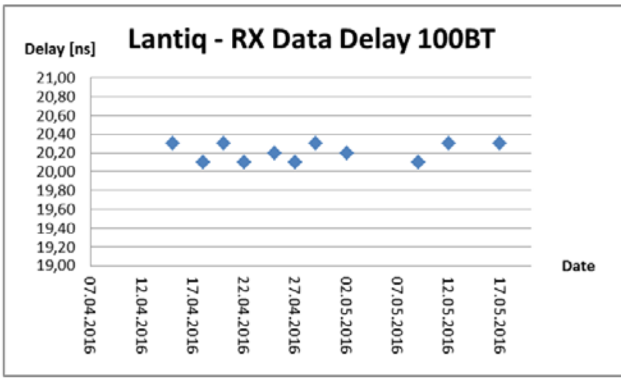


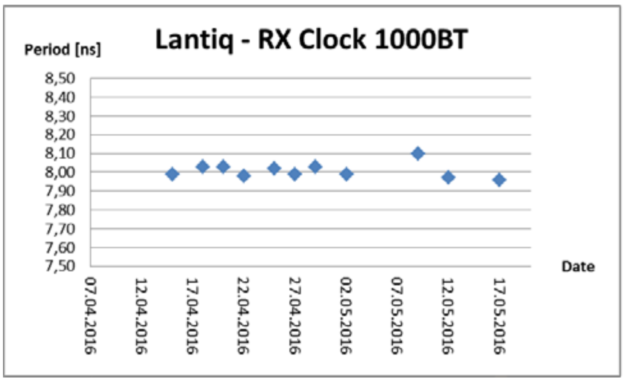
4.4.2.4 Lantiq Measurements

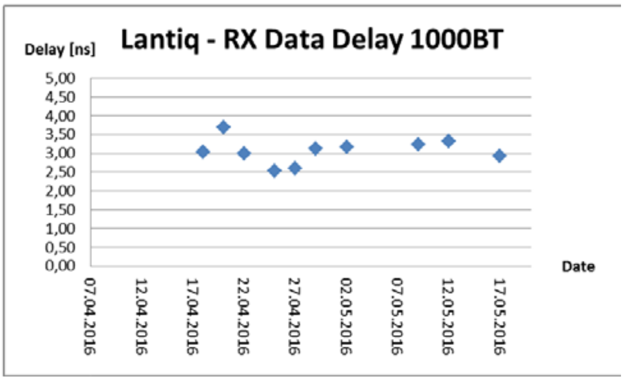
Lantiq Date	Current [mA] 1V@100BT	Current [mA] 2,5V@100BT	RX Clock [ns] 100BT	RX Data [ns] 100BT	Current [mA] 1V@1000BT	Current [mA] 2,5V@1000BT	RX Clock [ns] 1000BT	RX Data [ns] 1000BT	Remarks
07.04.2016	72	48			280	72			Initial Temperature 80°C, not 115°C
08.04.2016	72	56			280	72			
11.04.2016	72	48			280	72			
20.04.2016	96	56			288	72			Increase Temperature 87°C, not 115°C
12.04.2016	88	48			288	72			
13.04.2016	88	48	39,94	20,30	288	72	7,99	3,04	
14.04.2016	80	48			280	72			
15.04.2016	88	48	39,97	20,10	288	72	8,03	3,68	
18.04.2016	80	48	40,00	20,30	280	72	8,03	3,00	
19.04.2016	88	48			288	72			
20.04.2016	48	48	40,00	20,10	256	72	7,98	2,52	Replace integrated with external Heater (87°C)
21.04.2016	56	48			264	72			
22.04.2016	56	48	39,99	20,20	264	72	8,02	2,60	
25.04.2016	56	56	40,00	20,10	264	72	7,99	3,12	
27.04.2016	56	48	40,09	20,30	264	72	8,03	3,16	
28.04.2016	64	48			264	72			
29.04.2016	56	48	40,00	20,20	274	72	7,99	3,24	Increase Temperature to 115°C
02.05.2016	56	48	39,98	20,10	248	72	8,10	3,32	Replace PHYBASE #6 with PHYBASE #7, PHYBASE #6 was needed for HI test in Finland
04.05.2016	56	48			248	80			
09.05.2016	56	48	39,92	20,30	248	80	7,97	2,92	
11.05.2016	56	56			248	80			
12.05.2016	56	56	39,95	20,30	248	80	7,96	3,12	
13.05.2016	56	48			248	80			
17.05.2016	56	48	39,83	20,30	248	80	7,97	2,64	
18.05.2016	56	48			248	80			
19.05.2016	56	56			248	80			
20.05.2016	56	56			248	80			

4.4.2.4.1 Lantiq Timing

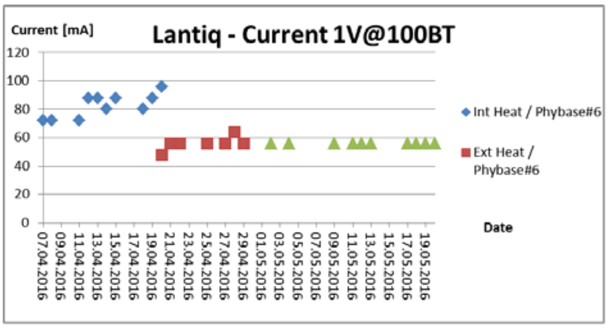


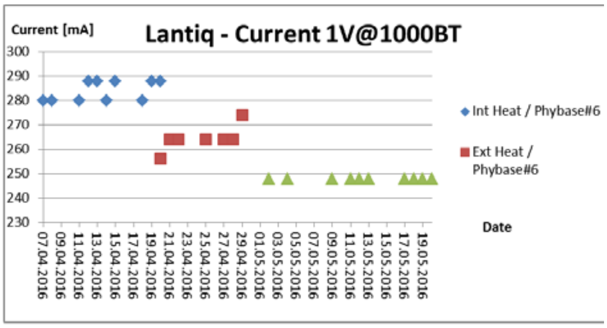


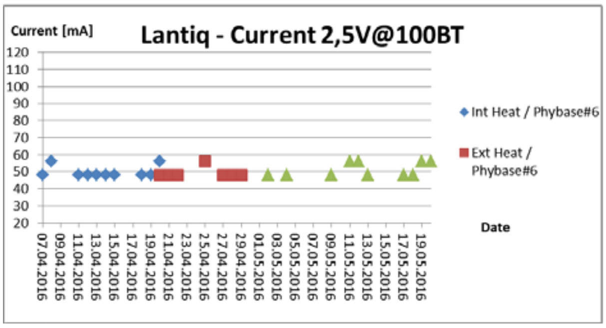


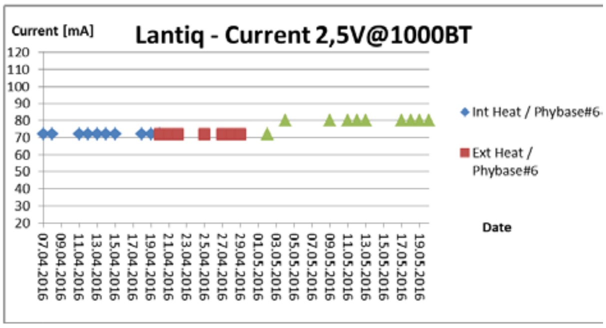


4.4.2.4.2 Lantiq Current Consumption









In conclusion, the results are presented below:

-Vitesse the temperature was 125°C for 12 days, after that the internal heating do longer worked and we replaced it to external heating, with a temperature of 115°C. No deterioration of the RX_clock or data delay timings were observed and the devices remained functional.

-Lantiq the temperature was 87°C for 12 days, after that the internal heating do longer worked and we replaced it to external heating, with a temperature of 115°C. No deterioration of the RX_clock or data delay timings were observed and the devices remained functional.

-Marvell the temperature was 80°C for 2 days, raised to 124°C after two days, after that the internal heating do longer worked and we replaced it to external heating, with a temperature of 119°C. No deterioration of the RX_clock or data delay timings were observed and the devices remained functional.

The devices remain functional after the life testing experiment.

4.5 Flammability

This test was skipped, in accordance with ESA decision.

4.6 Outgassing

4.6.1 Test conditions

The outgassing test was conducted at the test facility of the Airbus DS in Bremen.

This specification describes a thermal vacuum test to determine the outgassing properties as Total Mass Loss (TML), Recovered Mass Loss (RML), Water Vapour Regained (WVR) and Collected Volatile Condensed Material (CVCM). Test specification and performance are in accordance with the ESA ECSS-Q-ST-70-02C standard.

TML is calculated from the mass of the specimen as measured before and after the test and it is expressed as a percentage of the initial specimen mass. The RML is the total mass loss of the specimen itself without the adsorbed water. The WVR is the mass of the water vapour regained by the specimen after the optional reconditioning step. The CVCM is the quantity of the outgassed matter from a test specimen which condenses on a collector maintained at a specific temperature for a given time. CVCM is expressed as a percentage of the initial specimen mass and is calculated from the condensate mass determined from the difference in mass of the collector plate before and after the test.

Materials submitted for testing shall be accompanied by a completed (by customer) Material Identification Card (MIC), where the material density and the substrate density have to be indicated. The samples have to be prepared in advance, at least 24 hours in an environment of 20°C and 65% relative humidity (RH). These conditions are fulfilled by the nitrogen storage board where the PHY transceivers are stored from the moment they arrive at the Airbus DS facility until they will undergo any type of testing. Samples shall be handled with clean nylon or lint-free gloves only.

The standard test conditions are: Pressure less than 10^{-5} mbar, Temperature 125°C, Duration of test 24 hours.

Figure 6-5 and Figure 6-6 an overview of the procedure and calculation of the key parameters is given.

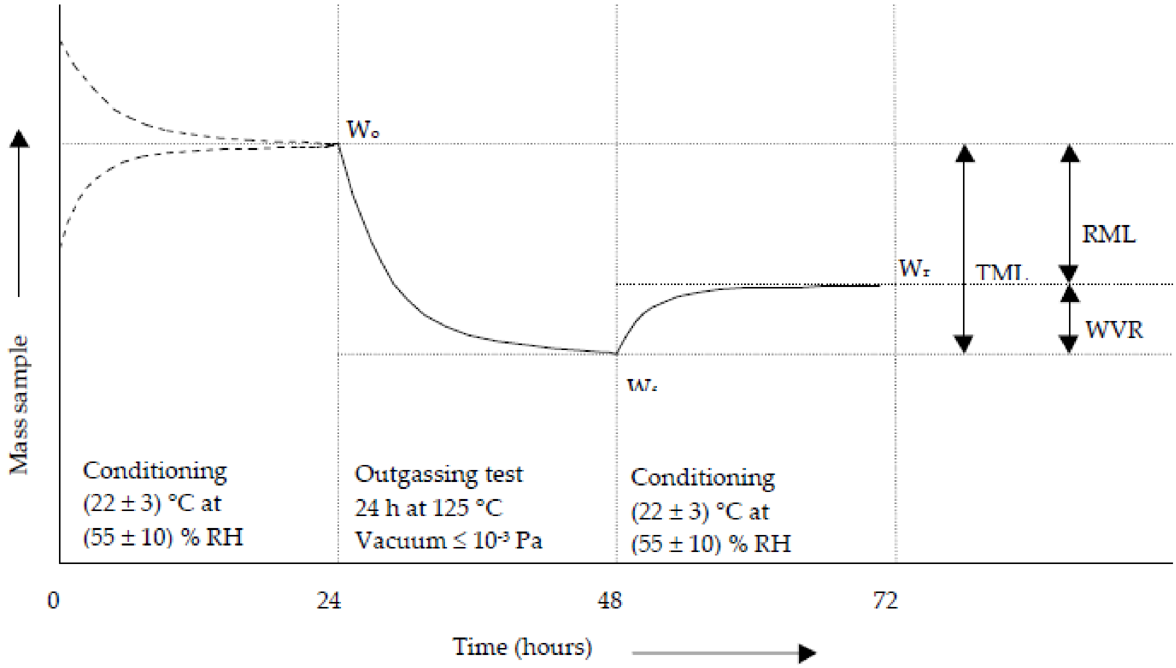


Figure 4-6 Overview of the sample parameters

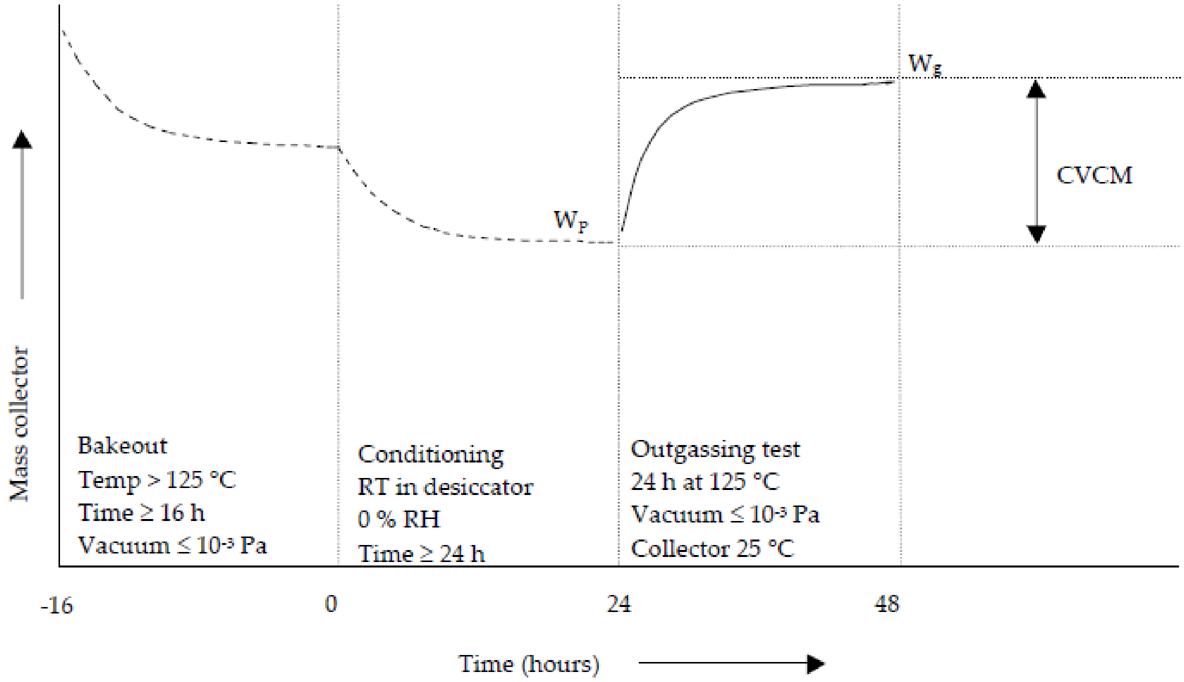


Figure 4-7 Overview of the collector plate parameters

For one supplier testing, at least 13 PHY transceiver samples were necessary in order to reach the critical mass required for the test. Therefore, only the PHY suppliers could be compared at the end of the test, and not the variability of the samples within one supplier class.

Following samples were tested:

Article / Sample Name	Batch No.	Traceability Code
Microcircuit Ethernet transceiver VSC8501XML	1527AVZPA	OUT/ER/137/15
Microcircuit Ethernet transceiver PEF7072HL	7G30613E07	OUT/ER/138/15
Microcircuit Ethernet transceiver 88E1111	GVK6441.5JW	OUT/ER/139/15

The results are presented below:

Results	Total Mass Loss	Recovered Mass	Water Vapour	Collected Volatile Condensed
OUT/ER/137/15	0,060 +/- 0,000	0,028 +/- 0,001	0,032 +/- 0,002	0,000 +/- 0,000
OUT/ER/138/15	0,058 +/- 0,002	0,029 +/- 0,002	0,029 +/- 0,000	0,003 +/- 0,006
OUT/ER/139/15	0,041 +/- 0,003	0,019 +/- 0,002	0,022 +/- 0,001	0,005 +/- 0,008

With respect to the ECSS-Q-ST-70-02C the following acceptance limits are valid:

RML: < 1.0 %

CVCM: < 0.10 %

All the samples passed the outgassing test acceptance criteria in compliance with the ECSS-Q-ST-70-02C.

4.7 Offgasing

4.7.1 Test conditions

The offgasing was conducted at the premises of the Bremer Umweltsistitut, which is an ESA-approved facility for the offgasing in accordance to the ESA ECSS-Q-ST-70-29C standard. A total of about 30 PHY transceiver samples were placed in a small test chamber of 0,7 l of Bremer Umweltsinstitut. The samples were subjected to an N_2 atmosphere at 50°C for 72 hours. At the end, the chamber will be cooled down to 25°C.

4.7.2 Test procedure

Following test procedure will be applied for analysis of volatile organic components:

- Samples of 100 ml test chamber air will be sampled with an air flow of 25 ml/min and offgased substances will be adsorbed on multi-bed desorption tubes.
- Thermal desorption of all tubes at 240°C
- Separation, identification and quantification compared to external standards
- Analysis of chromatograms where the concentrations best correspond to the external standard chromatograms

Following test procedure will be applied for analysis of carbon monoxide and methane by flame ionization detection:

- Following evacuation of the gas sampling loop connection of the test chamber to the gas sampling loop
- Injection of the sample into packed columns
- Reduction of carbon monoxide to methane by passing the gas stream through the methanizer
- Separation, identification and quantification following the standards

4.7.3 Samples description

Sample number	description	Sample amount	Test intention
K 2371 FM - 1	**PHY 2, 20677 Marvell**	8 pieces (equal to a mass of 1,15 g)	Offgassing-Test according to ECSS-Q-ST-70-29C
K 2371 FM - 1.1	Air samples	20 µL	Carbon monoxide, methane
K 2371 FM - 1.2	test chamber air	20 µL	Carbon monoxide, methane
K 2371 FM - 1.3	test chamber (V = 1,41 L)	100 mL	Backup sample
K 2371 FM - 1.4		100 mL	Backup sample
K 2371 FM - 1.5		200 mL	Volatile organic compounds by thermal desorption
K 2371 FM - 1.6		200 mL	Backup sample

Sample number	description	Sample amount	Test intention
K 2370 FM - 1	**PHY 1, 20672 Lantig**	8 pieces (equal to a mass of 2,81 g)	Offgassing-Test according to ECSS-Q-ST-70-29C
K 2370 FM - 1.1	Air samples	20 µL	Carbon monoxide, methane
K 2370 FM - 1.2	test chamber air	20 µL	Carbon monoxide, methane
K 2370 FM - 1.3	test chamber (V = 1,50 L)	100 mL	Backup sample
K 2370 FM - 1.4		100 mL	Backup sample
K 2370 FM - 1.5		200 mL	Volatile organic compounds by thermal desorption
K 2370 FM - 1.6		200 mL	Backup sample

Sample number	description	Sample amount	Test intention
K 2372 FM - 1	**PHY 3, 20675 Vitesse**	8 pieces (equal to a mass of 1,79 g)	Offgassing-Test according to ECSS-Q-ST-70-29C
K 2372 FM - 1.1	Air samples	20 µL	Carbon monoxide, methane
K 2372 FM - 1.2	test chamber air	20 µL	Carbon monoxide, methane
K 2372 FM - 1.3	test chamber (V = 1,47 L)	100 mL	Backup sample
K 2372 FM - 1.4		100 mL	Backup sample
K 2372 FM - 1.5		200 mL	Volatile organic compounds by thermal desorption
K 2372 FM - 1.6		200 mL	Backup sample

4.7.4 Results

V volume of chamber = 1,41 L

V_{SC} Spacecraft volume = 100 m³

Mass $_{abs}$ Overall absolute amount off-gassed from the item / payload [µg] = Emission in chamber / V

SMAC Spacecraft Maximum Allowable Concentration [µg/m³] listed in NASA-database MAPTIS;

in case a value can not be obtained a minimum level of 100 µg/m³ is defined

PSC Projected Spacecraft Concentration based on amount of compound emission in chamber re- lated to spacecraft volume

T $_{ind}$ individual Toxicity value of compound = PSC/SMAC

CAS-Nr.	Substance	Test chamber concentration [µg/m³]	SMAC [µg/m³]	Mass [µg]	PSC [µg/m³]	T ind
630-08-0	Carbon monoxide	49	63.000	0,0691	6,9E-04	1,1E-08
74-82-8	methane	n.d.	3.500.000	--	--	--
110-54-3	n-Hexane	44	176.000	0,0620	6,2E-04	3,5E-09
38640-62-9	Diisopropyl naphthaline	22	100	0,0310	3,1E-04	3,1E-06
84-69-5	Diisobutyl phthalate	7	100	0,0099	9,9E-05	9,9E-07
124-19-6	n-Nonanal	16	29.000	0,0226	2,3E-04	7,8E-09
64-19-7	Acetic acid	14	7.400	0,0197	2,0E-04	2,7E-08
541-05-9	D3 (Hexamethylcyclotrisiloxan)	64	90.000	0,0902	9,0E-04	1,0E-08
556-67-2	D4 (Octamethylcyclotetrasiloxan)	51	280.000	0,0113	1,1E-04	4,0E-10
various	Sum N-aromatic compound	8	100	0,0113	1,1E-04	1,1E-06

µg = microgram = 1 millionth gram n.d. = not detected detection limit: 5 µg/m³

*1) = estimated by the response of alpha Pinene

*2) = estimated by the response of 1,2,4-Trimethylbenzene

*3) = estimated by the response of n-Butyl acetate

T-value = Σ T ind

K 2371 FM	T-value =	0,000005

The acceptance level of the T-value < 0,5 is maintained.

CAS-Nr.	Substance	Test chamber concentration [µg/m³]	SMAC [µg/m³]	Mass [µg]	PSC [µg/m³]	T ind
630-08-0	Carbon monoxide	62	63.000	0,0931	9,3E-04	1,5E-08
74-82-8	methane	0	3.500.000	0,0000	0,0E+00	0,0E+00
123-42-2	Acetone	380	100.000	0,5708	5,7E-03	5,7E-08
110-54-3	n-Hexane	18	176.000	0,0270	2,7E-04	1,5E-09
111-65-9	n-Octane	5	348.920	0,0075	7,5E-05	2,2E-10
111-66-0	1-Octen	7	228.190	0,0105	1,1E-04	4,6E-10
71-43-2	Benzene	34	1.500	0,0511	5,1E-04	3,4E-07
141-78-6	Ethyl acetate	17	179.340	0,0255	2,6E-04	1,4E-09
111-71-7	n-Heptanal	5	28.000	0,0075	7,5E-05	2,7E-09
66-25-1	n-Hexanal	10	24.600	0,0150	1,5E-04	6,1E-09
124-13-0	n-Octanal	14	31.500	0,0210	2,1E-04	6,7E-09
124-19-6	n-Nonanal	110	29.000	0,1652	1,7E-03	5,7E-08
112-31-2	n-Decanal	22	31.900	0,0330	3,3E-04	1,0E-08
100-52-7	Benzaldehyde		173.000	0,0000	0,0E+00	0,0E+00
64-17-5	Ethanol <#	140	2.000.000	0,2103	2,1E-03	1,1E-09
67-63-0	2-Propanol #<	24	150.000	0,0360	3,6E-04	2,4E-09
541-05-9	D3 (Hexamethylcyclotrisiloxan)	24	90.000	0,0360	3,6E-04	4,0E-09

K 2370 FM	T-value =	0,0000005

The acceptance level of the T-value < 0,5 is maintained.

CAS-Nr.	Substance	Test chamber concentration [µg/m³]	SMAC	Mass	PSC	T ind
630-08-0	Carbon monoxide	110	63.000	0,1615	1,6E-03	2,6E-08
74-82-8	Methane	n.d.	3.500.000	--	--	--
110-54-3	n-Hexane	20	176.000	0,0294	2,9E-04	1,7E-09
124-19-6	n-Nonanal	39	29.000	0,0573	5,7E-04	2,0E-08
104-76-7	2-Ethylhexanol	6	213.000	0,0088	8,8E-05	4,1E-10
1066-40-6	Trimethylsilanol	19	4.000	0,0279	2,8E-04	7,0E-08

K 2372 FM **T-value =** **0,0000001**

The acceptance level of the T-value < 0,5 is maintained.

In summary, all the samples passed the outgassing test acceptance criteria and could be therefore used for manned spaceflight.

5. Final compliance table

In the following table, the general compliance with the acceptance conditions and testing results are shown, with 0 meaning test failed and 1 meaning test passed:

Test conducted	ESD 2000 V	Thermal 100 cy-cles	Vacuum	Life testing	Outgassing ECSS-Q_ST-70-02	Offgassing ECSS-Q-ST-70-29C
Marvell/Lantiq/Vitesse	1/1/1	1/0/1	1/1/1	1/1/1	1/1/1	1/1/1

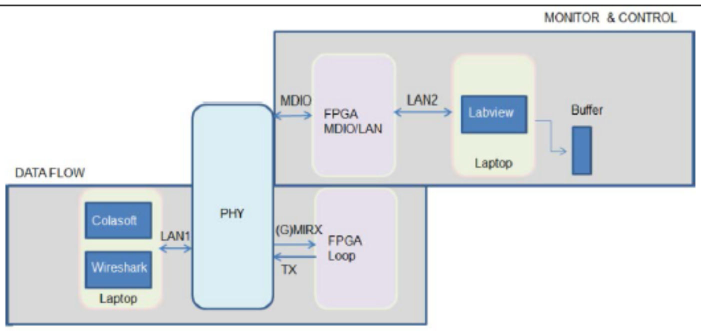
Test conducted	Radiation
Marvell/Lantiq/Vitesse	1/0/1

These test results prove that buying commercially off the shelf devices and subjecting them to a full environmental qualification campaign for space could bring valuable results.

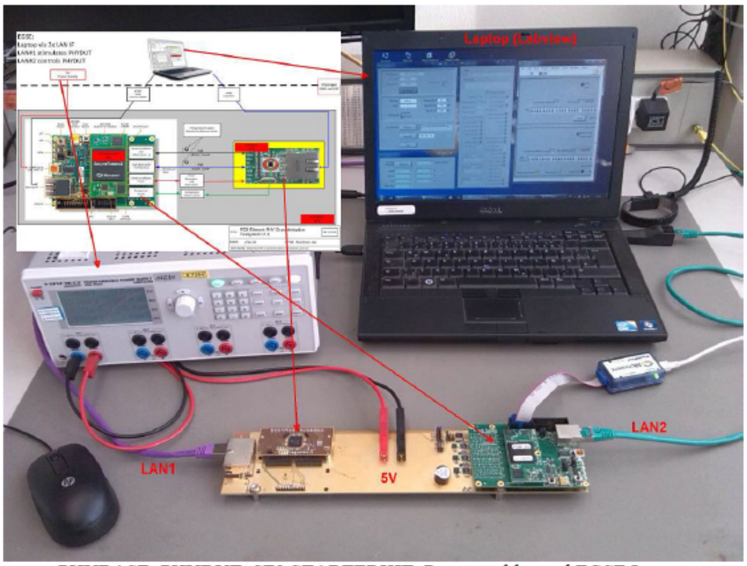
A 1. Appendix Test Sequence TID

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject	PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"	Operator : Date : 10.02.2016 Page : 1 von 14

EGSE Configuration

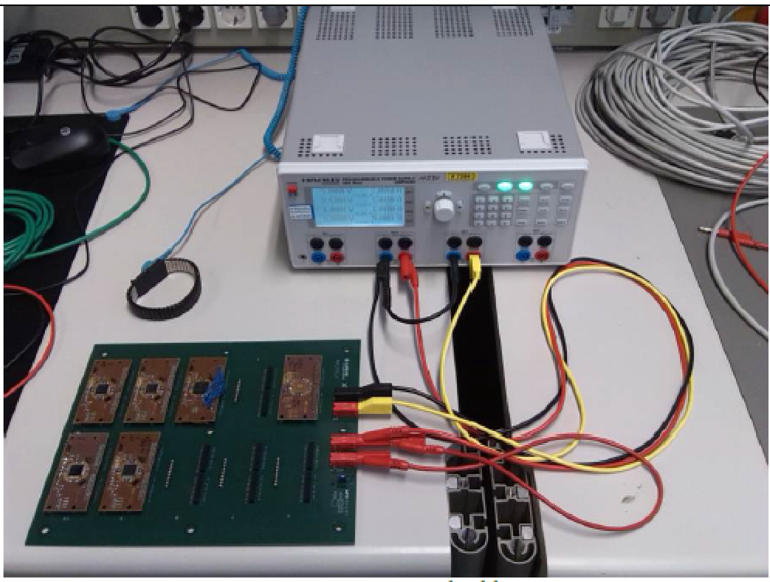


The overview of all software interfaces required to interact with the PHY.



PHYBASE, PHYDUT, SF2 STARTERKIT, Power, cables and EGSE Laptop

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 2 von 14



PHYTID, Power and cables

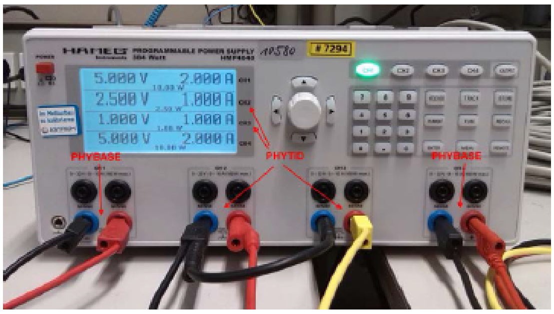
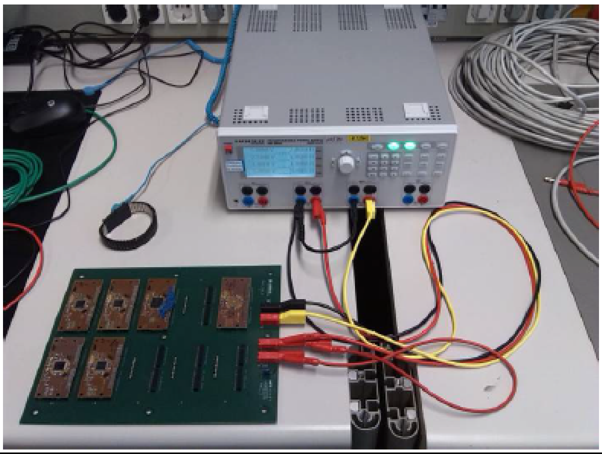
Test Configuration / Equipment		
Hardware / Ser. No.	Firmware/Driver / Version	Test SW / Version

`Power Supply 5V`
`Multimeter`
`2x PHYBASE PCB equipped with SF2 Starter Kit`
`2x PHYTID`
`10x PHYDUT Vitesse testsamples`
`10x PHYDUT Marvel testsamples`
`EGSE Laptop with Labview Test SW`
`Oscilloscope for timing measurement`
`Banana power Cables`
`LAN Cables`
`ESD protection`
		

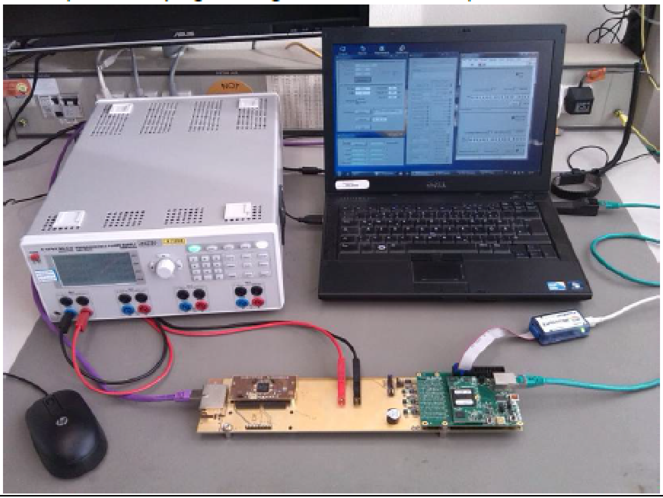
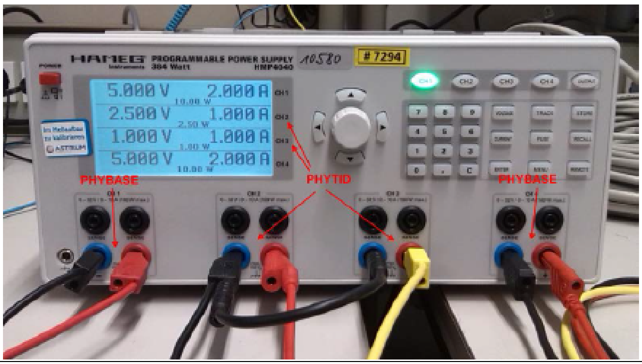
Test Requirements			
Spec. No./Issue:		Spec. No./Issue:	
Number	Title	Number	Title
1	**EGSE manual for PHY Transceiver Characterization** **Iss1 / 29.05.2015**		
2	**Ethernet Transceiver Characterization Test Plan:** **SPO-PC-RIBRE-PL-0020** **Iss1 / 29.09.2015**		

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 3 von 14

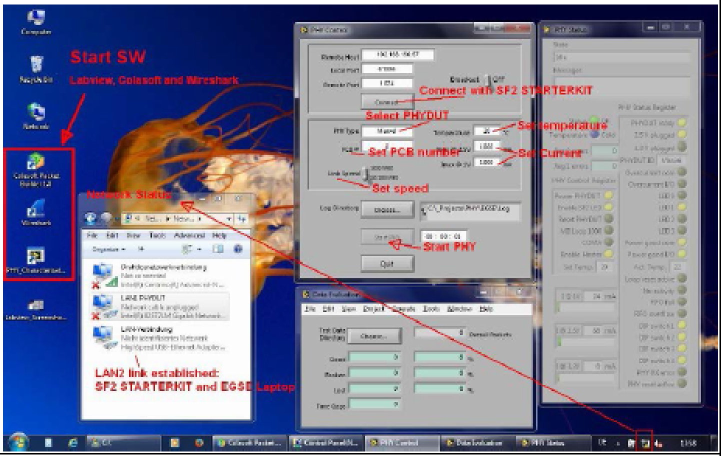
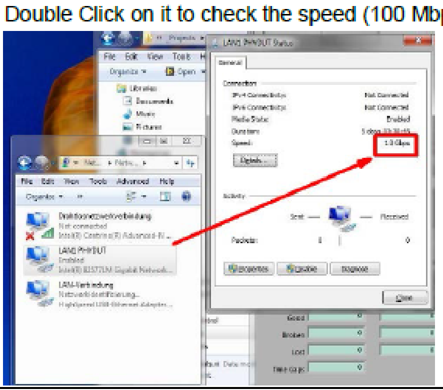
Test Execution

Step	Description	Result	Remarks
	PHYTID Test Preparation		
	YOU MUST BE ESD PROTECTED		
	Setup power supply for the PHYTID BIAS voltage. Select CH2 and CH3, disable CH1 and CH4. CH2 and CH3 should green glowing. 		
	Mount 10x PHYDUT of one vendor on one PHYTID. Results: 2 equipped PHYTID, with 10x PHYDUT each. Connect power (BIAS) cables: GND (black), 1V (yellow) and 2,5V, VCC_A (both red). 		

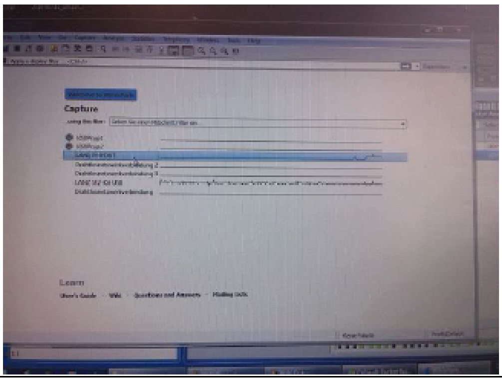
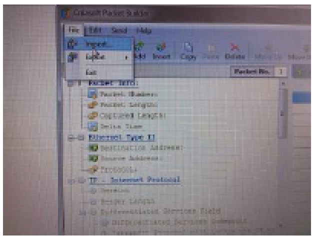
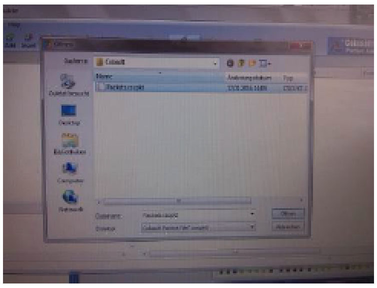
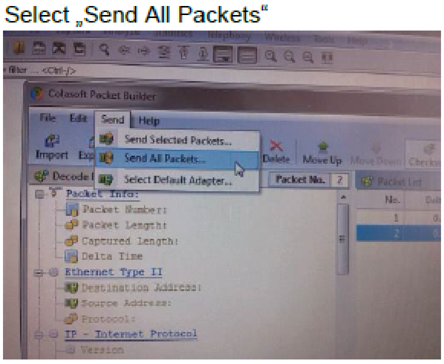
AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 5 von 14

	Test 4000 packets		
	YOU MUST BE ESD PROTECTED		
	After each TID radiation step each of the PHYDUT has to be tested for degradation and/or malfunction. The ""Test 4000 packets" is a short test to check the functionality and current consumption of the PHYs for 100BaseT and 1000BaseT.		
	Carefully plug a PHYDUT into PHYBASE and connect power and Lan cables (the FPGA programming cable is not needed!). 		
	The four channel Power Supply supports two functional tests with the PHYBASE PCB in parallel. Setup power supply (voltage and current) for PHYBASE. Select CH1 and CH4, disable CH2 and CH3. CH1 and CH4 should green glowing. 		
	Enable Power; push the OUTPUT button at the power supply.		

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 6 von 14

	Start SW (icons) on EGSE Laptop: • Labview Testapplication (PHY_Characterization) • Colasoft (LAN packet generator) • Wireshark (LAN packet analyzer) • Network status (Windows 7) 		
	Check Network Status. LAN2 link should be established (no red cross!)		
	Make following steps in the Labview PHY Control window: 1. Click "Connect" (This acquires LAN2 interface to SF2 Starterkit) 2. Select PHYDUT (Marvel, Vitesse or Lantiq) 3. Set PCB number (number are marked on PHYDUTs) 4. Set LAN Speed (100 or 1000 baseT) 5. Click "Start PHY" (This enables power and configuration of the PHYs) As soon the SW runs, Logfiles will be automatically generated in background and stored in the "Log" directory.		
	Check Network Status. LAN1 PHYDUT link should now be established (no red cross!). Double Click on it to check the speed (100 Mbps or 1 Gbps). 		Note: Compare the speed with the setting in the Labview application.

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 7 von 14

	Wireshark: Configure Wireshark to analyze LAN1 Traffic generated by Colasoft and looped back by the FPGA. Select LAN1 PHYDUT network adapter. Wireshark is now waiting for TX or RX packets at LAN1 port of the Laptop. 		
	Colasoft: Start Colasoft and configure it to generate packets for the LAN1 interface. Import prebuild LAN packets (packets.cscpkt):  		
	Colasoft: Select „Send All Packets“ 		

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject	PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"	Operator : Date : 10.02.2016 Page : 8 von 14

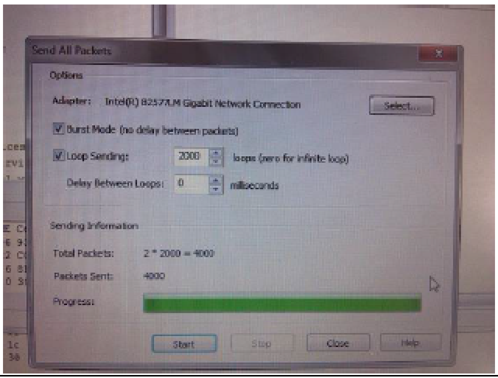
Colasoft:

Set Burst Mode (on), Loop Sending (2000), Delay (0 – no delay) and click on "Start".

Colasoft sends 4000 packets to the PHYDUT.

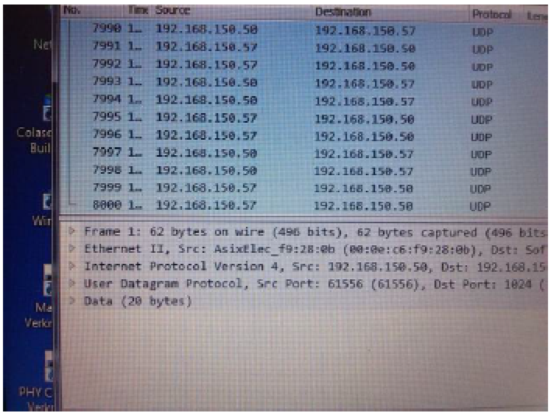
PHYDUT send it to the FPGA, where they are looped back to PHYDUT and then send back to the EGSE Laptop.

=> *We expect overall 8000 (2x4000) packets analyzed in Wireshark*



Wireshark:

Check number of analyzed packets: Must be 8000



Make Logbook entries

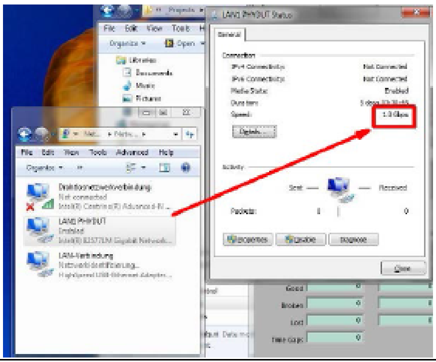
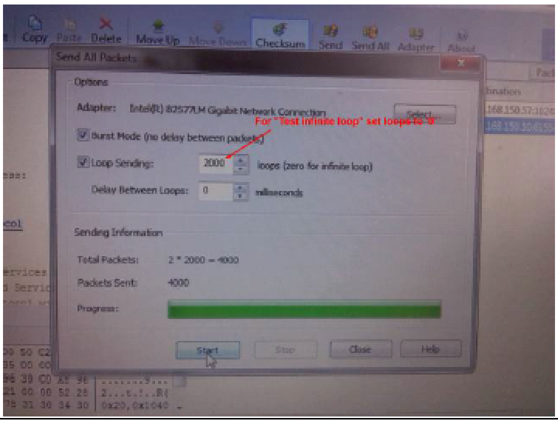
Note:

- For each PHYDUT the test must be executed for both speeds, 100 and 1000 BaseT
- This test will be repeated 4x after each TID radiation run and 1x after the last annealing process.

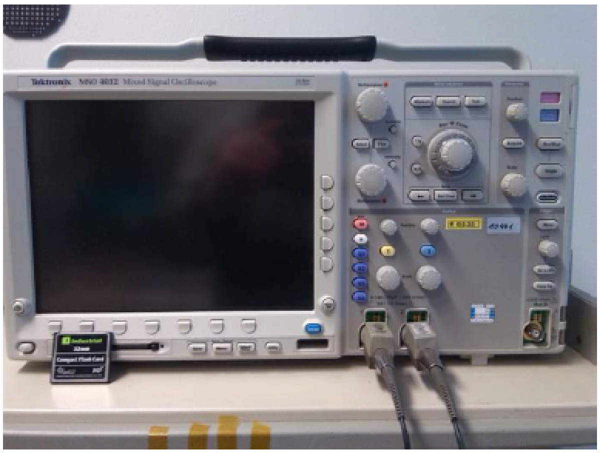
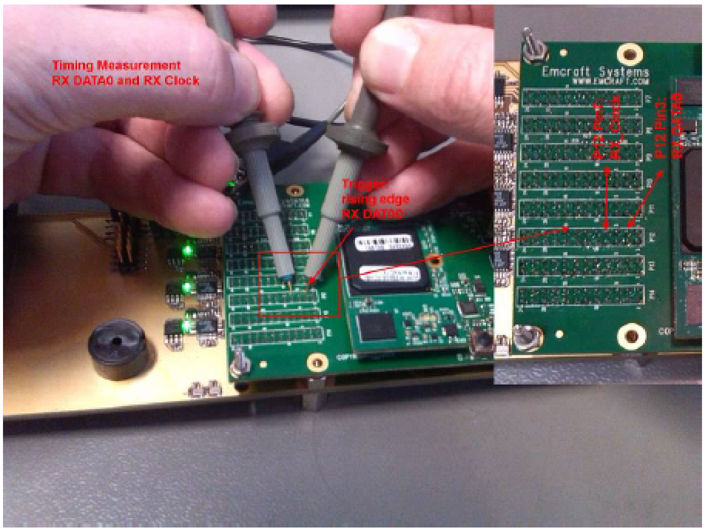
Wireshark:

Stop capturing in Wireshark.

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 9 von 14

	Test infinite loop		
	YOU MUST BE ESD PROTECTED		
	After each TID radiation step each of the PHYDUT has to be tested for degradation and/or malfunction. The "Test infinite loop" is a test to check for timing deviations of the PHY test samples for 100BaseT and 1000BaseT.		
	EGSE Laptop / Labview: To setup the EGSE Laptop use the "Test 4000 packets" procedure as a reference.		
	Check Network Status. LAN1 PHYDUT link should now be established (no red cross!). Double Click on it to check the speed (100 Mbps or 1 Gbps). 		Note: Compare the speed with the setting in the Labview application.
	Colasoft: Use the "Test 4000 packets" settings as reference; exception: Now set Loop Sending to "0" to generate infinite data and click on "Start". Colasoft sends (forever) packets to the PHYDUT. 		
	Wireshark: Disabled, not needed in this test.		

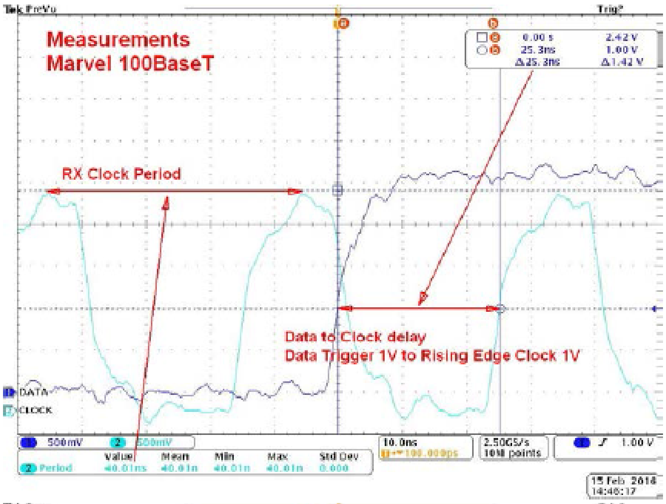
AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112832/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 10 von 14

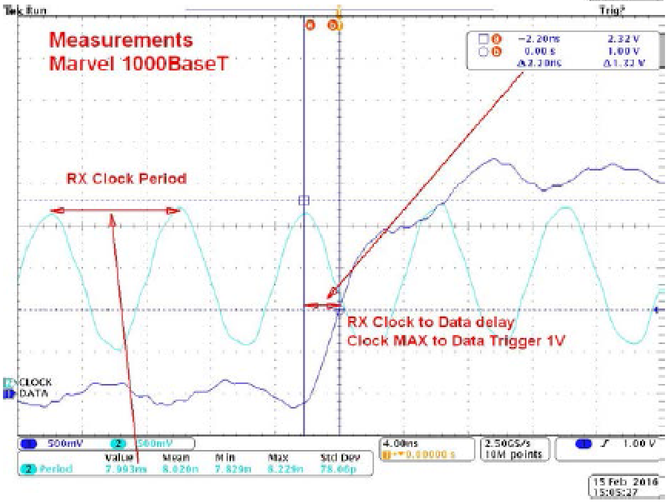
	Start oscilloscope and load TID configuration "PHY_CHARACTERIZATION". 		
	For each PHYDUT, measure RX Clock and Data3 at SF2 STARTERKIT (P12 Pin 3 and 7). Connect GND straps to the screws. 		

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 11 von 14

Write the RX Clock period and Clock/Data delay into Logbook.

Marvel Measurements:



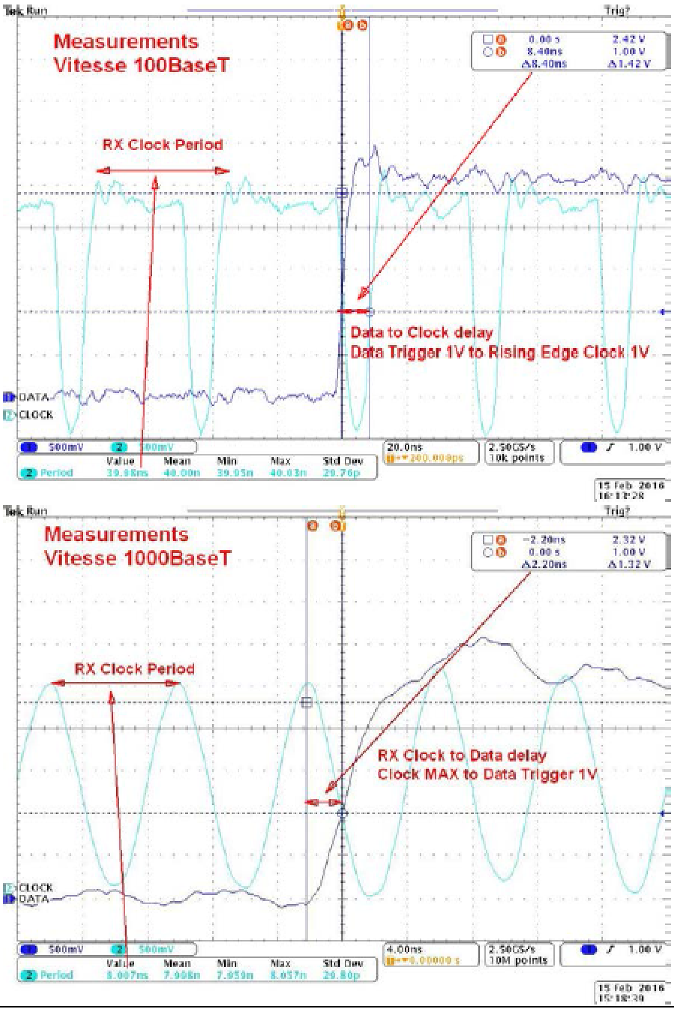


Make Logbook entries

Note:

- For each PHYDUT the test must be executed for both speeds, 100 and 1000 BaseT
- This test will be repeated 4x after each TID radiation run and 1x after the last annealing process.

	PHY Characterization	Test sequence
		BM/SPR :
		Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112832/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 12 von 14

	Vitesse Measurements: 		
	Save a picture of each measurement.		Make Logbook entry
	Save the Oscilloscope CSV data for each measurement.		Make Logbook entry

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 13 von 14

	Error Conditions and Error Handling => Always with Logbook entry		
	ERROR LAN Connection PHYDUT or SF2 STARTERKIT connection cannot be established.		Wait on heater finished (PHYDUT only, status must switch from cold to warm). NOT OK-> Check connector, cables and power. NOT OK-> Power Cycle the Laptop and re-start SW. NOT OK-> If Error persists replace PHYDUT or Laptop
	ERROR Laptop SW SW doesn't work (properly).		Close and re-start SW NOT OK-> Windows re-start NOT OK-> Use another Laptop
	ERROR Readout An error message will be shown in the Labview application. PHYDUT error while readout housekeeping data using the MDIO interface, e.g. due to degradation in the device.		Will be automatically logged into housekeeping report NOT OK-> If Error persists go to ERROR SEFI
	ERROR Overcurrent An error message will be shown in the Labview application. After an overcurrent event, all power rails will be switched off automatically.		Will be automatically logged into housekeeping report. Restart PHY Test SW NOT OK-> If Error persists replace PHYDUT with next sample
	ERROR SEFI An error message will be shown in the Labview application. LAN1 100/1000Mbps test patterns are permanent corrupted or LAN2 MDIO register readout permanent fails.		Will be automatically logged into housekeeping report or Wireshark Logfiles. Restart PHY Test SW. NOT OK-> If Error persists replace PHYDUT with next sample
	ERROR SEU An error message will be shown in the Labview application. LAN1 100/1000Mbps test patterns are temporary corrupted or LAN2 MDIO register readout temporary fails.		Will be automatically logged into housekeeping report or Wireshark Logfiles. No operator intervention needed

AIRBUS DEFENCE & SPACE	PHY Characterization	Test sequence BM/SPR : Procedure : Section :
Subject PHY Characterization – TID Radiation 15 December 2014 ESA Contract No. 4000112932/14/NL/LF "Ethernet PHY Transceiver Characterization"		Operator : Date : 10.02.2016 Page : 14 von 14

Agenda 19.02.2016 / Bremen Airbus DS

1. Re-Test

Re-test PHYDUTs which have packet lost, push finger on IC (solder problem?)

2. PHYDUT Replacement / Spare Parts usage

In case that one PHYDUT has an extremely deviation (malfunction) compared to the other devices, this device shall be replaced by a spare part.

For each vendor we have two Spare Parts, which have to be initial characterized.

3. Lantiq PHYDUT / Minimal Parallel Testing

We setup a third PHYTID with 10x Lantiq v1.3 devices, to get an initial impression of their behavior. After each run, two of them shall be removed from the PHYTID. All measurements and functional tests will be executed at Airbus DS in Bremen after the TID test. At the end of the TID runs, we have two LANTIQ parts from each run, which can be analyzed.