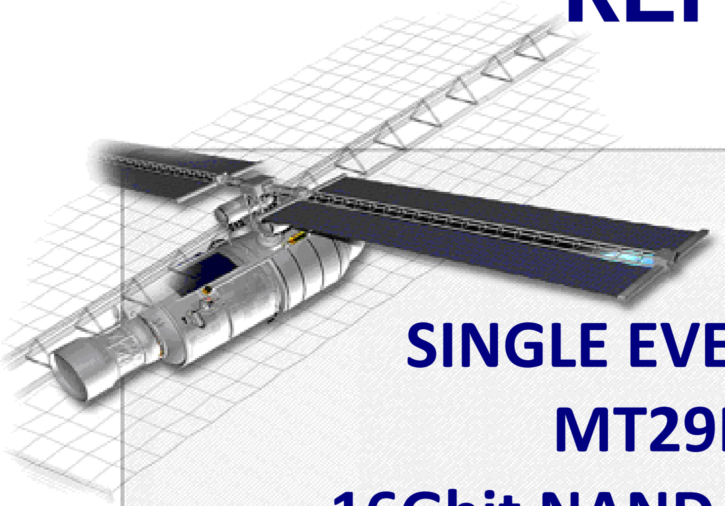
HEAVY IONS TEST REPORT



SINGLE EVENT EFFECTS
MT29F16G08
16Gbit NAND Flash Memory
(DC1434 & 1442)
From
Micron

TRAD/TI/MT29F16G08/XXX1/ESA/LS/1603		Labège, July 18th, 2016
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Revision:			
	0	Creation of document	13/05/16
	1	§6.1.3: Indication of the test cycle time+ Clarification on the SET detection in read only and erase write mode §8.2.3: Added information about the increasing number of bad block after Xenon irradiation §8.3: Added explanation of the actual number of tested bit for SEU cross section normalization §8.3.8: Repartition of detected SEFI in read only mode	22/06/16
	2	§8. & §8.2 Added information about high current events Supply current monitoring of all runs added in appendix A	18/07/16

To:	**ESA** **Christian POIVEY**	Project/Program: ESA Contract 4000105666 Ref: CO07

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FIGURES

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1. Introduction

This report includes the test results of the heavy ions Single Event Effects (SEEs) test sequence carried out on the MT29F16G08, a 16Gbit NAND Flash Memory from Micron.

The test was performed for ESA at U.C.L (Université Catholique de Louvain) on April 25th and 26th, 2016. 18 delidded samples were irradiated.

This test was performed for ESA on the MT29F16G08 susceptible to show Single Event Latchups (SELs), Single Event Upsets (SEUs), Multiple Bit Upsets (MBUs), Single Event Transients (SETs), Erase and Write Errors (EWEs) and Single Event Functional Interrupt (SEFIs) induced by heavy ions.

2. Documents

2.1. Applicable documents

ESA statement of work: ESA-TRP-TECQEC-SOW-1260 Issue 1 of 15/12/2015
Technical Proposal: TRAD/P/ESA/COO7/AV/020216 Rev.0
Irradiation Test Plan: TRAD/ITP/ESA/MT29-K9/LS/120416-Rev.1

2.2. Reference documents

Basic specification: ESCC N°25100 Issue 2 of October 2014
Data Sheet: Micron No. 09005aef859aa114 Rev B of March 2015

3. Organization of Activities

The relevant company has performed the following tasks during this evaluation:

1	Procurement of Test Samples	3D Plus
2	Preparation of Test Samples (delidding)	TRAD
3	Preparation of Test Hardware and Test Program	TRAD
4	Samples Check out	TRAD
5	Accelerator Test	TRAD
6	Heavy Ion Test Report	TRAD

Table 1: Organization of activities

4. Parts information

4.1. Device description

Micron NAND Flash devices include an asynchronous data interface for high-performance I/O operations. These devices use a highly multiplexed 8-bit bus (DQx) to transfer commands, address, and data. There are five control signals used to implement the asynchronous data interface: CE#, CLE, ALE, WE#, and RE#. Additional signals control hardware write protection (WP#) and monitor device status (R/B#). This Micron NAND Flash device additionally includes a synchronous data interface for high-performance I/O operations. When the synchronous interface is active, WE# becomes CLK and RE# becomes W/R#. Data transfers include a bidirectional data strobe (DQS).
This hardware interface creates a low pin-count device with a standard pinout that remains the same from one density to another, enabling future upgrades to higher densities with no board redesign.

4.2. Identification

Type:	MT29F16G08ABABAWP-IT :B
Manufacturer:	Micron
Function:	16Gbit NAND Flash Memory

4.3. Procurement information

Packaging:	48-Pin TSOP Type 1
Date Code:	DC1434 & 1442
Sample size:	10 parts DC1434 and 10 parts DC1442 All parts were provided by 3D Plus

4.4. Sample Preparation

18 parts were delidded by TRAD.
No sample was damaged during this operation.
A functional test sequence was performed on the delidded samples to check that devices were not degraded by the delidding operation.
Among the 18 delidded samples available for the test campaign all were irradiated.
Samples with DC1434 were identified with a No. from 1 to 9 and samples with DC1442 from 11 to 19.

Sample pictures

4.4.1. External view

No marking at the bottom of the package was observed.

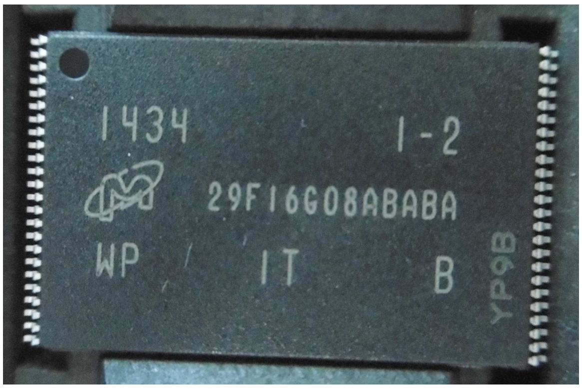


Figure 1: Package marking DC1434

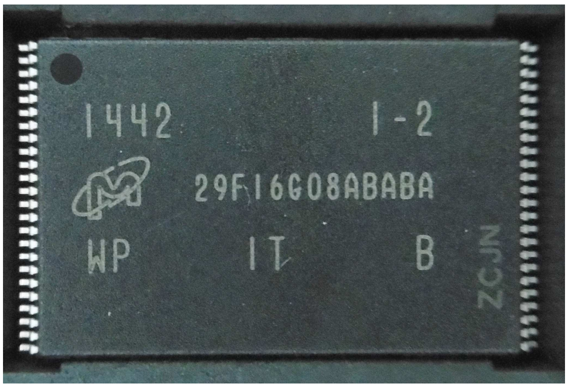


Figure 2: Package marking DC1442

4.4.2. Internal view

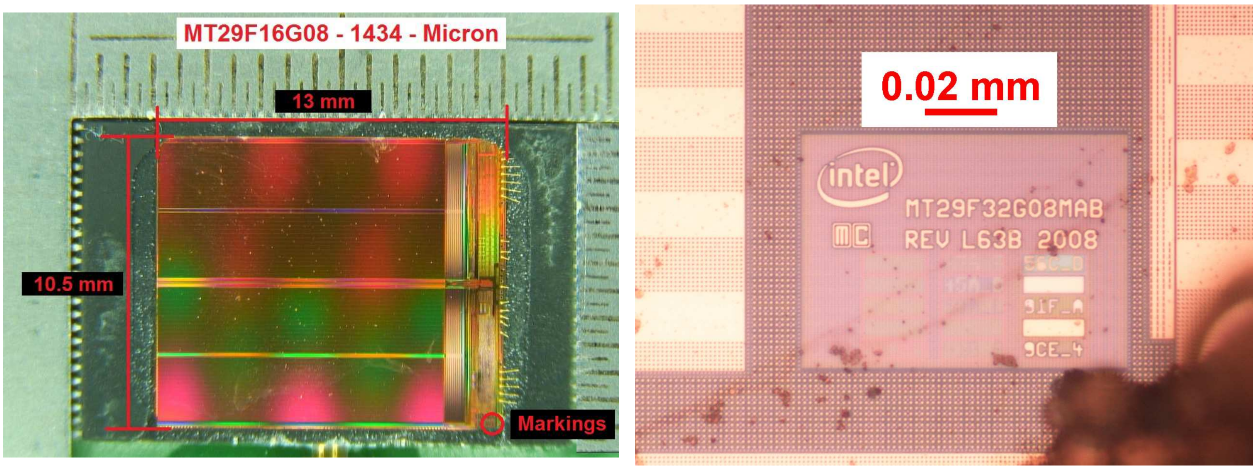


Figure 3: Internal overall views DC1434

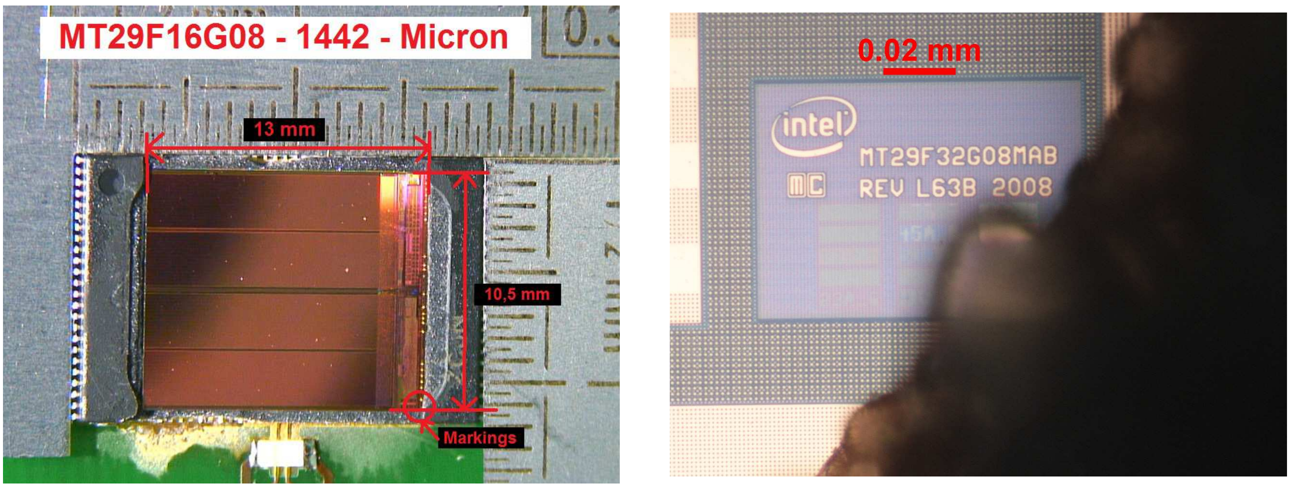


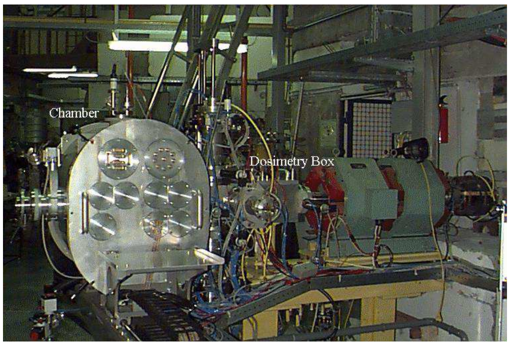
Figure 4: Internal overall views DC1442

5. Dosimetry and Irradiation Facilities

The test was performed at U.C.L (Université Catholique de Louvain) on April 25th and 26th, 2016.
18 delidded samples were irradiated.

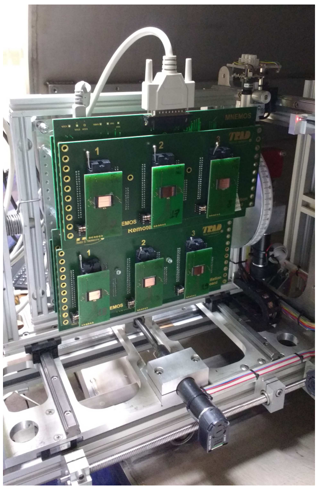
5.1. UCL Heavy Ion Test Facility (Université Catholique de Louvain - Belgique)

The CYClotron of LOuvain la NEuve (CYCLONE) is a multi-particle, variable energy, cyclotron capable of accelerating protons (up to 85 MeV), alpha particles and heavy ions.
For the heavy ions, the covered LET range is between 1.3 MeV.cm².mg^{-1} and 69.2 MeV.cm².mg^{-1}. Heavy ions available are separated in two "Ion Cocktails" named M/Q=5 and M/Q=3.33.



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

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



5.2. Dosimetry

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

5.3. Beam characteristics

The beam flux is variable between a few particles $s^{-1}cm^{-2}$ and $1.8 \cdot 10^4 s^{-1}cm^{-2}$ depending on the device sensitivity.

Available heavy ion characteristics are listed in the following tables (heavy ions used during the experiment are yellow highlighted):

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{15}N^{3+}$	62	60.4	3.2
$^{20}Ne^{4+}$	80.5	46.3	6.1
$^{40}Ar^{8+}$	155	41.1	15.1
$^{84}Kr^{17+}$	324	41.1	40.0
$^{124}Xe^{25+}$	461	38.5	69.2

Table 2: UCL cocktail M/Q=5

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg^{-1})
$^{13}C^{4+}$	131	269.3	1.3
$^{14}N^{4+}$	122	170.8	1.9
$^{22}Ne^{7+}$	238	202	3.3
$^{40}Ar^{12+}$	379	120.5	10.0
$^{58}Ni^{18+}$	582	100.5	20.4
$^{84}Kr^{25+}$	769	94.2	32.4
$^{124}Xe^{35+}$	995	73.1	62.5

Table 3: UCL cocktail M/Q=3.33

6. Test Procedure and Setup

6.1. Test procedure

6.1.1. Description of the test method

The test was divided in two parts, with respect to reference or applicable documents:

- Runs were performed up to a fluence of 1.10^7 cm^{-2} with only SEL monitoring. This configuration allowed us to verify the latchup sensitivity of the device.
- Runs were performed up to a fluence of 1.10^6 cm^{-2} for the SEU, SET, MBU, EWE and SEFI detection in Standby, Retention, Read Only and Erase write modes. This configuration allowed us to verify the device sensitivity in these different modes.

The test was terminated when the maximum fluence was reached or when we got enough events to be statistically representative of the part behaviour.

6.1.2. SEL Test Principle

The test was performed at maximum operating voltage, 3.6V, and at 125°C. The device under test is configured in standby mode.
TRAD has developed a fully integrated test bench to perform Single Event Latchup tests (SEL). The GUARD system (Graphical Universal Autorange Delatcher) allows the user to easily protect his device under test and perform SEL characterization.
The power supply is applied to the device under test through the GUARD system.
The threshold current of the GUARD system is set according to the nominal current. If the nominal current exceeds the threshold current, the GUARD system is triggered and the event is counted as an SEL. Then, the GUARD system sends a trigger command to the oscilloscope, maintains the power supply during a defined 'Time hold' and cut off during a defined 'Time cut'. Then, the power supply is restarted with the nominal current expected consumption.
At the end of each run, the test program reads the oscilloscope's "Local Scope Counter" which represents the total event count and downloads the records currents waveforms to store them and a functional test is operated on the DUT, to ensure its full functionality.

Figure 5 shows an example of the SEL detection.

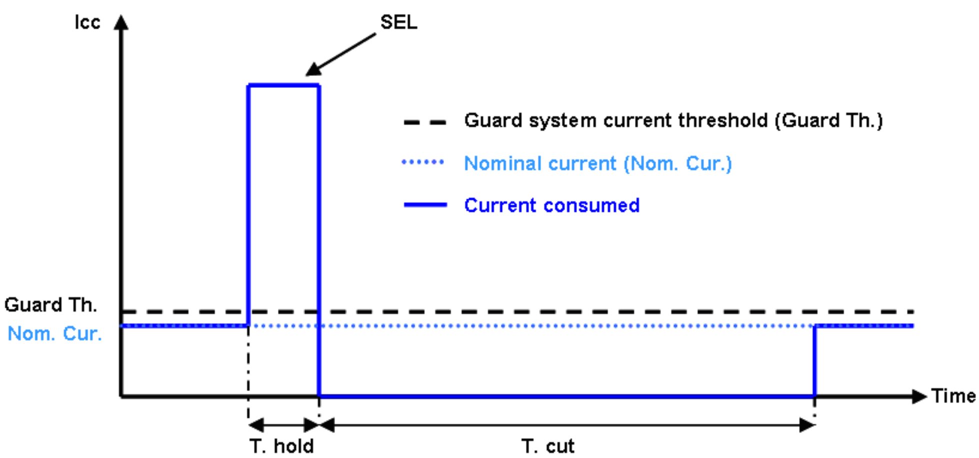


Figure 5: Common SEL characteristic

6.1.3. SEE test principle in standby, read only and erase/write modes

These tests were performed at nominal operating voltage and ambient temperature, the latchup protection is still used to protect the device. Tests in standby, read only and erase/write modes were performed up to a fluence of 1.10^6 cm^{-2}, at ambient temperature and with a current protection set to 100mA. The tested pattern was a checkerboard pattern for all SEE modes, with data xAA at even addresses and x55 at odd addresses. Test in read only standby and retention mode were performed on a certain percentage of the memory plane according to the number of observed SEU.

Retention mode:

The Device Under Test (DUT) is written with a checkerboard and verified before irradiation. During irradiation, the DUT is turned OFF. At the end of the irradiation, the DUT is powered ON and its content is read back in order to observe if events have occurred. SEUs are defined as a one bit difference between the read and the expected data while MBUs are defined as multiple bit differences between the read and the expected data.
The pre-irradiation initialization of the 4096 block of the memory last 15min. One complete test cycle on the 4096 block of the memory last 10min.

Standby mode:

The Device Under Test (DUT) is written with a checkerboard pattern and verified before irradiation. During irradiation, the DUT is put in standby condition. At the end of the irradiation, the DUT is powered OFF and ON and its content is read back in order to observe if events have occurred. SEUs are defined as a one bit difference between the read and the expected data while MBUs are defined as multiple bit differences between the read and the expected data.
The pre-irradiation initialization of the 4096 block of the memory last 15min. One complete test cycle on the 4096 block of the memory last 10min.

Read only mode:

The Device Under Test (DUT) is written with a checkerboard pattern and verified before irradiation.
During irradiation, the part is read continuously block by block. After the end of irradiation a complete cycle of memory read is operated to get all the remaining events. All events are recorded during the test process and are sorted after the runs by post-processing.
SETs are defined as one or multiple bit temporary differences between the read and the expected data. SEUs are defined as a one bit difference between the read and the expected data while MBUs are defined as multiple bit differences between the read and the expected data. The differentiation between SEUs/MBUs and SETs is operated by the post-processing sorting. An error that only occurs once is counted as an SET and any other number of duplicate errors as 1 SEU or 1 MBU. With the exception of errors that occur once during the post-irradiation read cycle, which is operated off-beam, that are not transient and are then counted as SEUs/MBUs
A SEFI is counted when half a page is erroneous within a block or if a time out, loss of communication with the DUT, occurs (monitoring of the ready/busy signal). In case of a SEFI or a Time Out event, the DUT is powered cycled OFF-ON and the test continues with the next block.
The pre-irradiation initialization of the 4096 block of the memory last 15min. One complete test cycle on the 4096 block of the memory last 10min.

Erase/Write/Read mode:

Before irradiation, the DUT is functionally tested. During this mode, all valid blocks are tested consecutively. First the block is erased, the erase operation is verified on the first page of the block, then

the first page of the block is written with a checkerboard pattern and the writing is verified. The verifying operation consists in a three time read operation on the first page of the block.
Events are recorded when the read data doesn't match with the expected data. SETs are defined as one or multiple bit temporary differences between the read and the expected data. An EWE is defined as any number of errors within a page from 1 to half a page minus 1. Differentiation between SETs and EWEs is done during the read operation, if the data is only seen once in error during the three read verifications it is counted as a SET, in the others cases an EWE is counted for the current tested page.
A SEFI is considered if half a tested page is erroneous or if a time out, loss of communication with the DUT, occurs (monitoring of the ready/busy signal). In case of a SEFI, the DUT is powered cycled OFF-ON and the test continues with the next block.
The pre-irradiation validation of the 4096 block of the memory last 15min. One complete test cycle on the 4096 block of the memory last 3.5min.

6.2. Test bench description

6.2.1. Preparation of test hardware and program

TRAD has developed a specific test program and a specific motherboard to feed power supply to components.
The test system is driven by a personal computer through a standard IEEE488 communication interface. All signals are delivered and monitored by this equipment.
At the end of each test run, data is transferred to the hard disk for storage. An overall description of the test system is given in figure 6.

6.2.2. Test equipment identification

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

COMPUTER	PO-TE-157
REF. TEST BOARD	MNEMOS_1, MNEMOS_2
EQUIPMENT	MI-60, SM-92, ME-77, GR-53
TEST PROGRAM	TRAD_TI_MT29-K9_V10.llb TRAD_TI_MT29-K9_V10.xise

6.2.3. Test Bench description

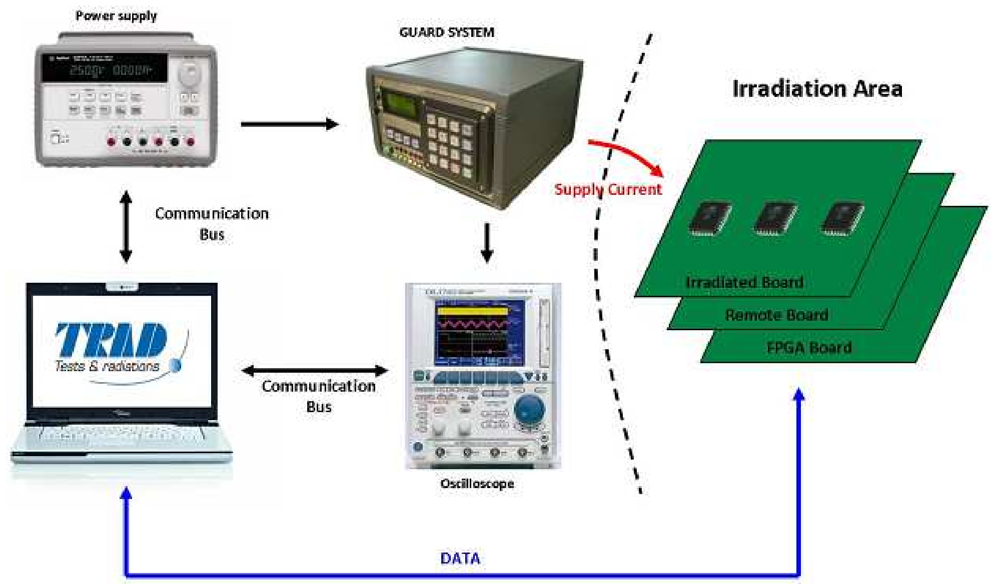


Figure 6: Test system description

7. Non Conformance

Test sequence, test and measurement conditions were nominal.

8. RESULTS

8.1. Summary of runs

Hereafter you will find the Runs performed during this campaign. The test campaign was supervised by M. POIVEY from ESA.

MT29F8G16ABABA SEL Test : VCC=3.6V (*: Run No.1 : Vcc = 3.3V) T° = 125°C, Tilt = 0°, LATCHUP protection = 100mA											SEL	Cross section
Run	Part	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)		
1(*)	11	124 Xe 35+	995	73.1	62.5	6.90E+03	1450	1.00E+07	10.000	10.000	7	7.00E-07
2	2	124 Xe 35+	995	73.1	62.5	1.03E+04	972	1.00E+07	10.000	10.000	17	1.70E-06
3	12	124 Xe 35+	995	73.1	62.5	1.07E+04	938	1.00E+07	10.000	10.000	-	-
4	3	124 Xe 35+	995	73.1	62.5	1.05E+04	956	1.00E+07	10.000	10.000	32	3.20E-06

Table 4: MT29F16G08 SEL mode test results

Run No.1 was operated with Vcc = 3.3V.
Run No.3 was operated without Latchup protection with a recording of the supply current.
SELs were detected during this test.
Test results are described hereafter.

MT29F16G08 SEE Standby Mode : VCC=3.3V T° = 25°C, Tilt = 0°													
Run	**Part**	**No. of tested Blocks**	**Ion**	**Energy (MeV)**	**Range (µm)**	**LET (MeV.cm²/mg)**	**Flux (φ) ($cm^{-2}.s^{-1}$)**	**Time (s)**	**Run Fluence (Φ) (cm^{-2})**	**Run Dose (krad)**	**Cumulated Dose (krad)**	**SEU**	**Cross Section / bit**
9	**13**	408	**124 Xe 35+**	995	73.1	62.5	1.00E+03	**202**	**2.02E+05**	0.202	0.579	**22674**	1.31E-10
12	**1**	409	**124 Xe 35+**	995	73.1	62.5	4.87E+03	**45**	**2.19E+05**	0.219	0.411	**27552**	1.47E-10
17	**4**	409	**84 Kr 25+**	769	94.2	32.4	4.81E+03	**43**	**2.07E+05**	0.107	0.317	**10671**	6.01E-11
23	**14**	409	**84 Kr 25+**	769	94.2	32.4	4.84E+03	**43**	**2.08E+05**	0.108	0.406	**11966**	6.71E-11
29	**15**	409	**40 Ar 12+**	379	120.5	10	5.44E+03	**93**	**5.06E+05**	0.081	0.266	**9459**	2.18E-11
33	**5**	409	**40 Ar 12+**	379	120.5	10	5.66E+03	**90**	**5.09E+05**	0.081	0.737	**10193**	2.33E-11
37	**6**	1637	**22 Ne 7+**	238	202	3.3	1.03E+04	**99**	**1.02E+06**	0.054	0.107	**901**	2.57E-13
41	**16**	1637	**22 Ne 7+**	238	202	3.3	9.81E+03	**103**	**1.01E+06**	0.053	0.106	**330**	9.52E-14
47	**7**	4094	**13 C 4+**	131	269.3	1.3	1.02E+04	**100**	**1.02E+06**	0.021	0.042	**8**	9.14E-16
48	**18**	4091	**13 C 4+**	131	269.3	1.3	1.01E+04	**101**	**1.02E+06**	0.021	0.042	**12**	1.37E-15
58	**17**	4091	**14 N 4+**	122	170.8	1.9	1.02E+04	**99**	**1.01E+06**	0.031	0.052	**25**	2.89E-15

Table 5: MT29F16G08 Standby mode test results

SEUs were detected during this test.
No MBU was detected during this test.
Test results are described hereafter.

MT29F16G08 SEE Read Retention Mode : VCC=3.3V T° = 25°C, Tilt = 0°													
Run	Part	No. of tested Blocks	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	SEU	Cross Section /bit
10	13	407	124 Xe 35+	995	73.1	62.5	4.98E+03	42	2.09E+05	0.209	0.788	25154	1.41E-10
13	1	409	124 Xe 35+	995	73.1	62.5	4.66E+03	44	2.05E+05	0.205	0.616	25894	1.47E-10
18	4	409	84 Kr 25+	769	94.2	32.4	4.81E+03	43	2.07E+05	0.107	0.425	10904	6.14E-11
24	14	409	84 Kr 25+	769	94.2	32.4	4.93E+03	42	2.07E+05	0.107	0.514	11747	6.62E-11
30	15	409	40 Ar 12+	379	120.5	10	5.23E+03	97	5.07E+05	0.081	0.347	9676	2.23E-11
34	5	409	40 Ar 12+	379	120.5	10	5.13E+03	99	5.08E+05	0.081	0.818	9784	2.25E-11
38	6	1638	22 Ne 7+	238	202	3.3	1.00E+04	102	1.02E+06	0.054	0.161	868	2.48E-13
50	7	4094	13 C 4+	131	269.3	1.3	1.02E+04	100	1.02E+06	0.021	0.063	10	1.14E-15
52	18	4091	13 C 4+	131	269.3	1.3	1.01E+04	101	1.02E+06	0.021	0.084	4	4.57E-16
59	7	4094	14 N 4+	122	170.8	1.9	9.90E+03	103	1.02E+06	0.031	0.146	102	1.16E-14

Table 6: MT29F16G08 Retention mode test results

SEUs were detected during this test.
No MBU was detected during this test.
Test results are described hereafter.

MT29F16G08 SEE Read Only Mode : VCC=3.3V T° = 25°C, Tilt = 0°																	
Run	Part	No. of tested Blocks	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (Φ) (cm^{-2})	Run Dose (krad)	Cumulated Dose (krad)	SEU	Cross Section	SET	Cross Section	SEFI	Cross Section /bit
6	1	4094	124 Xe 35+	995	73.1	62.5	1.08E+03	178	1.92E+05	0.192	0.192	231252	1.40E-10	809	4.21E-03	12	6.25E-05
7	13	4083	124 Xe 35+	995	73.1	62.5	5.02E+02	177	8.89E+04	0.089	0.141	102209	1.34E-10	708	7.96E-03	7	7.87E-05
8	13	408	124 Xe 35+	995	73.1	62.5	9.92E+02	238	2.36E+05	0.236	0.377	27390	1.36E-10	765	3.24E-03	10	4.24E-05
16	4	409	84 Kr 25+	769	94.2	32.4	1.04E+03	196	2.04E+05	0.106	0.210	10487	5.99E-11	324	1.59E-03	9	4.41E-05
22	14	409	84 Kr 25+	769	94.2	32.4	9.62E+02	208	2.00E+05	0.104	0.299	10690	6.23E-11	315	1.58E-03	4	2.00E-05
25	5	409	84 Kr 25+	769	94.2	32.4	1.04E+03	193	2.01E+05	0.104	0.104	10629	6.17E-11	308	1.53E-03	6	2.99E-05
27	15	409	84 Kr 25+	769	94.2	32.4	1.06E+03	191	2.02E+05	0.105	0.105	9904	5.72E-11	275	1.36E-03	10	4.95E-05
28	15	409	40 Ar 12+	379	120.5	10	2.07E+03	241	5.00E+05	0.080	0.185	9209	2.15E-11	220	4.40E-04	13	2.60E-05
32	5	409	40 Ar 12+	379	120.5	10	1.71E+03	119	2.03E+05	0.032	0.655	3909	2.25E-11	112	5.52E-04	4	1.97E-05
36	6	409	22 Ne 7+	238	202	3.3	3.54E+03	285	1.01E+06	0.053	0.053	223	2.57E-13	37	3.66E-05	2	1.98E-06
40	16	1637	22 Ne 7+	238	202	3.3	4.93E+03	203	1.00E+06	0.053	0.053	276	8.04E-14	39	3.90E-05	2	2.00E-06
43	7	4094	13 C 4+	131	269.3	1.3	5.21E+03	194	1.01E+06	0.021	0.021	27	3.11E-15	0	<9.90E-07	0	<9.90E-07
44	18	4092	13 C 4+	131	269.3	1.3	5.15E+03	196	1.01E+06	0.021	0.021	19	2.19E-15	0	<9.90E-07	0	<9.90E-07
45	9	4091	13 C 4+	131	269.3	1.3	5.02E+03	201	1.01E+06	0.021	0.021	23	2.65E-15	1	9.90E-07	0	<9.90E-07
46	17	4090	13 C 4+	131	269.3	1.3	4.95E+03	204	1.01E+06	0.021	0.021	23	2.65E-15	2	1.98E-06	1	9.90E-07
53	7	4094	14 N 4+	122	170.8	1.9	5.15E+03	196	1.01E+06	0.031	0.115	128	1.48E-14	4	3.96E-06	0	<9.90E-07
54	18	4090	14 N 4+	122	170.8	1.9	5.23E+03	193	1.01E+06	0.031	0.115	31	3.58E-15	0	<9.90E-07	0	<9.90E-07
55	19	4092	14 N 4+	122	170.8	1.9	5.18E+03	195	1.01E+06	0.031	0.031	57	6.58E-15	2	1.98E-06	1	9.90E-07

Table 7: MT29F16G08 Read only mode test results

SET, SEU and SEFI were detected during this test.
No MBU was detected during this test.
Test results are described hereafter.

MT29F8G08ABABA SEE Erase Write Test : VCC=3.3V, T° = 25°C, Tilt = 0°																	
Run	**Part**	**Ion**	**Energy (MeV)**	**Range (µm)**	**LET (MeV.cm²/mg)**	**Flux (φ) ($cm^{-2}.s^{-1}$)**	**Time (s)**	**Run Fluence (Φ) (cm^{-2})**	**Run Dose (krad)**	**Cumulated Dose (krad)**	**SEL**	**Cross Section**	**EWE**	**Cross Section**	**SET**	**Cross Section**	**SEFI**	**Cross Section**
11	13	124 Xe 35+	995	73.1	62.5	8.60E+02	616	5.30E+05	0.530	1.318	1	1.89E-06	22	4.15E-05	125	2.36E-04	34	6.42E-05
14	1	124 Xe 35+	995	73.1	62.5	6.41E+03	156	1.00E+06	1.000	1.616	1	1.00E-06	21	2.10E-05	159	1.59E-04	35	3.50E-05
20	4	84 Kr 25+	769	94.2	32.4	9.87E+02	152	1.50E+05	0.078	0.627	0	<6.67E-06	2	1.33E-05	24	1.60E-04	8	5.33E-05
21	14	84 Kr 25+	769	94.2	32.4	1.02E+03	369	3.76E+05	0.195	0.195	0	<2.66E-06	14	3.72E-05	31	8.24E-05	14	3.72E-05
26	5	84 Kr 25+	769	94.2	32.4	1.07E+03	936	1.00E+06	0.518	0.623	0	<1.00E-06	17	1.70E-05	100	1.00E-04	32	3.20E-05
31	15	40 Ar 12+	379	120.5	10	1.93E+03	15	2.90E+04	0.005	0.351								
35	5	40 Ar 12+	379	120.5	10	9.89E+02	1011	1.00E+06	0.160	0.978	0	<1.00E-06	10	1.00E-05	42	4.20E-05	22	2.20E-05
39	6	22 Ne 7+	238	202	3.3	2.11E+03	475	1.00E+06	0.053	0.214	0	<1.00E-06	0	<1.00E-06	1	1.00E-06	4	4.00E-06
42	16	22 Ne 7+	238	202	3.3	1.73E+03	578	1.00E+06	0.053	0.159	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06	5	5.00E-06
49	18	13 C 4+	131	269.3	1.3	2.08E+03	481	1.00E+06	0.021	0.063	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06
51	7	13 C 4+	131	269.3	1.3	2.04E+03	490	1.00E+06	0.021	0.084	0	<1.00E-06	0	<1.00E-06	1	1.00E-06	0	<1.00E-06
56	19	14 N 4+	122	170.8	1.9	2.03E+03	492	1.00E+06	0.030	0.061	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06
57	9	14 N 4+	122	170.8	1.9	1.97E+03	507	1.00E+06	0.030	0.051	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06	0	<1.00E-06
60	8	40 Ar 12+	379	120.5	10	1.02E+03	779	7.98E+05	0.128	0.128	0	<1.25E-06	5	6.27E-06	51	6.39E-05	17	2.13E-05
61	8	40 Ar 12+	379	120.5	10	8.38E+02	1194	1.00E+06	0.160	0.288	0	<1.00E-06	14	1.40E-05	50	5.00E-05	21	2.10E-05

Table 8: MT29F16G08 Erase Write mode test results

▨: Functional failure (see §8.3.9).

EWE, SET and SEFI were detected during this test.
Test results are described hereafter.

8.2. SEL tests results

SEL test was performed at 125°C with a latchup protection set at 100mA, under Xenon Heavy Ion (LET = 62.5 MeV.cm²/mg). Power supply was set at Vcc = 3.6V except for run No. 1 which was operated at Vcc = 3.3V.

High Current states were observed during all performed SEL runs, an example is presented on figure 7, some would trigger the latchup protection and are then counted as SEL.
No other high current event was observed during experiments with Vcc = 3.3V and T =25°C.

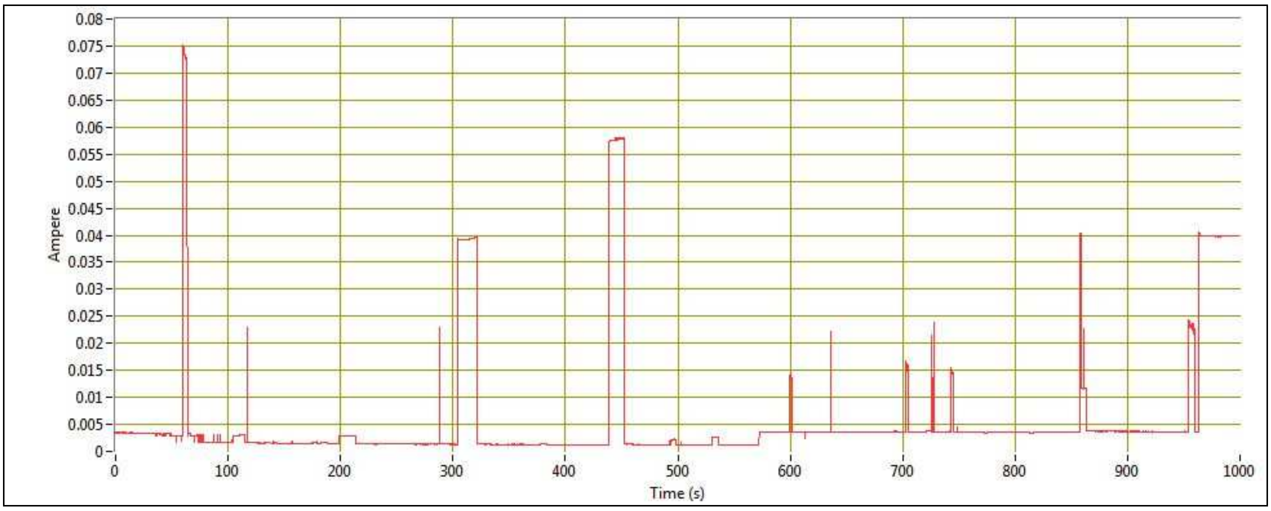


Figure 7: High current state during SEL test with Latchup protection at 100mA (part No. 2, run No. 2)

During experiments under Xenon irradiations, at $1.10^{7}.cm^{-2}$, no functional failure was observed on the 4 tested devices, even without the latchup protection.

8.2.1. SEL Cross section

MT29F16G08 SEL Mode SEL Cross Section (cm²)			
LET Eff (MeV.cm².mg⁻¹)	SEL		
	2	3	11
62.5	1.70E-06	3.20E-06	7.00E-07

Table 9: MT29F16G08 SEL cross section results

8.2.2. Worst Cases SEL Observed

The worst SEL case occurs on part No.3 during run No.4 event No.14 (Xe, 62.5 MeV.cm²/mg).

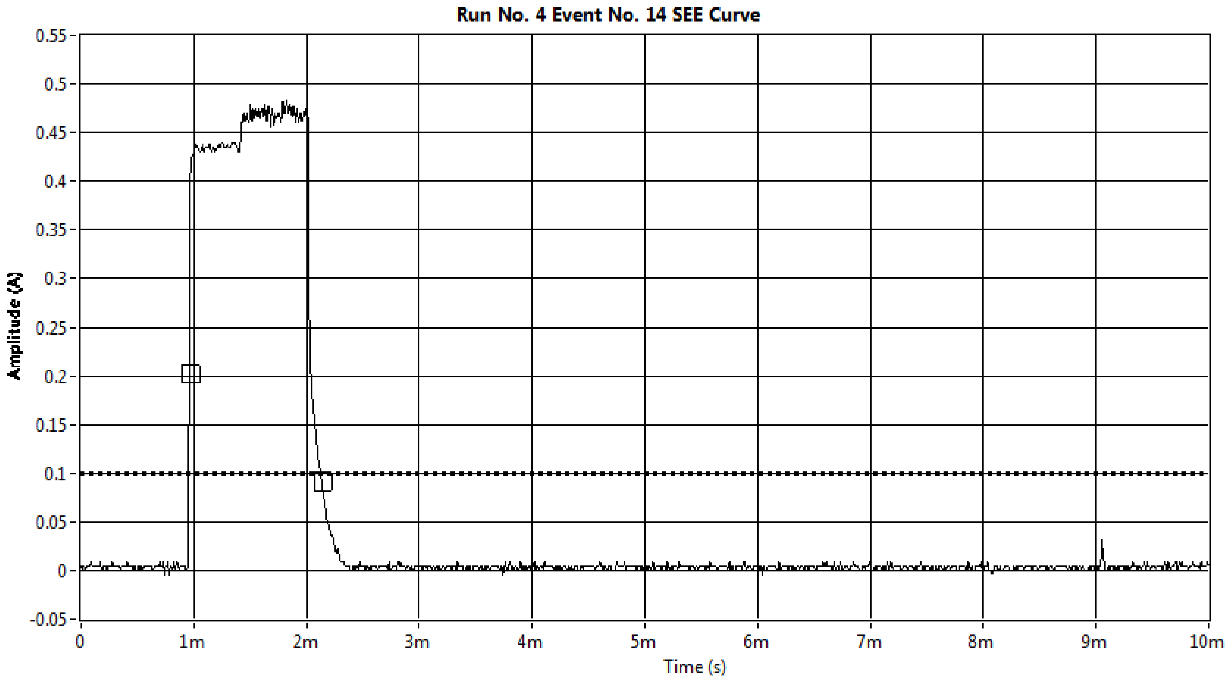


Figure 8: Worst curve SEL, Heavy Ion Xe, part No.3, run No.4 event No.3, Amplitude = 493mA

8.2.3. Non protected SEL run

Run No.3 was operated without Latchup protection with a recording of the supply current, this allow a visualization of the complete high current profile without the power cycle induced by the latchup protection.

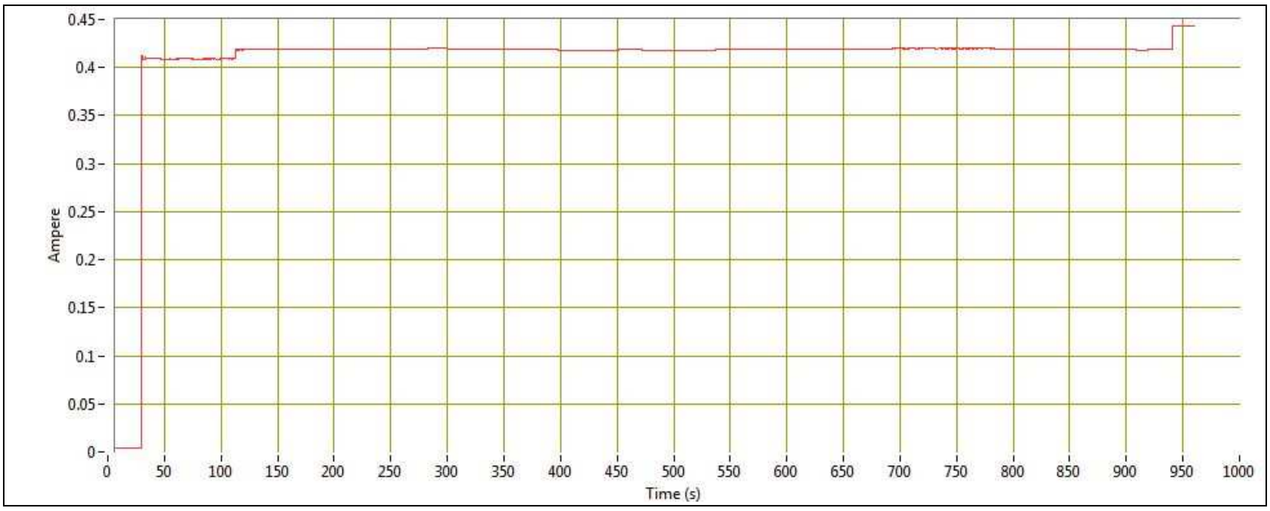


Figure 9: High current state during SEL test without Latchup protection (part No. 12, run No. 3)

After the SEL test we noticed an increasing number of bad blocks in the tested devices. Table 10 sums up the number of bad blocks before and after Xenon irradiations. We can observe that the number of new bad blocks is more important for part No. 12 which was irradiated without latchup protection.

MT29F16G08 Post SEL bad block number								
PART	2		3		11		12	
	Before	After	Before	After	Before	After	Before	After
Number of Bad Blocks	3	17	34	56	2	15	1	61

Table 10: Number of bad blocks before and after Xenon irradiation

8.3. SEE tests results

The SEE tests were performed at 25°C.
Test in read only standby and retention mode were performed on a certain percentage of the memory plane according to the number of observed SEU. The number of bit per block of the memory is 4194304 bits. SEU can only provoke a bit transition from ‘0’ to ‘1’. This phenomenon has been confirmed by the acquired data. Considering the checkerboard test pattern (half bits at ‘0’ and the other half at ‘1’) the actual number of tested bit per block is 2097152 bits. SEU cross section is then normalized, taking into account the total number of tested bits (approximately 8Gb for 4096 blocks).
Cross section for other type of events (SET, EWE and SEFI) has not been normalized as these types of events do not impact directly the memory plane and therefore are not dependant of the number of tested bits.

Error bars have been calculated as described in the ESCC25100, using 95% confidence level and 10% fluence uncertainty.

8.3.1. Standby mode results

SEUs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
No MBU was observed during irradiation with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion).

8.3.2. Standby mode SEU Cross section

MT29F16G08 Standby Mode SEU Cross Section/bit (cm^2/bit)											
LET Eff (MeV.cm².mg^{-1})	SEU										
	1	4	5	6	7	13	14	15	16	17	18
62.5	1.47E-10					1.31E-10					
32.4		6.01E-11					6.71E-11				
10			2.33E-11					2.18E-11			
3.3				2.57E-13					9.52E-14		
1.9										2.89E-15	
1.3					9.14E-16						1.37E-15

Table 11: MT29F16G08 standby mode SEU cross section results

The following figure presents the cross section per bit of the SEU events on the MT29F16G08 in standby mode.

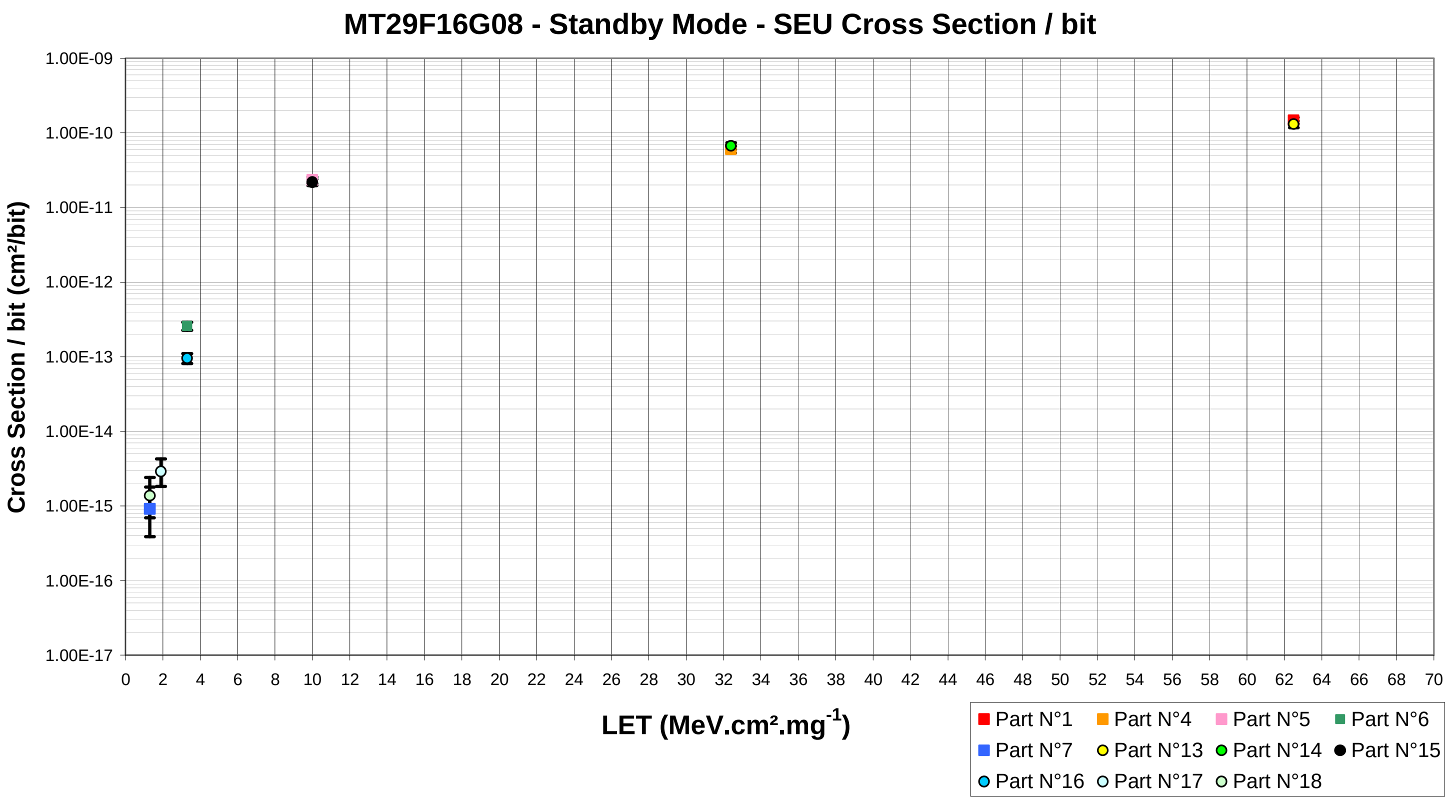


Figure 10: MT29F16G08 standby mode SEU cross section curve

8.3.3. Retention mode results

SEUs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
No MBU was observed during irradiation with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion).

8.3.4. Retention mode SEU Cross section

MT29F16G08 Retention Mode SEU Cross Section/bit (cm^2/bit)									
LET Eff ($MeV.cm^2.mg^{-1}$)	SEU								
	1	4	5	6	7	13	14	15	18
62.5	1.47E-10					1.41E-10			
32.4		6.14E-11					6.62E-11		
10			2.25E-11					2.23E-11	
3.3				2.48E-13					
1.9					1.16E-14				
1.3					1.14E-15				4.57E-16

Table 12: MT29F16G08 Retention mode SEU cross section results

The following figure presents the cross section per bit of the SEU events on the MT29F16G08 in Retention mode.

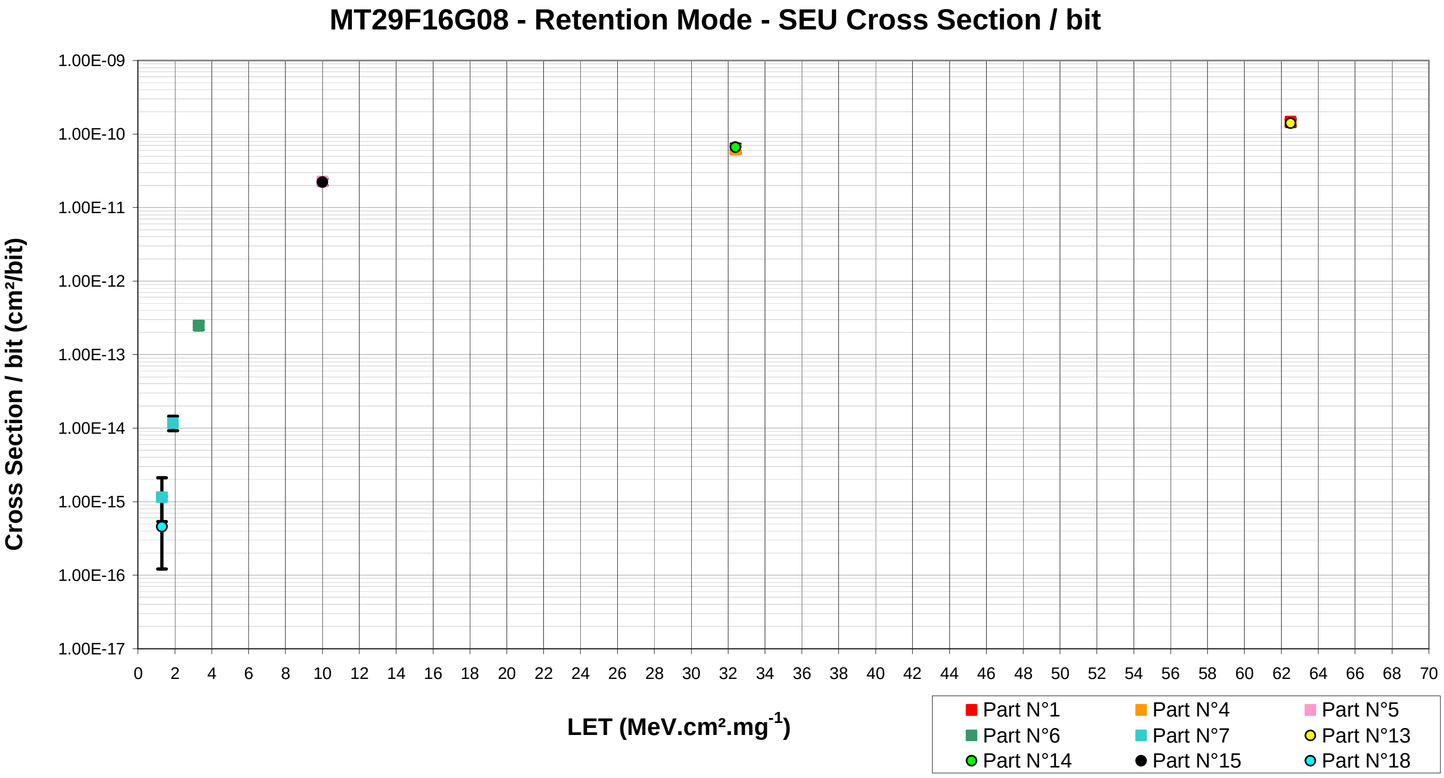


Figure 11: MT29F16G08 Retention mode SEU cross section curve

8.3.5. Read only mode results

SEUs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
No MBU was observed during irradiation with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion).
SETs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).

SEFIs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
In read only mode, all observed SEFI except one were the half page in error condition. One time out SEFI was observed at LET 62.5 on part No. 1 during run No. 6.

8.3.6. Read only mode SEU Cross section

MT29F16G08 Read Only Mode SEU Cross Section/bit (cm²/bit)													
LET Eff (MeV.cm².mg-1)	SEU												
	1	4	5	6	7	9	13	14	15	16	17	18	19
62.5	1.40E-10						1.34E-10						
32.4		5.99E-11	6.17E-11					6.23E-11	5.72E-11				
10			2.25E-11						2.15E-11				
3.3				2.57E-13						8.04E-14			
1.9					1.48E-14							3.58E-15	6.58E-15
1.3					3.11E-15	2.65E-15					2.65E-15	2.19E-15	

Table 13: MT29F16G08 Read only mode SEU cross section results

The following figure presents the cross section per bit of the SEU events on the MT29F16G08 in read only mode.

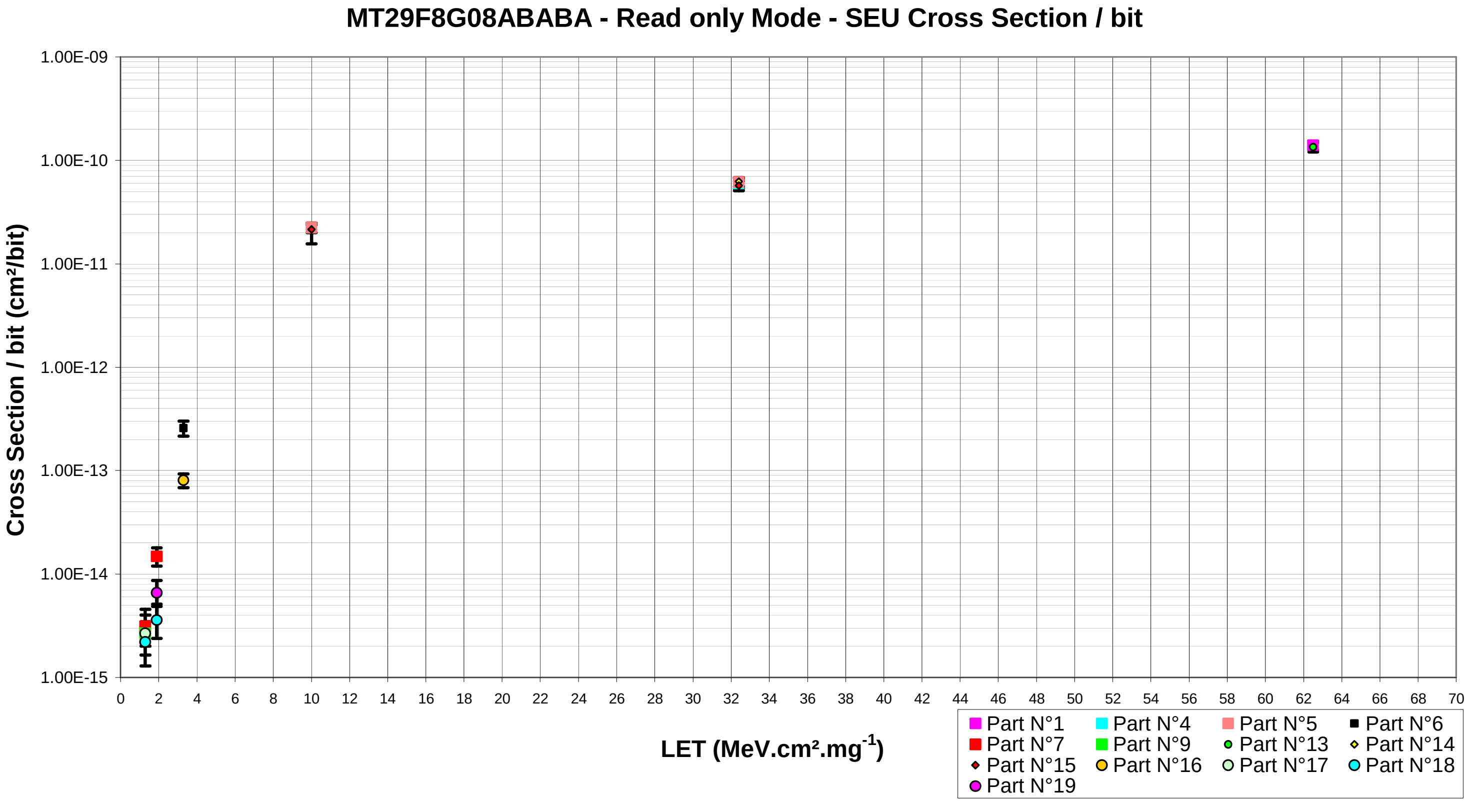


Figure 12: MT29F16G08 read only mode SEU cross section curve

8.3.7. Read only mode SET Cross section

MT29F8G08ABABA Read Only Mode SET Cross Section (cm^2)													
LET Eff (MeV.cm².mg^{-1})	**SET**												
	1	4	5	6	7	9	13	14	15	16	17	18	19
62.5	4.21E-03						7.96E-03						
32.4		1.59E-03	1.53E-03					1.58E-03	1.36E-03				
10			5.52E-04						4.40E-04				
3.3				3.66E-05						3.90E-05			
1.9					3.96E-06							<1.00E-06	1.98E-06
1.3					<1.00E-06	9.90E-07					1.98E-06	<1.00E-06	

Table 14: MT29F16G08 Read only mode SET cross section results

The following figure presents the cross section of the SET events on the MT29F16G08 in read only mode. Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.00 $10^{-6} cm^{-2}$, value corresponding to one event at maximum fluence.

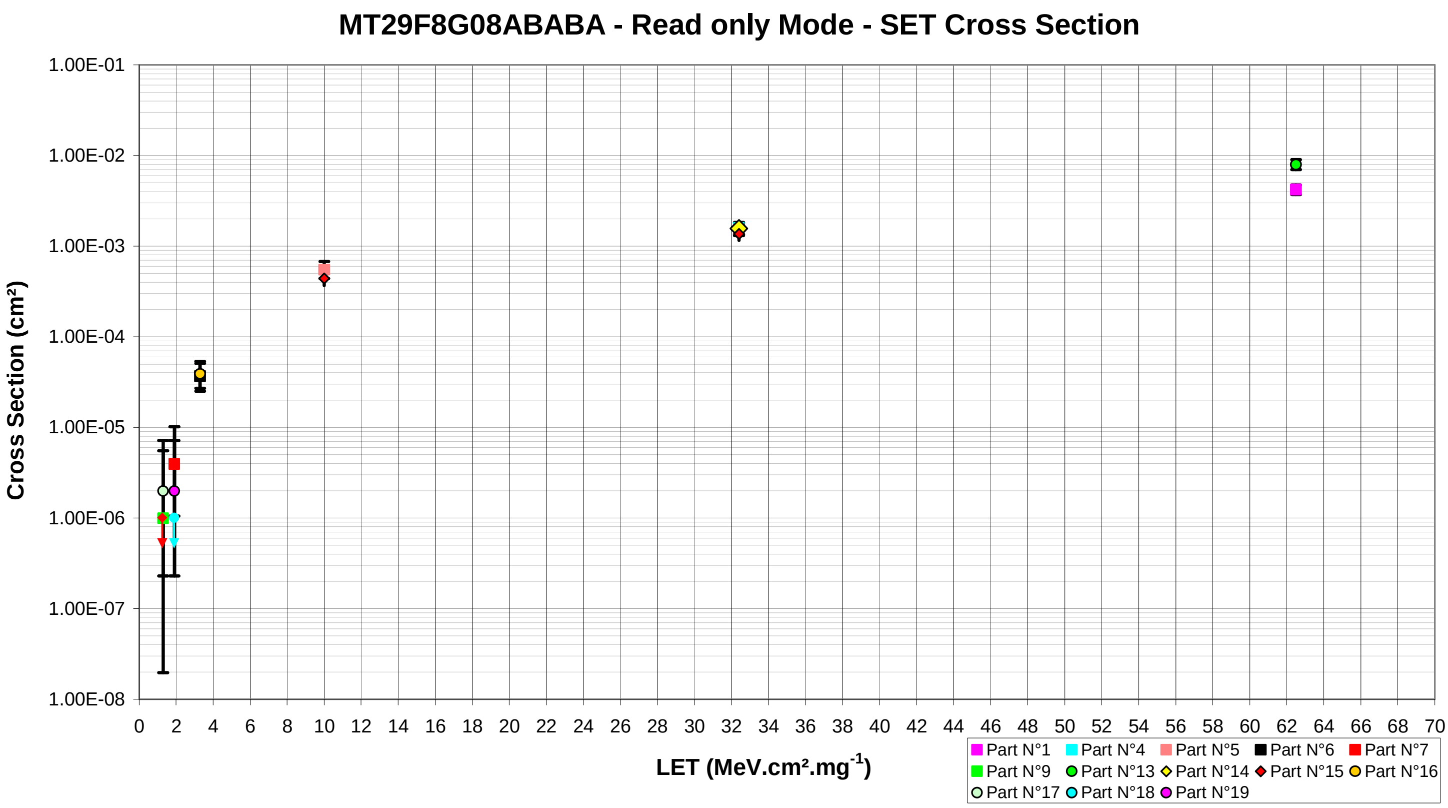


Figure 13: MT29F16G08 read only mode SET cross section curve

8.3.8. Read only mode SEFI Cross section

MT29F8G08ABABA Read Only Mode SEFI Cross Section (cm^2)													
LET Eff ($MeV.cm^2.mg^{-1}$)	**SEFI**												
	1	4	5	6	7	9	13	14	15	16	17	18	19
62.5	6.25E-05						7.87E-05						
32.4		4.41E-05	2.99E-05					2.00E-05	4.95E-05				
10			1.97E-05						2.60E-05				
3.3				1.98E-06						2.00E-06			
1.9					<1.00E-06							<1.00E-06	9.90E-07
1.3					<1.00E-06	<1.00E-06					9.90E-07	<1.00E-06	

Table 15: MT29F16G08 Read only mode SEFI cross section results

The following figure presents the cross section of the SEFI events on the MT29F16G08 in read only mode. Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.00 $10^{-6}cm^{-2}$, value corresponding to one event at maximum fluence.

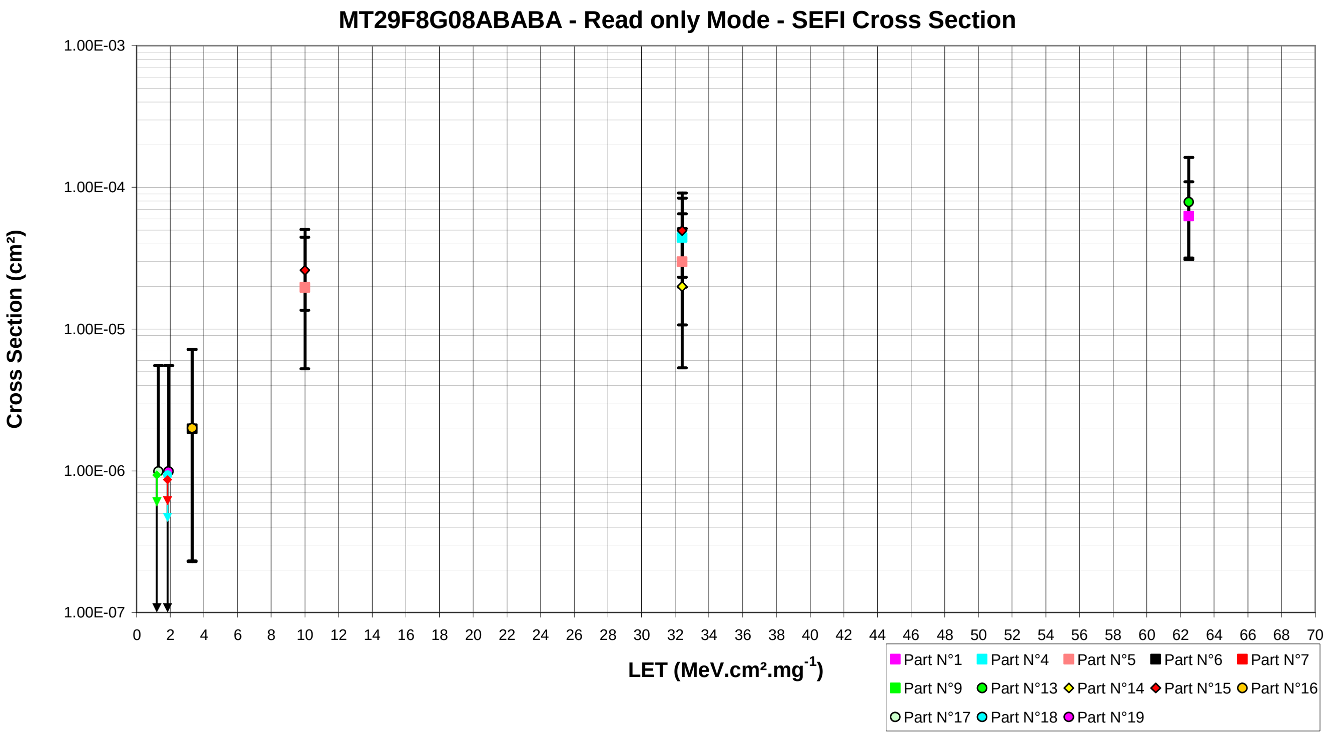


Figure 14: MT29F16G08 read only mode SEFI cross section curve

8.3.9. Erase write mode results

During runs No. 11, 20 and 31, parts No. 13, 4 and 15 entered in a time out loop that wasn't stopped by the automatic power cycle. Concerned runs were stopped, the time out loop was filtered and counted as a SEFI in the logs, and parts were functionally checked. Parts No. 13 and 4 remained functional after this event but part No. 15 became not functional. Part No. 15 was tested again 48 hours after the test campaign and remained non functional.

During runs No. 19, 21 and 60, parts No. 4, 14 and 15 presented an atypical number of EWE and SET during irradiations, after the end of irradiations EWE and SET still occurred, but the number of event per page was too low to trigger the SEFI detection. This event has been filtered and counted as a SEFI in the logs. Tested parts were functionally checked after the run, all parts remained functional after this event.

During runs 14 and 26 in Erase Write mode, large burst of SETs were observed with more than 200 SETs in one single tested block. These bursts have been filtered from the SET counting and a SEFI has been counted instead in the logs.

EWEs were observed during irradiation with a minimum LET of 10 MeV.cm²/mg (Argon heavy ion).
No EWE was observed during irradiation with a LET of 3.3 MeV.cm²/mg (Neon heavy ion).
SETs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
SEFIs were observed during irradiation with a minimum LET of 3.3 MeV.cm²/mg (Neon heavy ion).
No SEFI was observed during irradiation with a LET of 1.9 MeV.cm²/mg (Nitrogen heavy ion).

8.3.10. Erase write mode EWE Cross section

MT29F16G08 Erase Write Mode EWE Cross Section (cm²)												
LET Eff (MeV.cm².mg^{-1})	EWE											
	1	4	5	6	7	8	9	13	14	16	18	19
62.5	2.10E-05							4.15E-05				
32.4		1.33E-05	1.70E-05						3.72E-05			
10			1.00E-05			1.40E-05						
3.3				<1.00E-06						<1.00E-06		
1.9							<1.00E-06					<1.00E-06
1.3					<1.00E-06						<1.00E-06	

Table 16: MT29F16G08 erase write mode EWE cross section results

The following figure presents the cross section of the EWE events on the MT29F16G08 in erase write mode. Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.00 $10^{-6}cm^{-2}$, value corresponding to one event at maximum fluence.

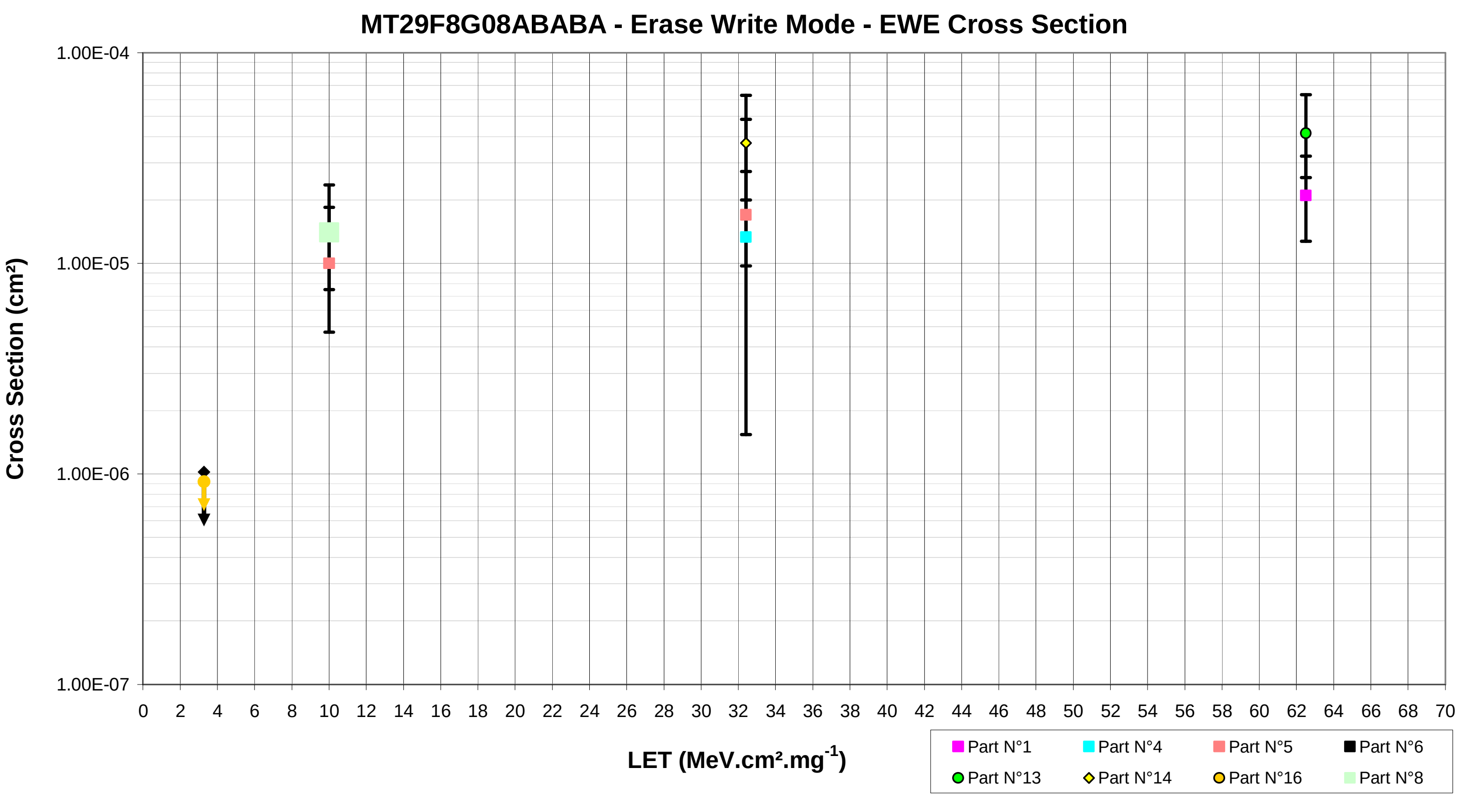


Figure 15: MT29F16G08 erase write mode EWE cross section curve

8.3.11. Erase write mode SET Cross section

MT29F16G08 Erase Write Mode SET Cross Section (cm2)												
LET Eff (MeV.cm².mg^{-1})	SET											
	1	4	5	6	7	8	9	13	14	16	18	19
62.5	1.59E-04							2.36E-04				
32.4		1.60E-04	1.00E-04						8.24E-05			
10			4.20E-05			6.39E-05						
3.3				1.00E-06						<1.00E-06		
1.9							<1.00E-06					<1.00E-06
1.3					1.00E-06						<1.00E-06	

Table 17: MT29F16G08 erase write mode SET cross section results

The following figure presents the cross section of the SET events on the MT29F16G08 in erase write mode. Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.00 10^{-6}cm^{-2}, value corresponding to one event at maximum fluence.

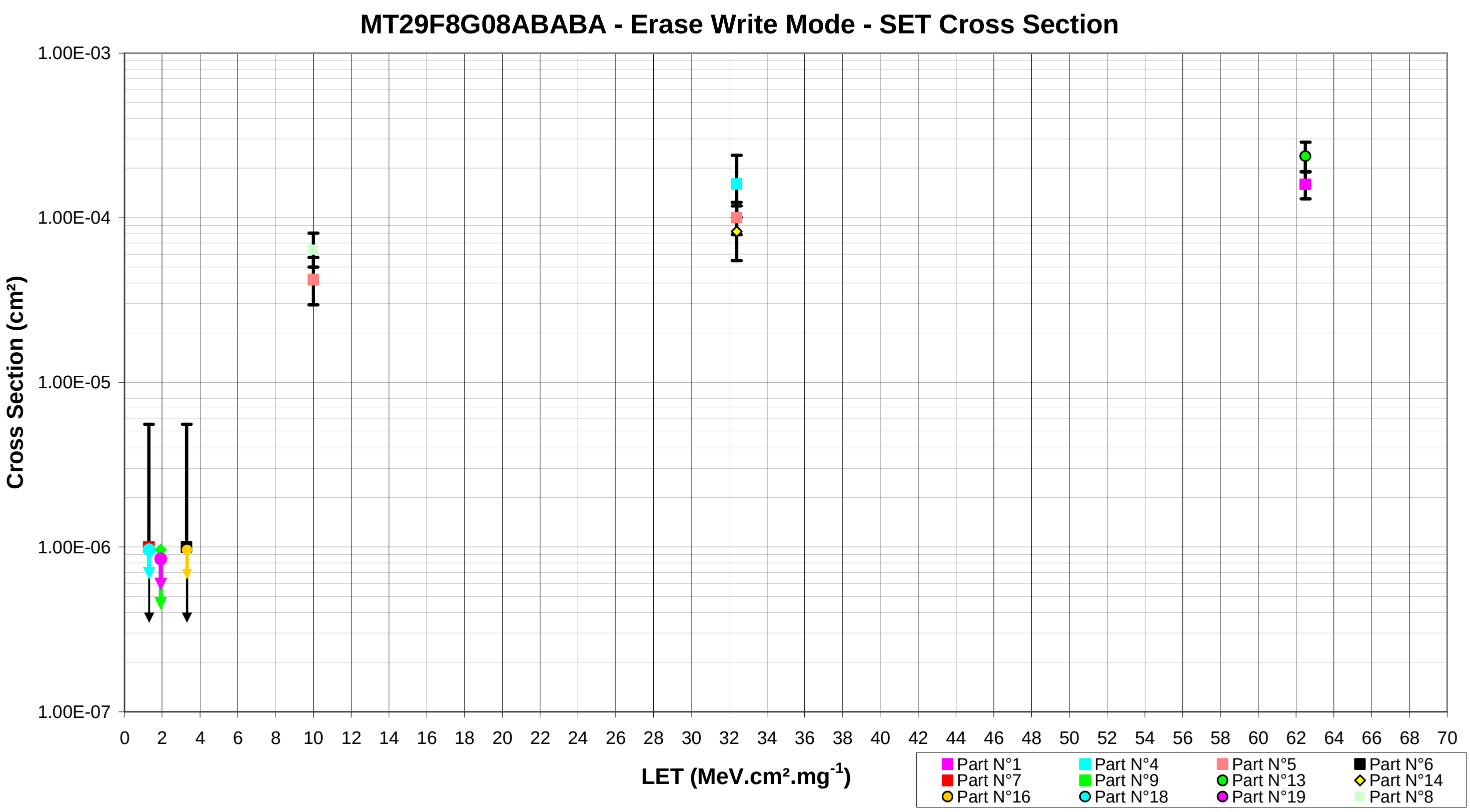


Figure 16: MT29F16G08 erase write mode SET cross section curve

8.3.12. Erase write mode SEFI Cross section

MT29F16G08 Erase Write Mode SEFI Cross Section (cm2)												
LET Eff (MeV.cm².mg^{-1})	SEFI											
	1	4	5	6	7	8	9	13	14	16	18	19
62.5	3.50E-05							6.42E-05				
32.4		5.33E-05	3.20E-05			2.13E-05			3.72E-05			
10			2.20E-05									
3.3				4.00E-06						5.00E-06		
1.9							<1.00E-06					<1.00E-06
1.3					<1.00E-06						<1.00E-06	

Table 18: MT29F16G08 Erase Write mode SEFI cross section results

The following figure presents the cross section of the SEFI events on the MT29F16G08 in erase write mode. Points represented by an arrow pointing down indicate that no events were observed at the corresponding LET. The evaluated cross section is then lower than 1.00 10^{-6}cm^{-2}, value corresponding to one event at maximum fluence.

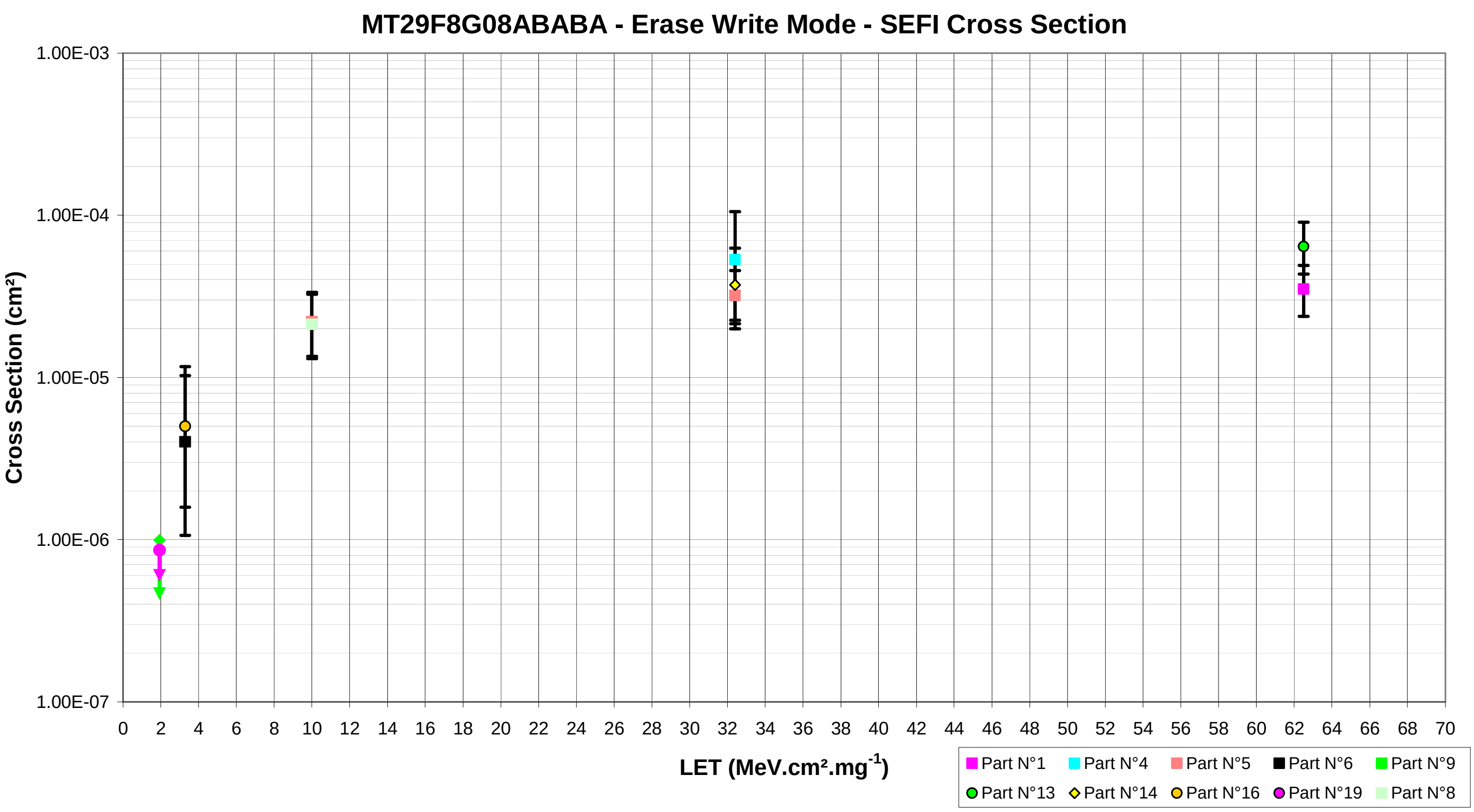


Figure 17: MT29F16G08 erase write mode SEFI cross section curve

9. Conclusion

Heavy ions test were performed on MT29F16G08. The aim of the test was to evaluate the sensitivity of the device versus SEL, SEU, SET, MBU, EWE and SEFI in 5 different test modes.

SEL mode results

High Current states were observed with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion) with supply voltage at Vcc = 3.6 V and Vcc = 3.3V.
No functional failure was observed on the 4 tested devices under Xenon irradiations up to 1.10^{7}.cm^{-2}.
High current events were only observed during SEL runs, with Vcc = 3.6 V and Vcc = 3.3V and T° = 125°C.
No high current event was observed dwith Vcc = 3.3V and T =25°C under Xenon irradiations up to 2.10^{5}.cm^{-2}.

Standby mode results

SEUs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
No MBU was observed during irradiation with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion).

Retention mode results

SEUs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
No MBU was observed during irradiation with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion).

Read only mode results

SEUs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
No MBU was observed during irradiation with a LET of 62.5 MeV.cm²/mg (Xenon heavy ion).
SETs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
SEFIs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).

Erase write mode results

EWEs were observed during irradiation with a minimum LET of 10 MeV.cm²/mg (Argon heavy ion).
No EWE was observed during irradiation with a LET of 3.3 MeV.cm²/mg (Neon heavy ion).
SETs were observed during irradiation with a minimum LET of 1.3 MeV.cm²/mg (Carbon heavy ion).
SEFIs were observed during irradiation with a minimum LET of 3.3 MeV.cm²/mg (Neon heavy ion).
No SEFI was observed during irradiation with a LET of 1.9 MeV.cm²/mg (Nitrogen heavy ion).

10. Appendix A: Supply current monitoring

FIGURES

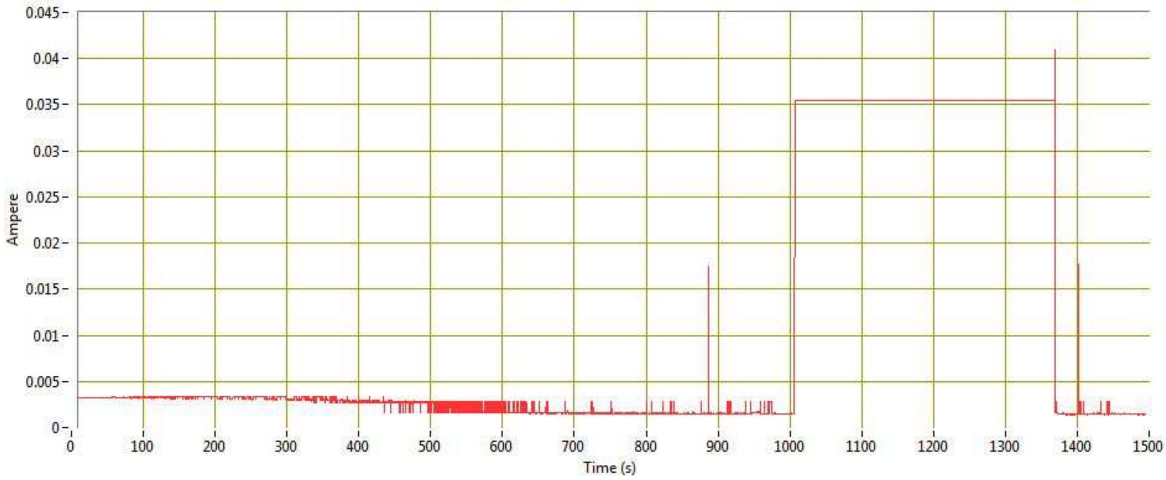


Figure A-1: Run No. 1 supply current monitoring

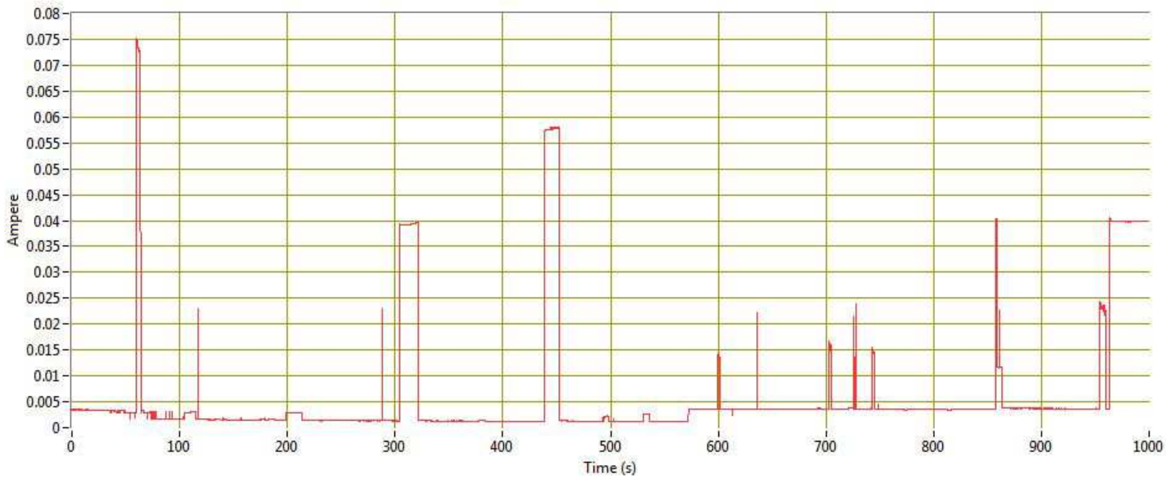


Figure A-2: Run No. 2 supply current monitoring

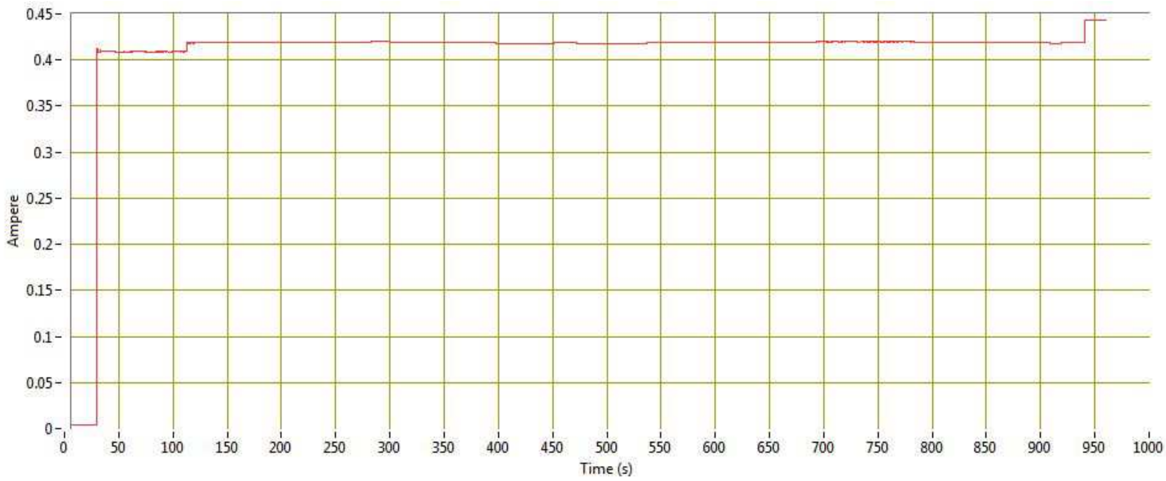


Figure A-3: Run No. 3 supply current monitoring

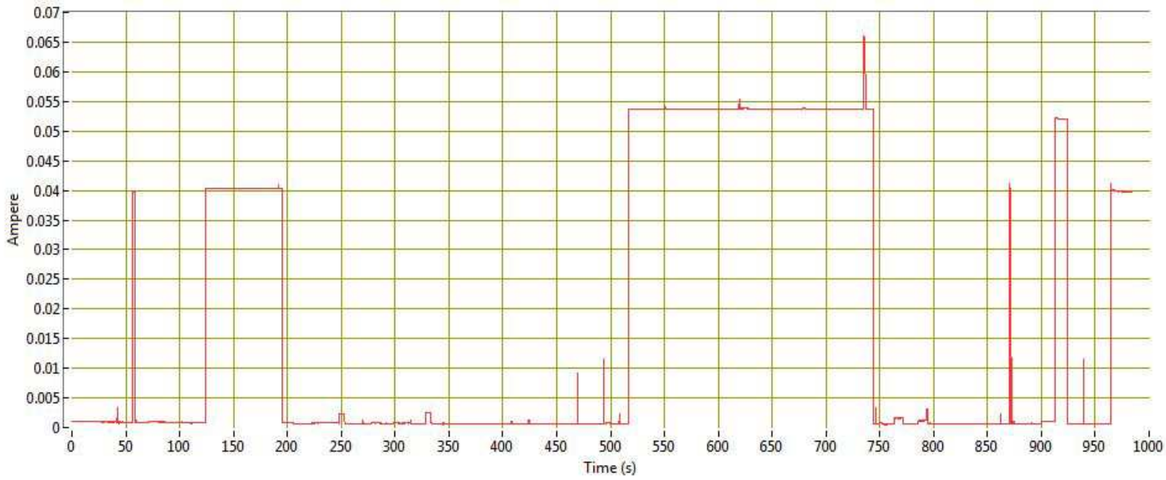


Figure A-4: Run No. 4 supply current monitoring

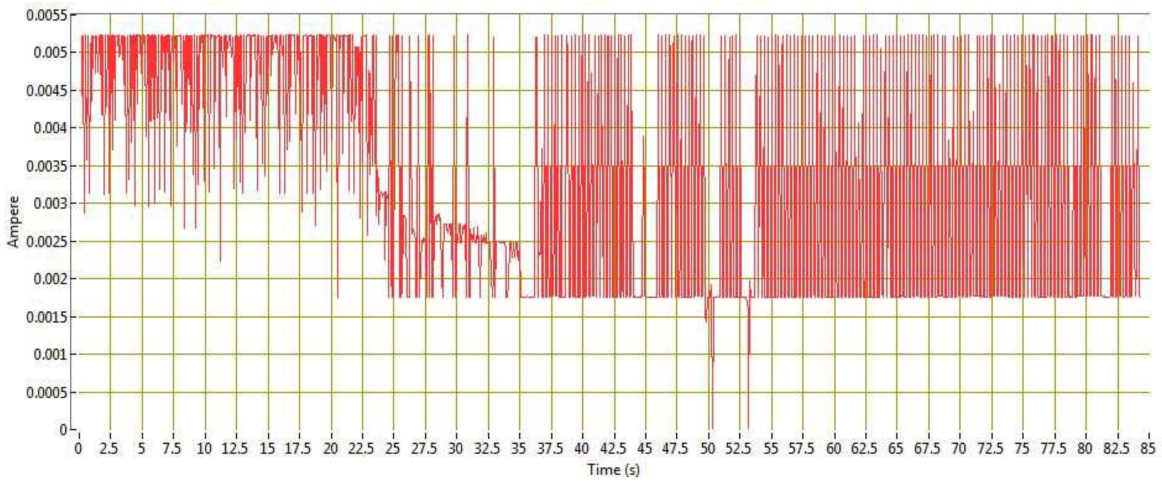


Figure A-5: Run No. 5 supply current monitoring

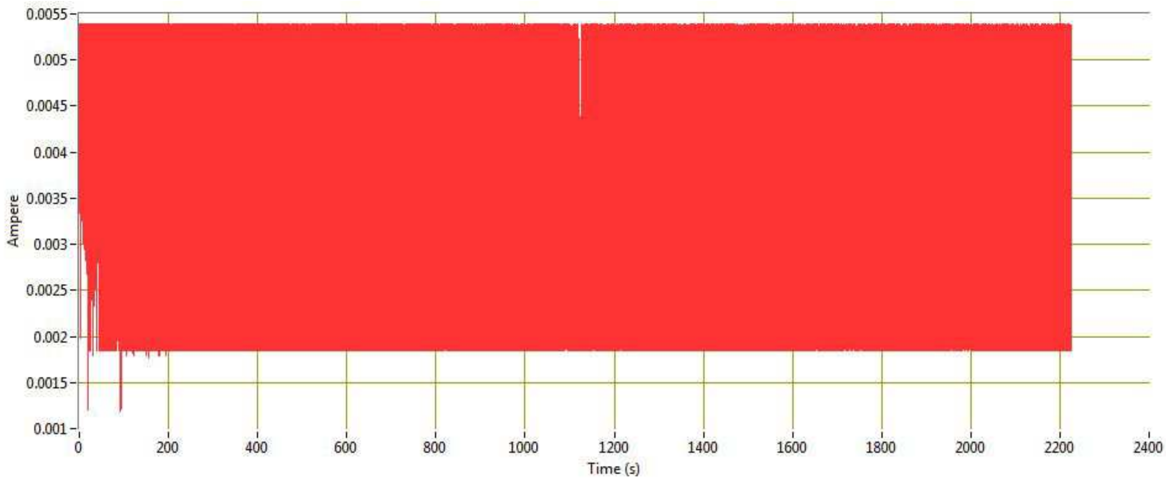


Figure A-6: Run No. 6 supply current monitoring

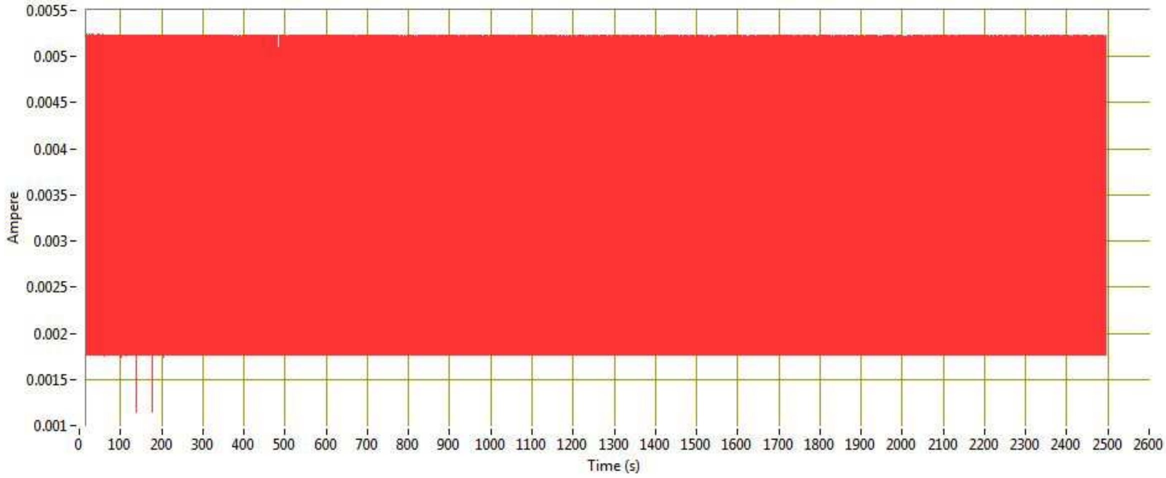


Figure A-7: Run No. 7 supply current monitoring

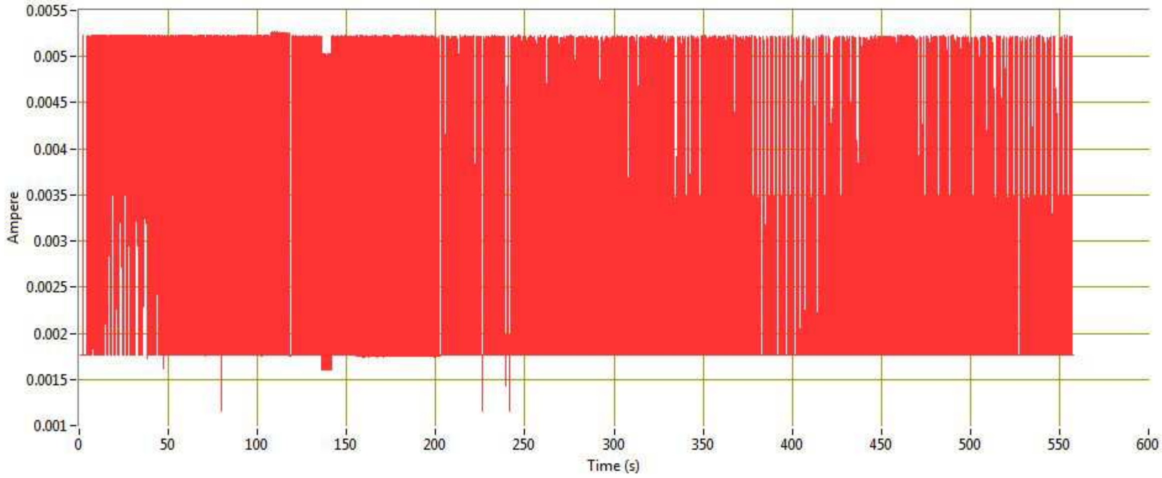


Figure A-8: Run No. 8 supply current monitoring

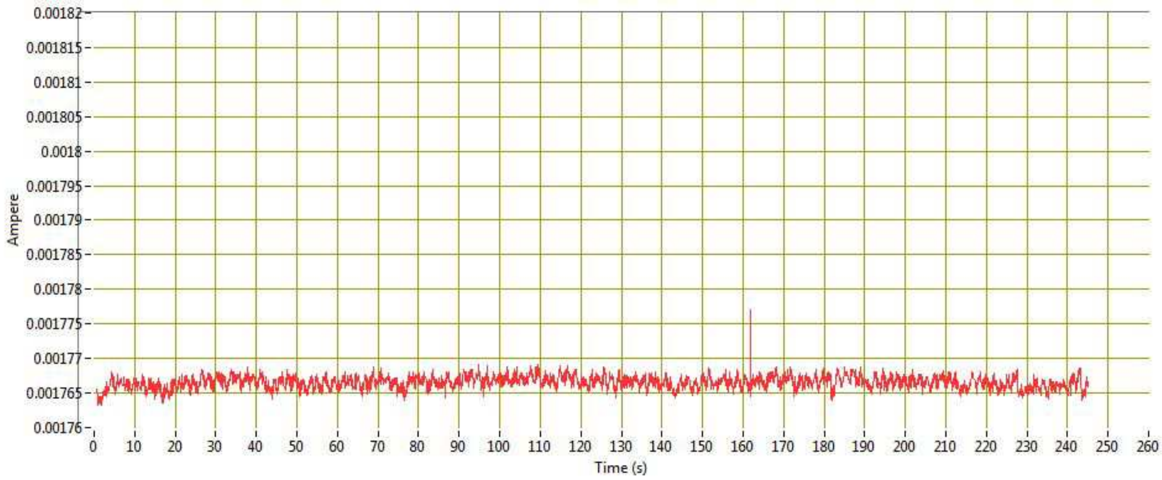


Figure A-9: Run No. 9 supply current monitoring

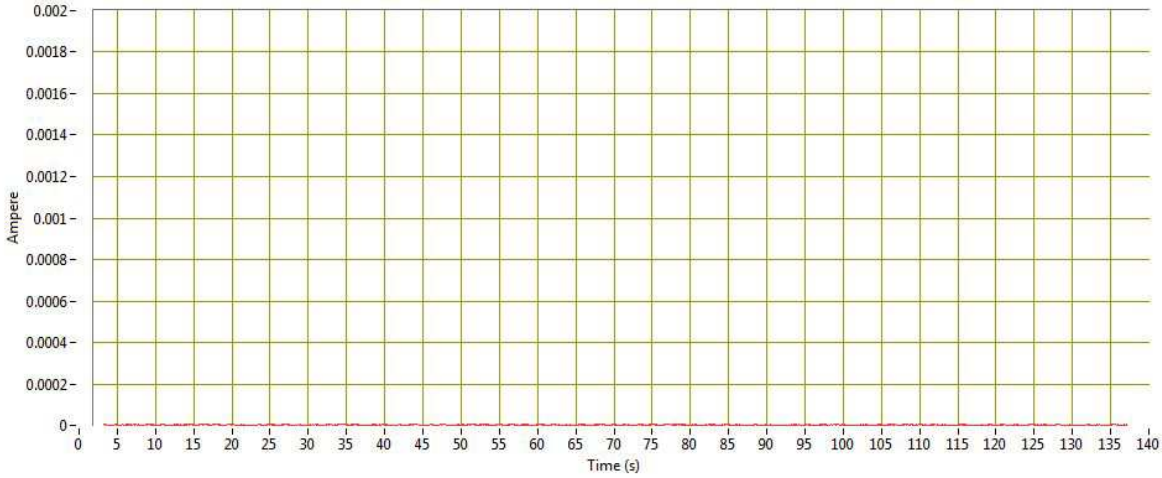


Figure A-10: Run No. 10 supply current monitoring

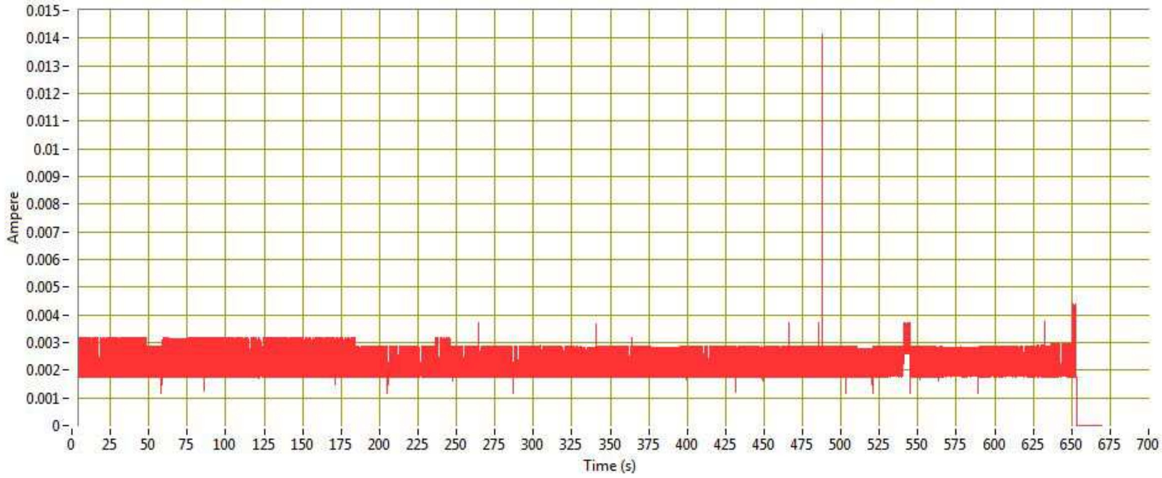


Figure A-11: Run No. 11 supply current monitoring

Figure A-12: Run No. 12 supply current monitoring

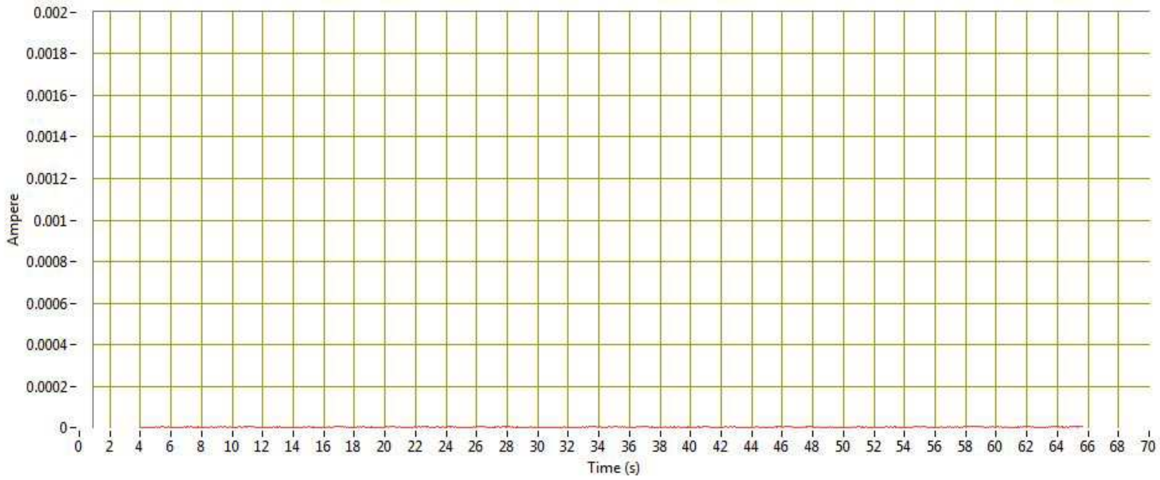


Figure A-13: Run No. 13 supply current monitoring

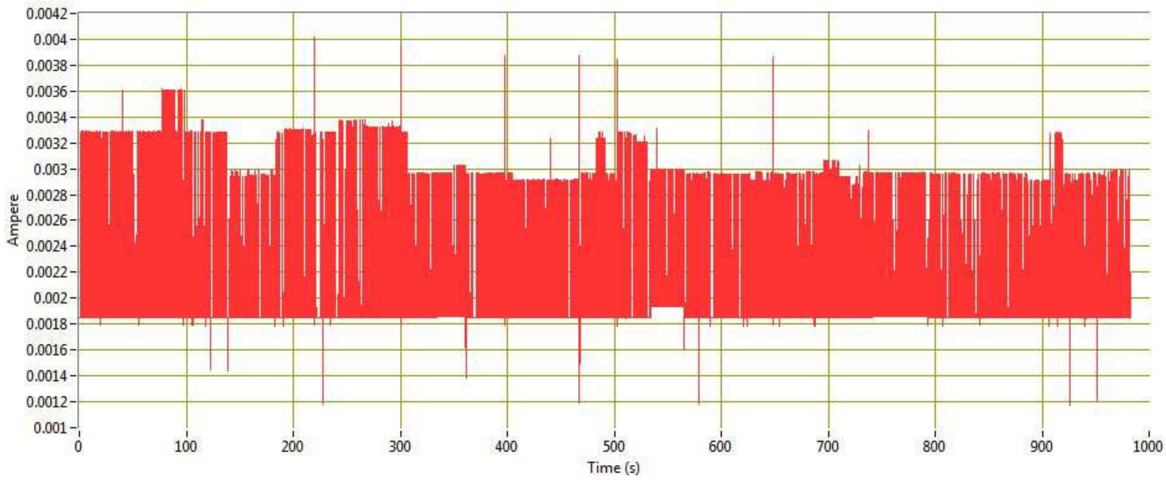


Figure A-14: Run No. 14 supply current monitoring

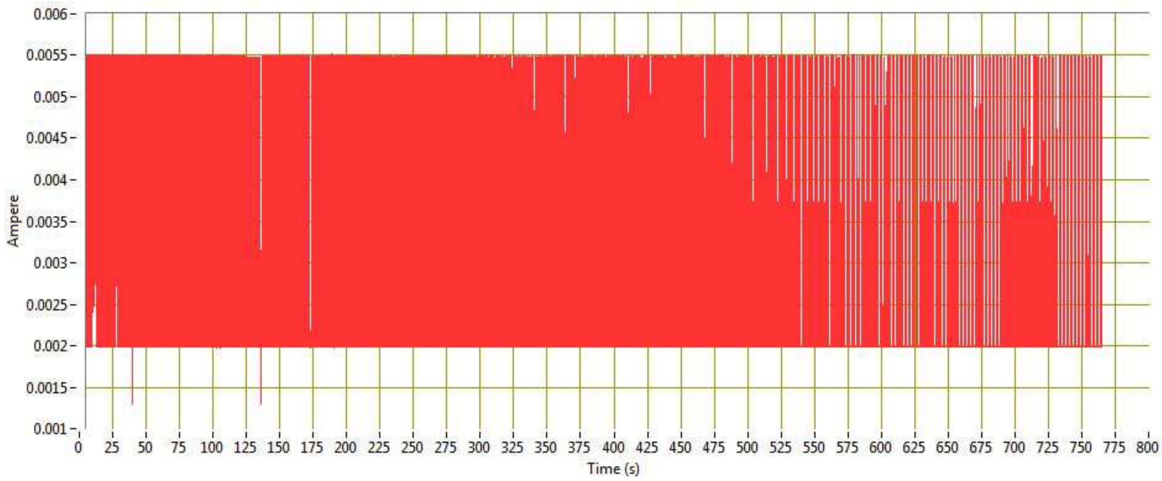


Figure A-15: Run No. 15 supply current monitoring

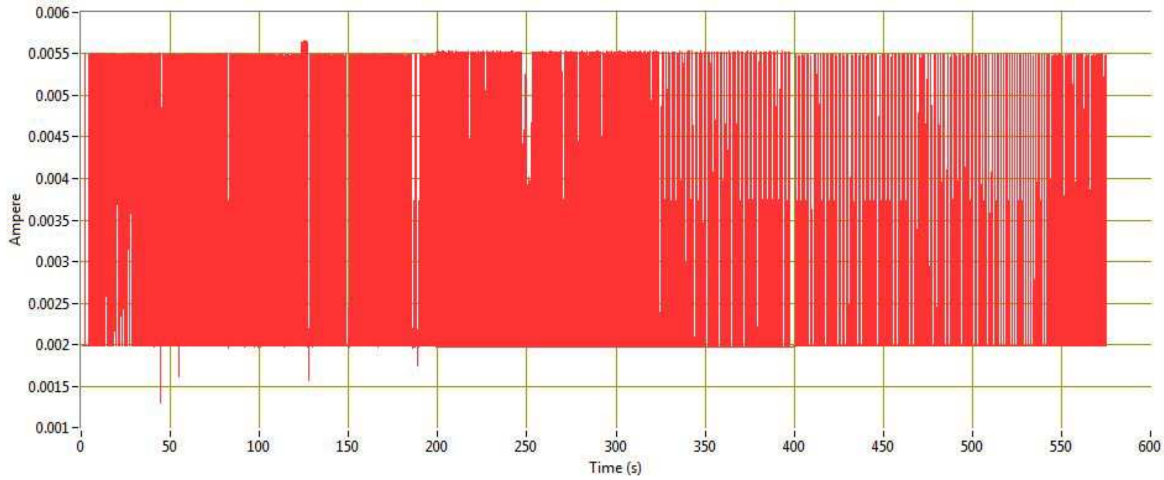


Figure A-16: Run No. 16 supply current monitoring

Figure A-17: Run No. 17 supply current monitoring

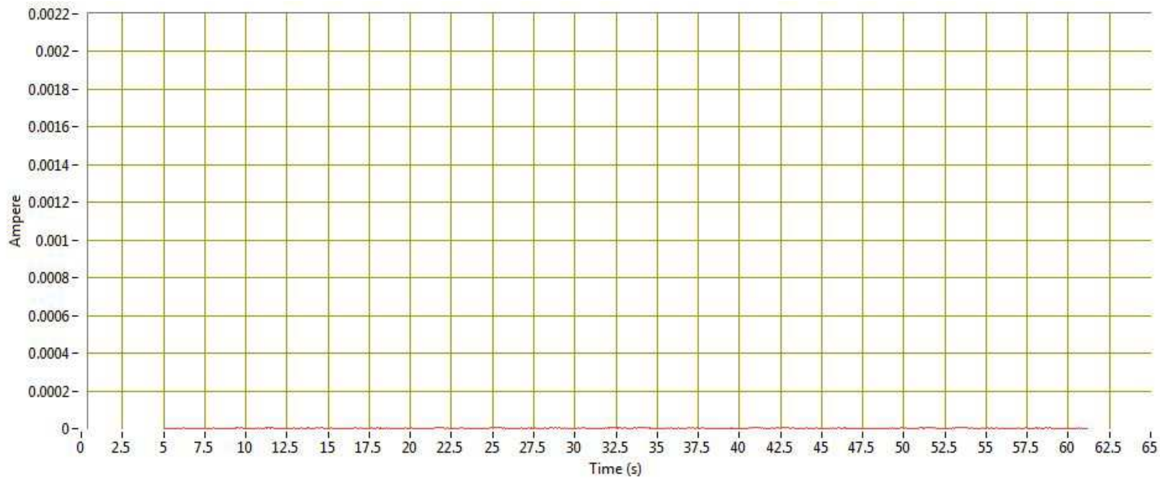


Figure A-18: Run No. 18 supply current monitoring

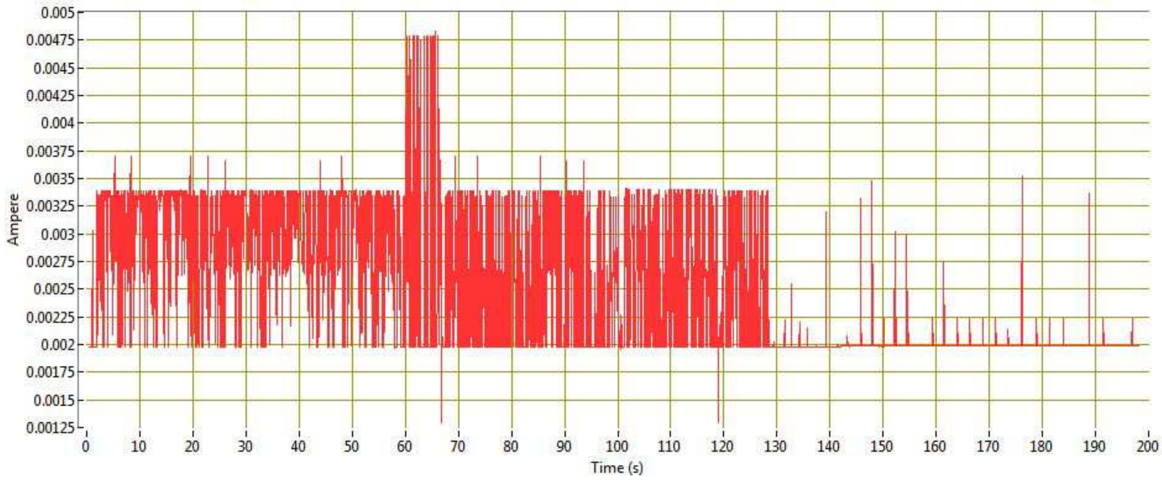


Figure A-19: Run No. 19 supply current monitoring

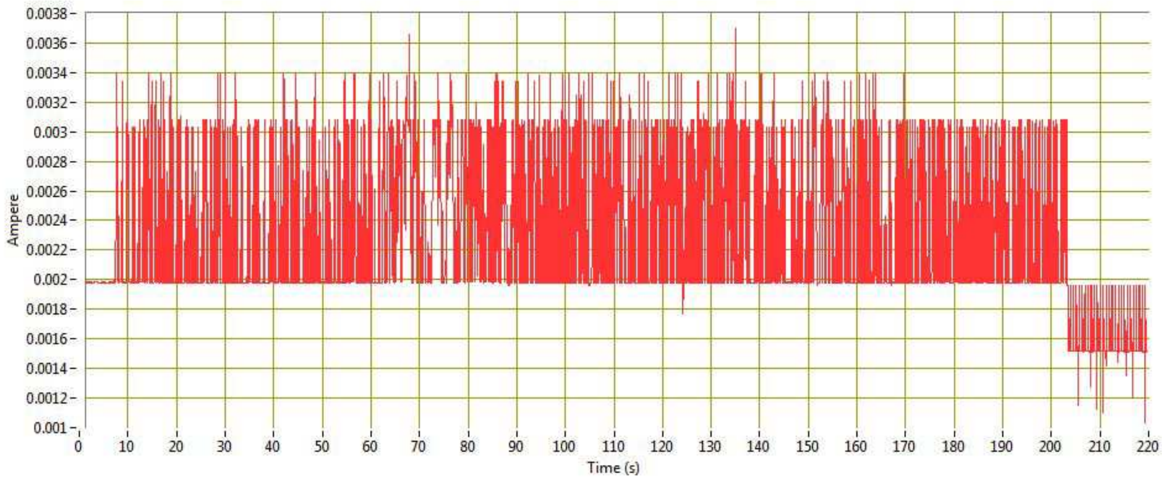


Figure A-20: Run No. 20 supply current monitoring

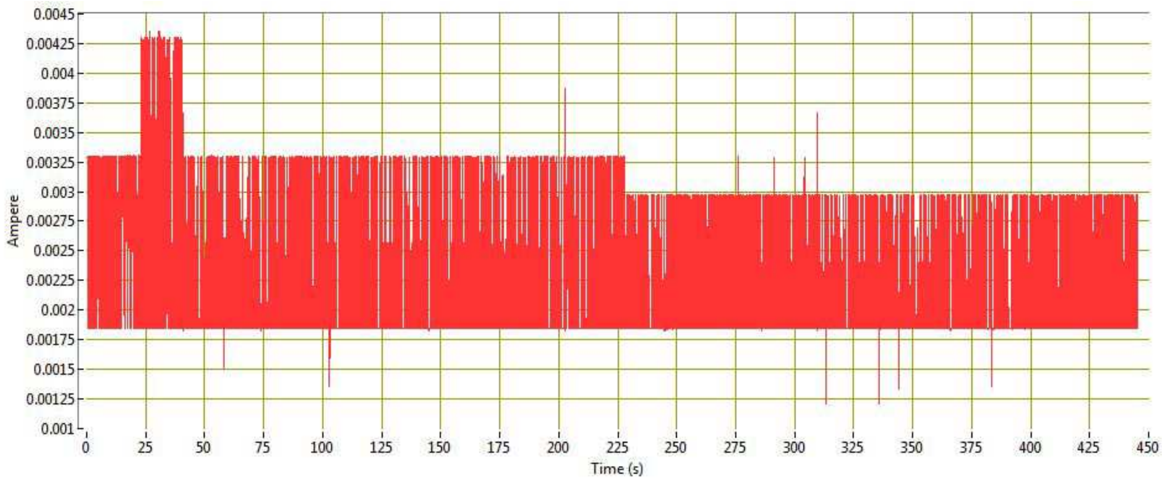


Figure A-21: Run No. 21 supply current monitoring

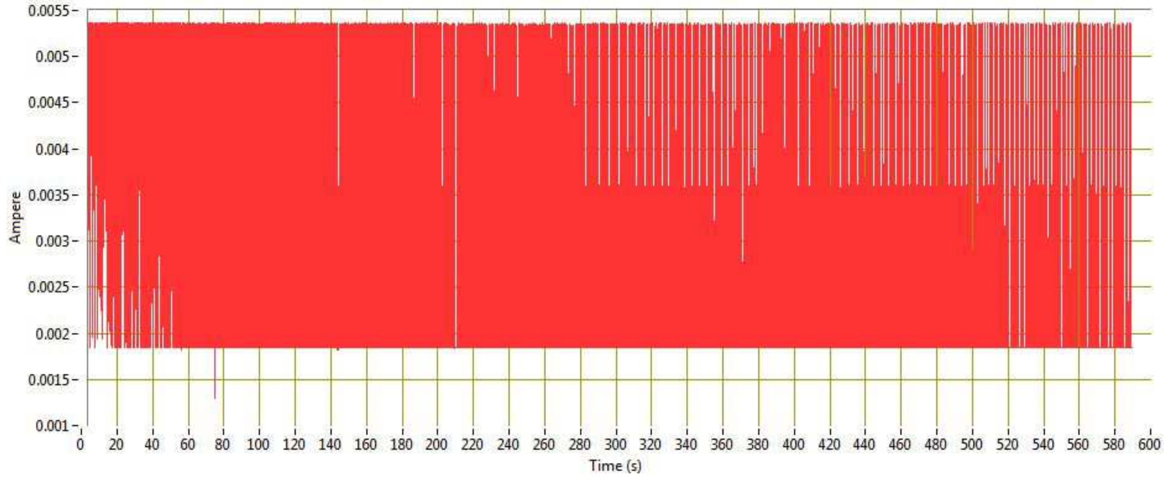


Figure A-22: Run No. 22 supply current monitoring

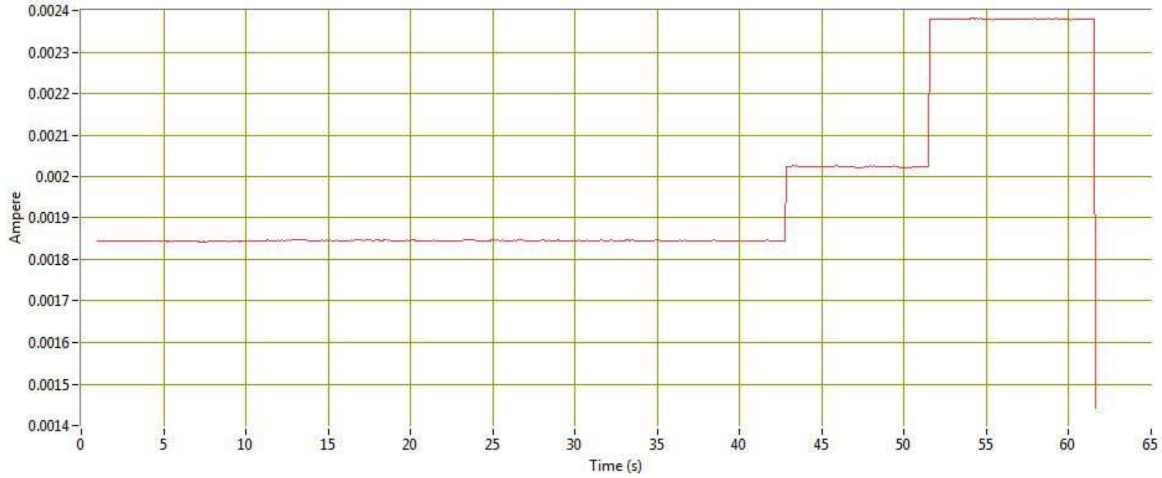


Figure A-23: Run No. 23 supply current monitoring

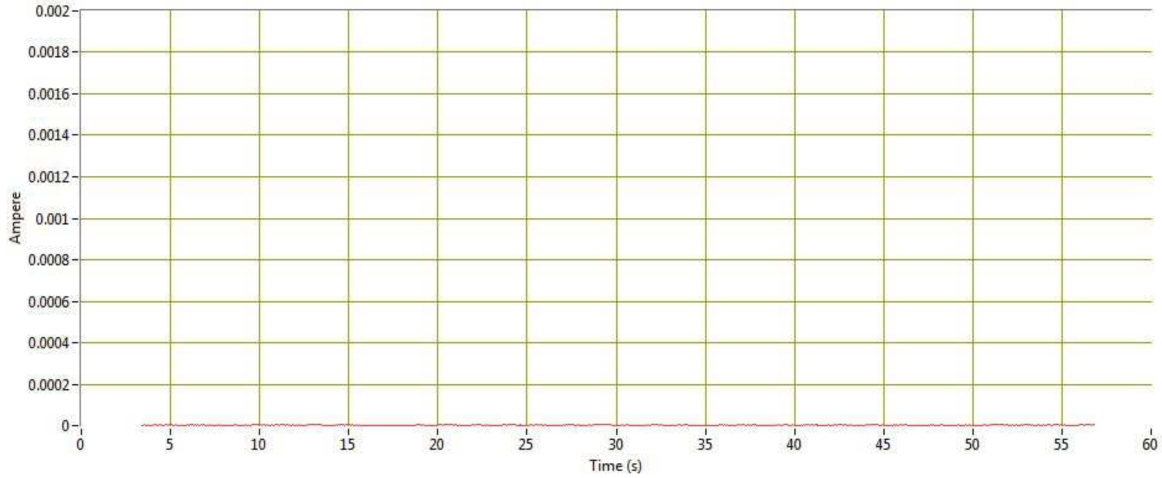


Figure A-24: Run No. 24 supply current monitoring

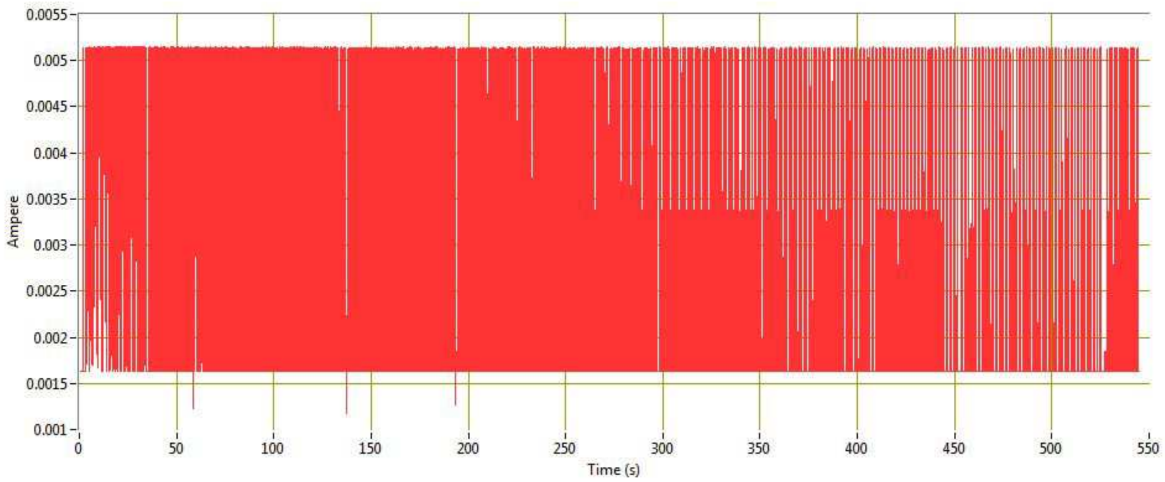


Figure A-25: Run No. 25 supply current monitoring

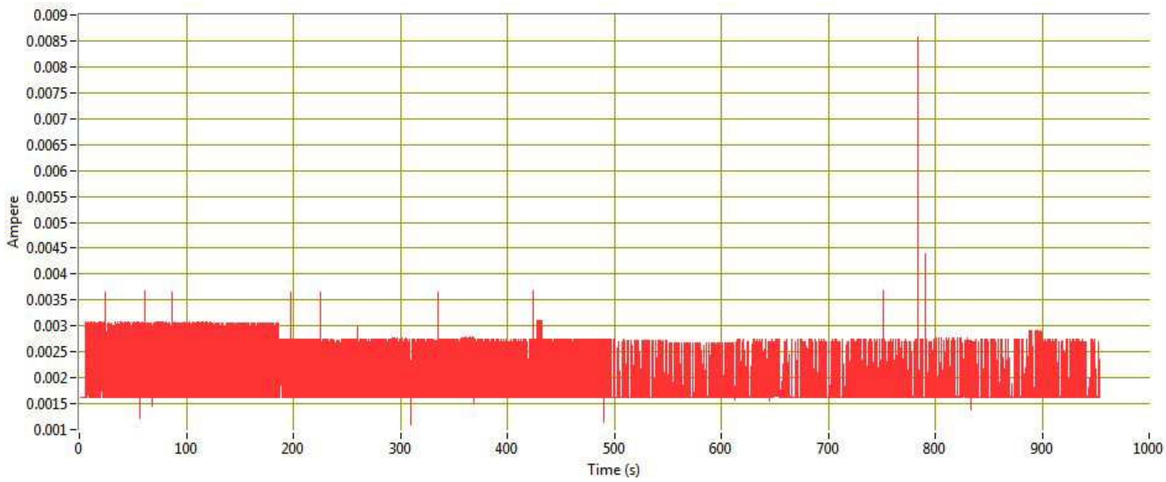


Figure A-26: Run No. 26 supply current monitoring

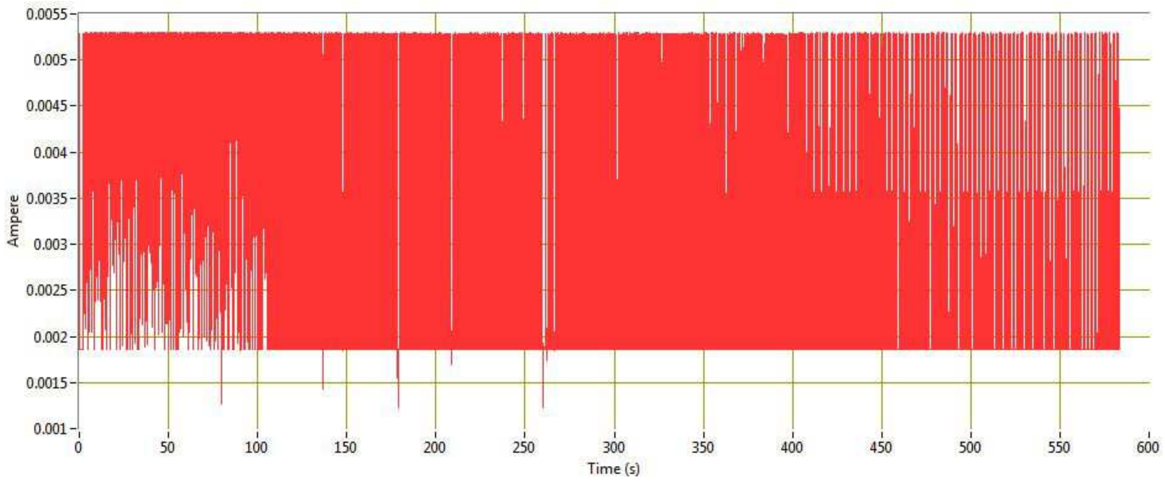


Figure A-27: Run No. 27 supply current monitoring

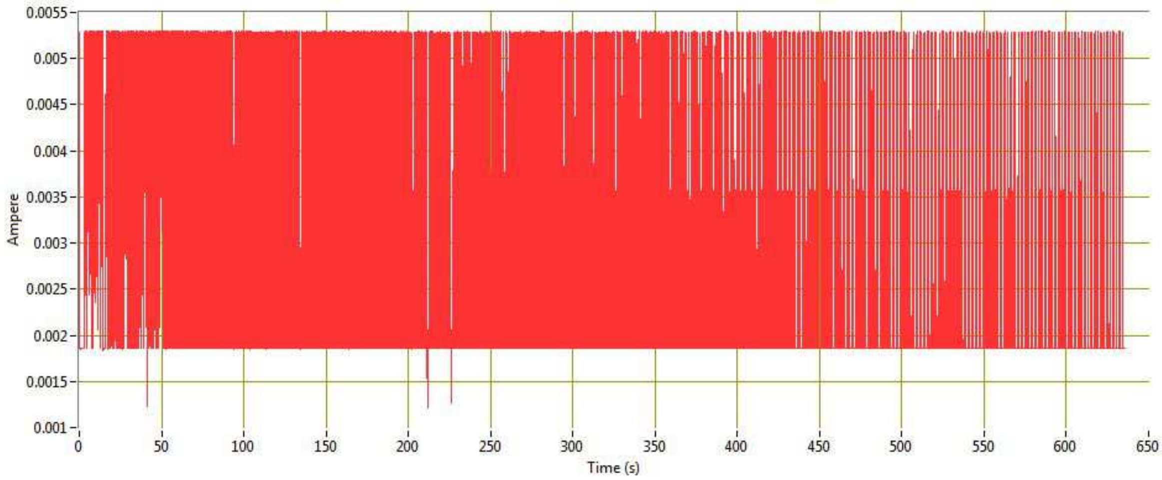


Figure A-28: Run No. 28 supply current monitoring

Figure A-29: Run No. 29 supply current monitoring

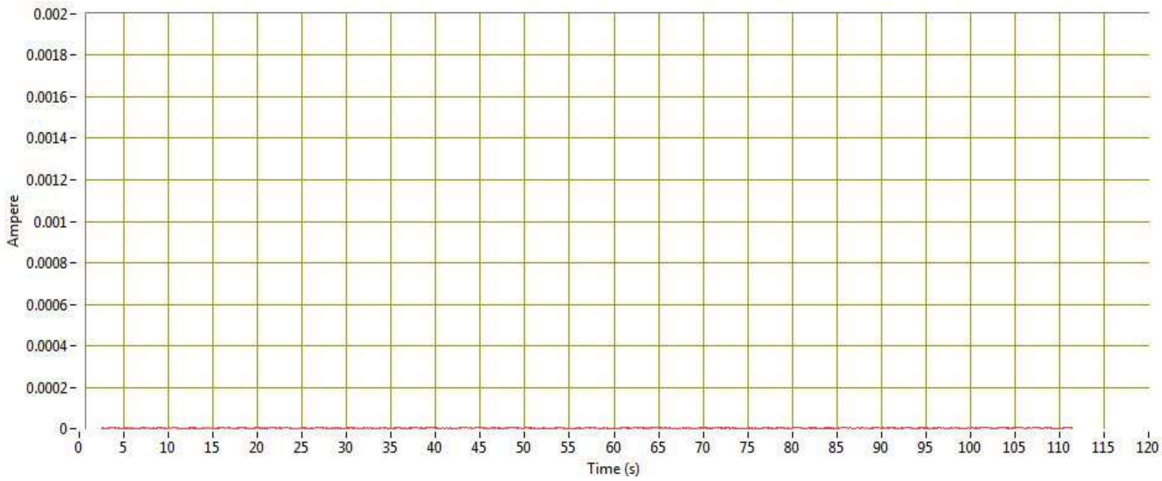


Figure A-30: Run No. 30 supply current monitoring

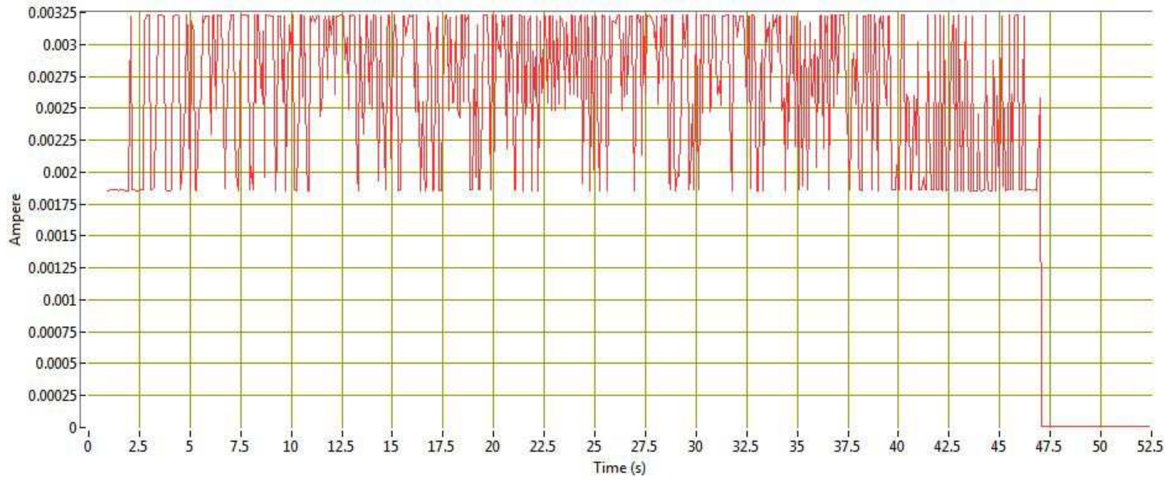
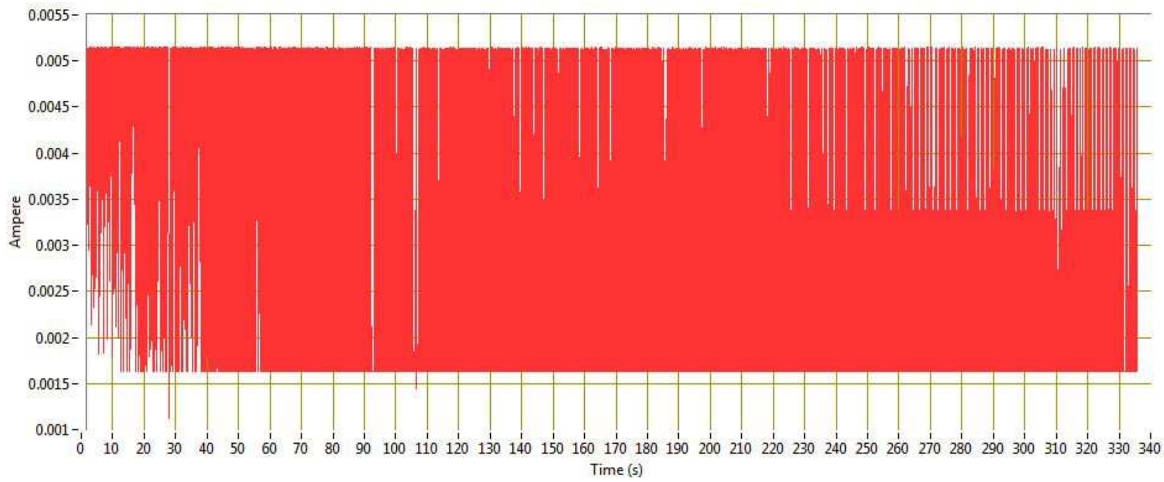


Figure A-31: Run No. 31 supply current monitoring



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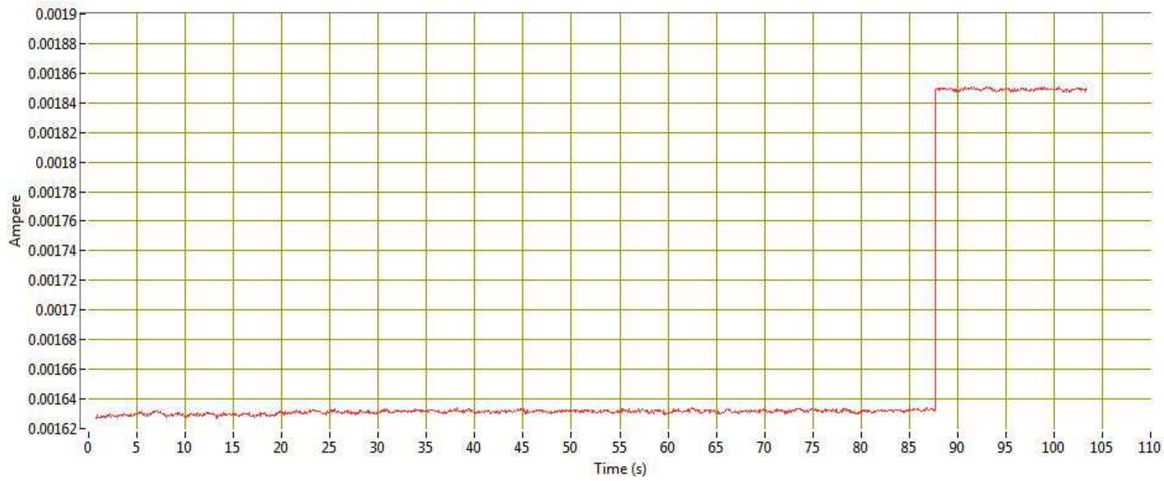


Figure A-33: Run No. 33 supply current monitoring

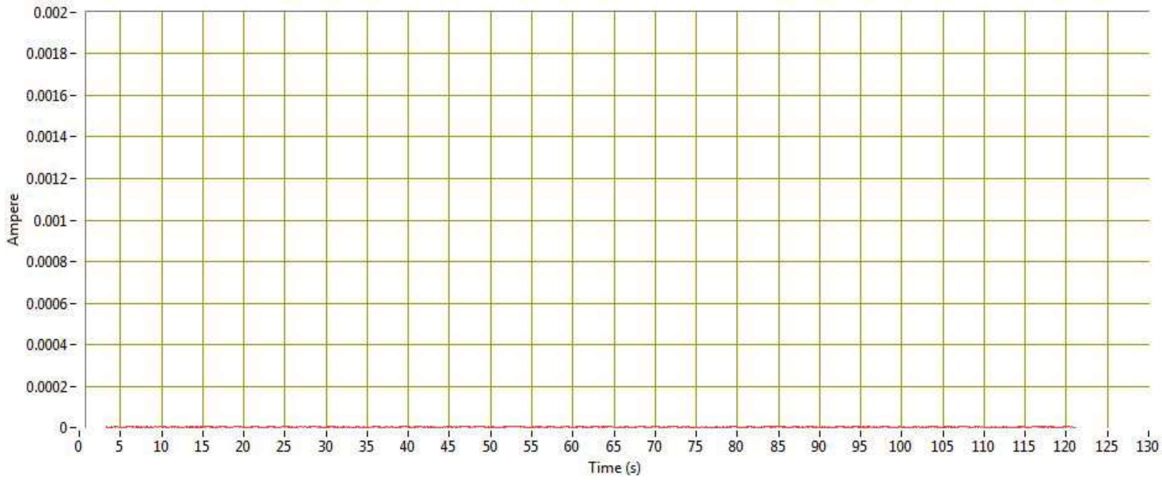


Figure A-34: Run No. 34 supply current monitoring

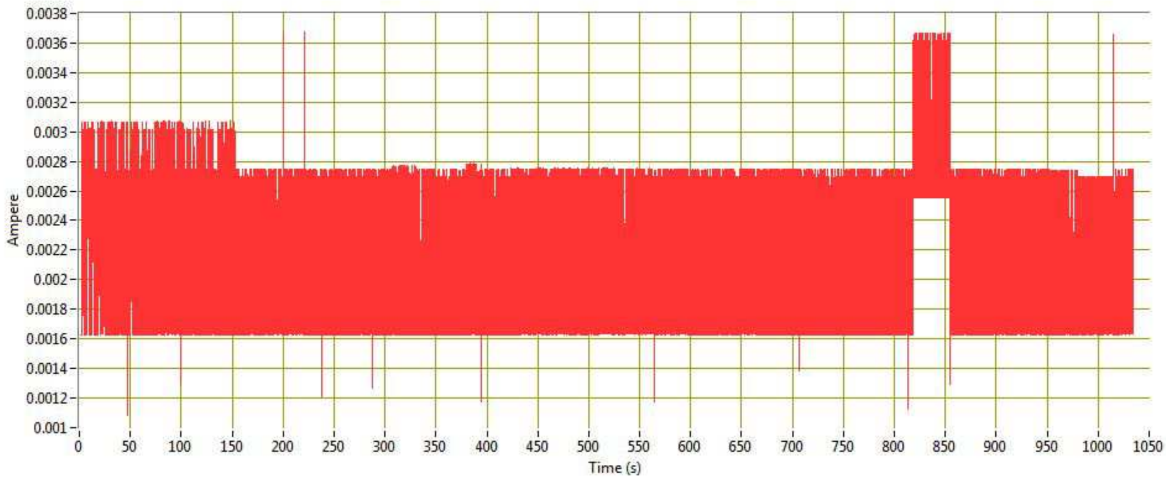


Figure A-35: Run No. 35 supply current monitoring

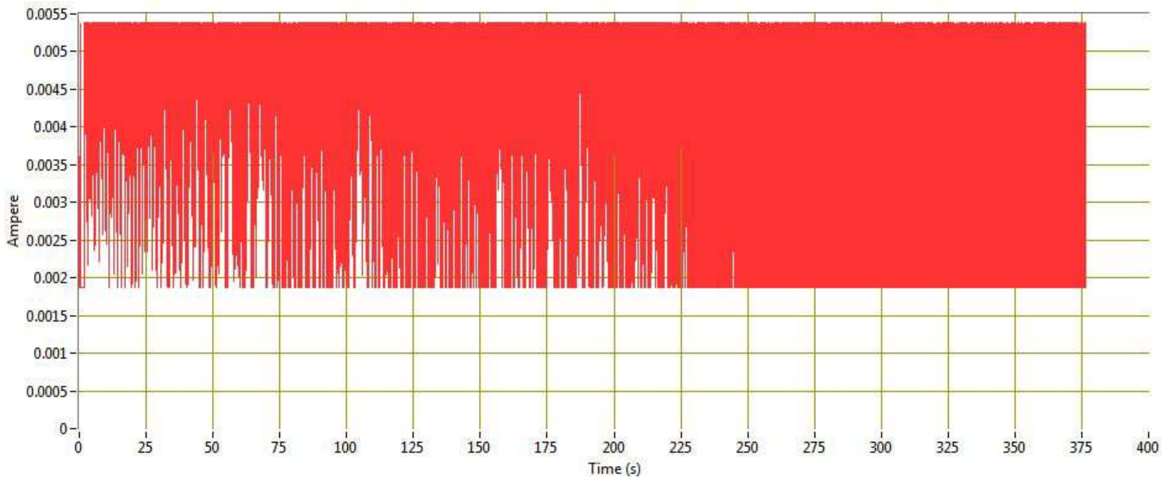


Figure A-36: Run No. 36 supply current monitoring

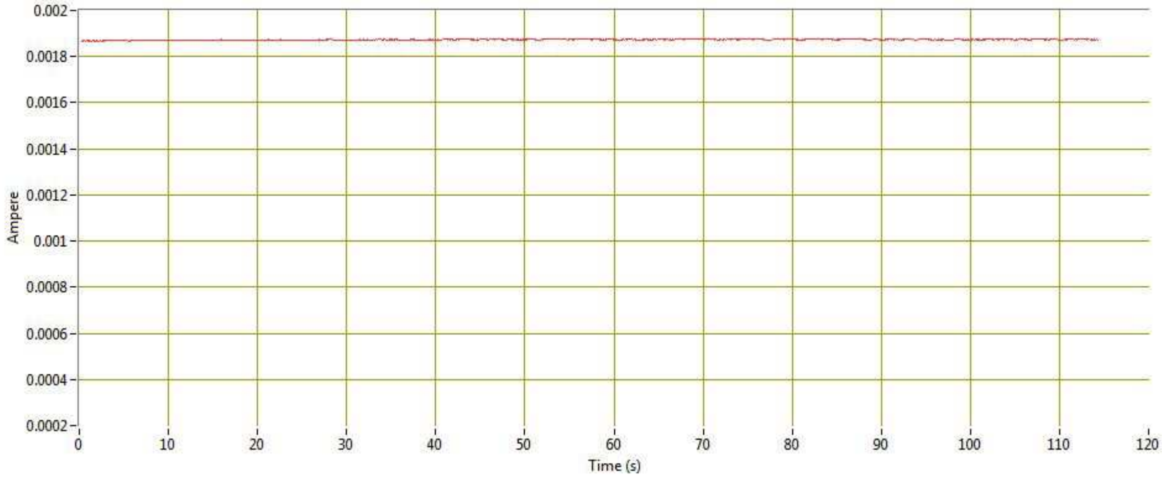


Figure A-37: Run No. 37 supply current monitoring

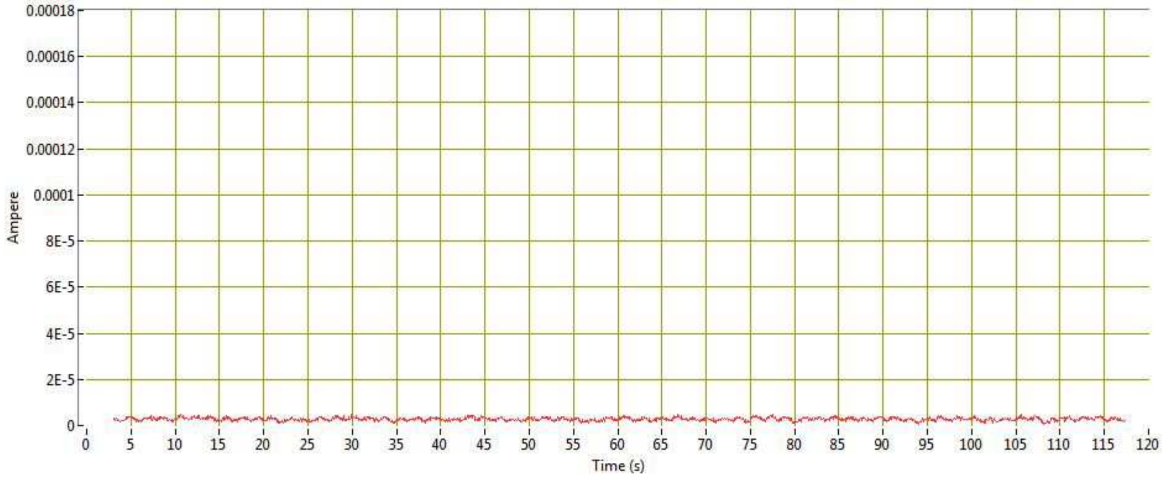


Figure A-38: Run No. 38 supply current monitoring

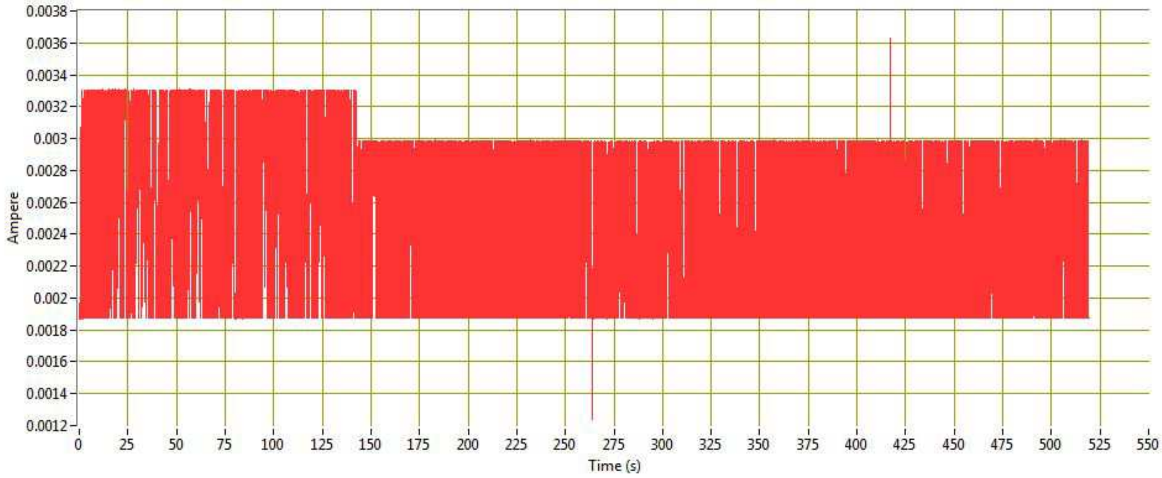


Figure A-39: Run No. 39 supply current monitoring

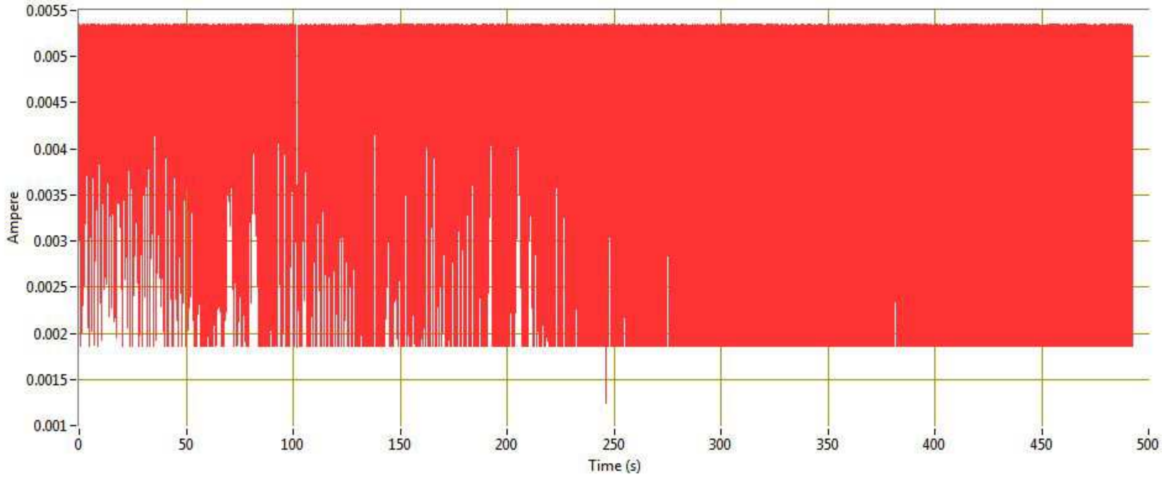


Figure A-40: Run No. 40 supply current monitoring

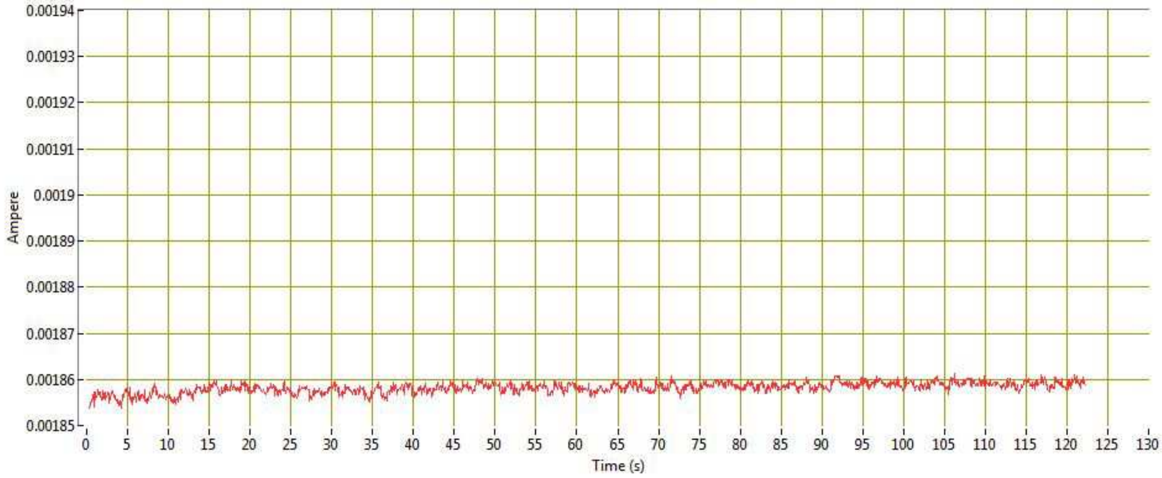


Figure A-41: Run No. 41 supply current monitoring

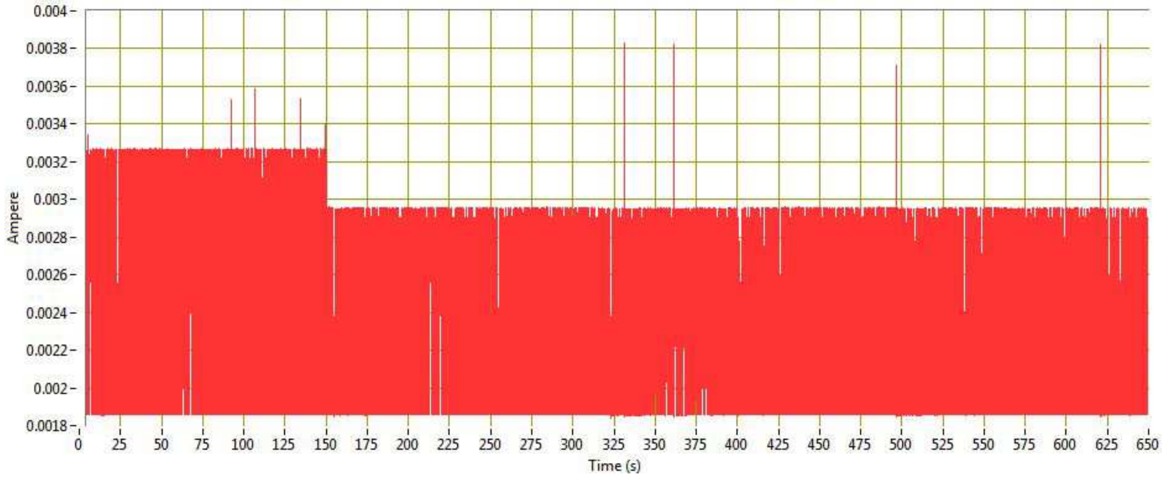


Figure A-42: Run No. 42 supply current monitoring

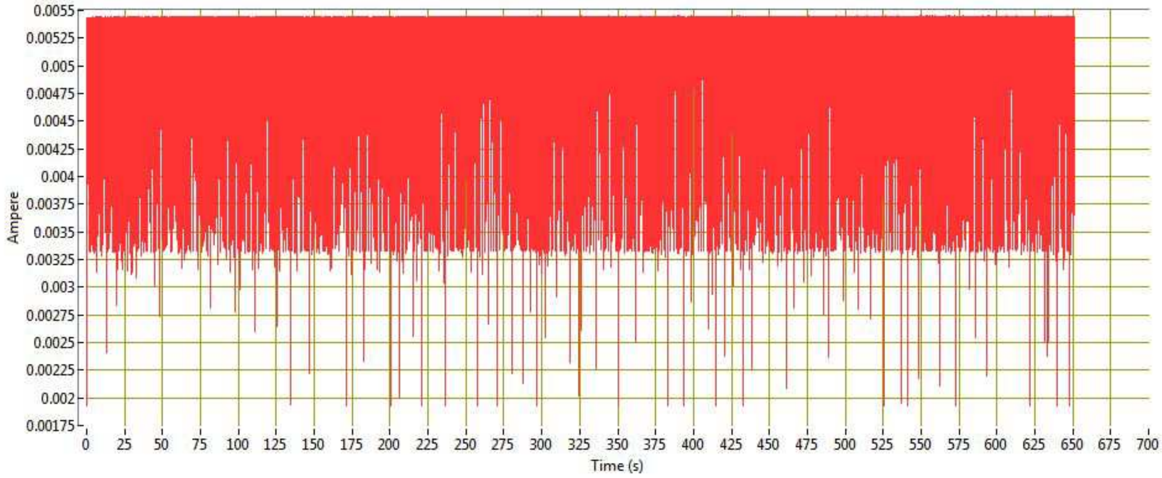


Figure A-43: Run No. 43 supply current monitoring

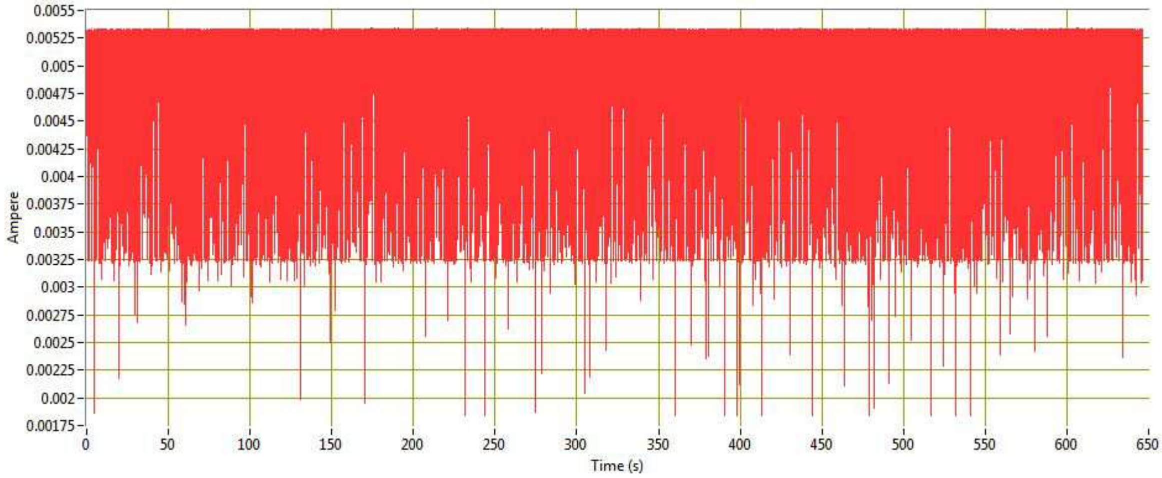


Figure A-44: Run No. 44 supply current monitoring

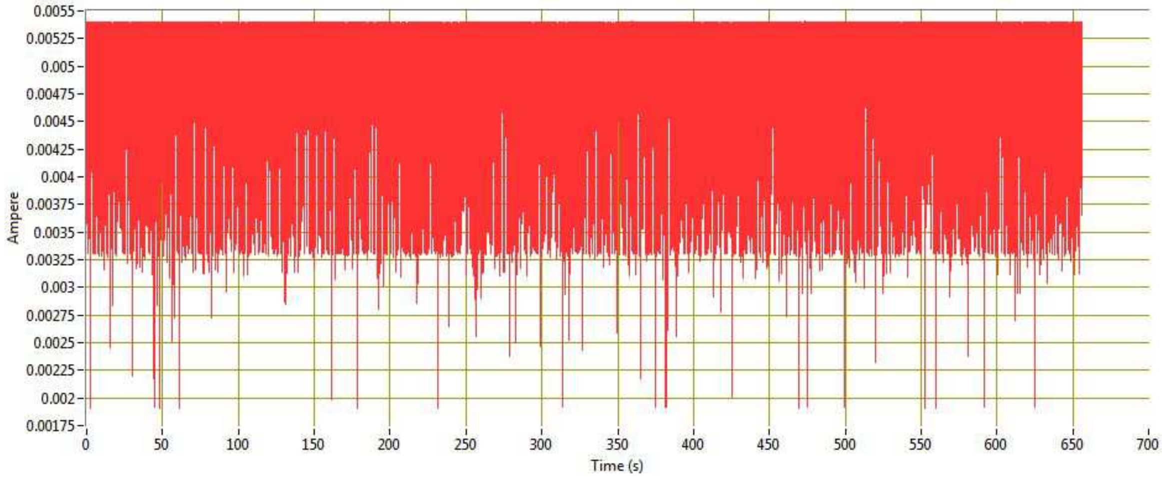


Figure A-45: Run No. 45 supply current monitoring

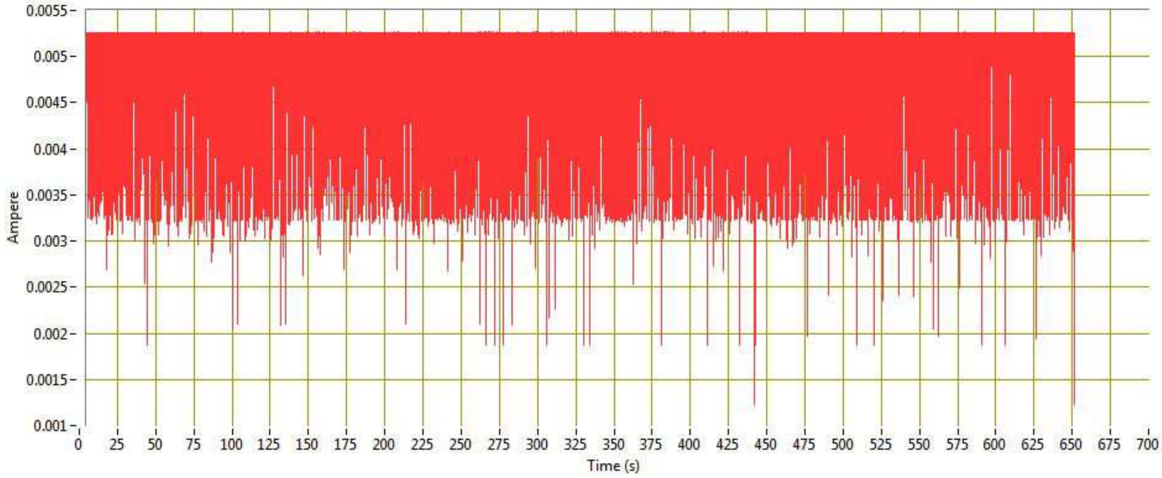


Figure A-46: Run No. 46 supply current monitoring

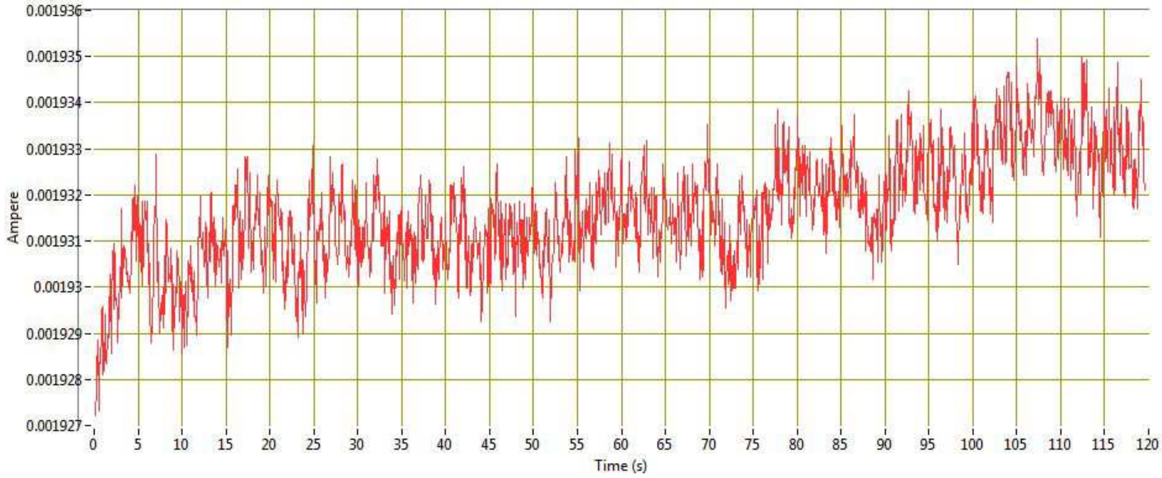


Figure A-47: Run No. 47 supply current monitoring

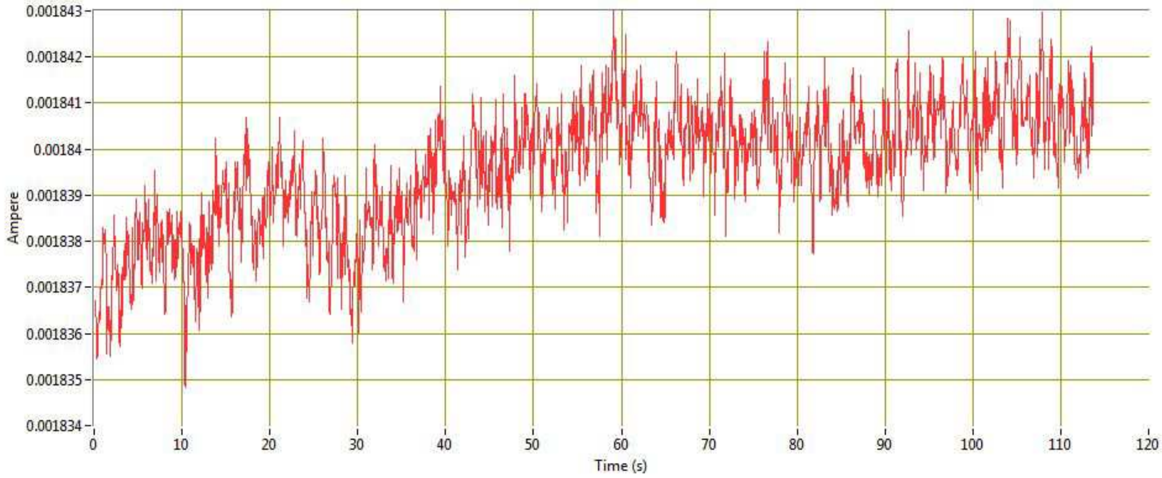


Figure A-48: Run No. 48 supply current monitoring

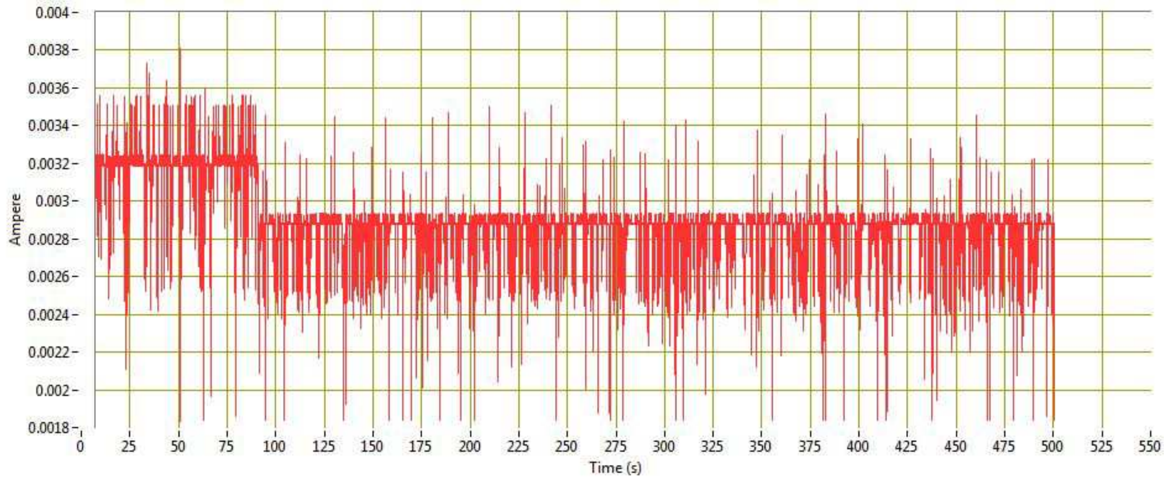


Figure A-49: Run No. 49 supply current monitoring

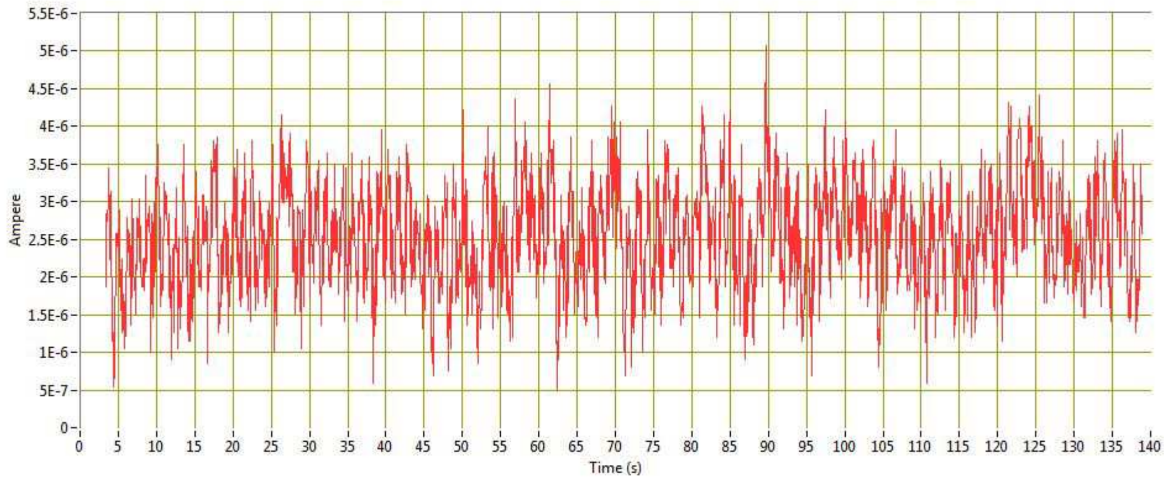


Figure A-50: Run No. 50 supply current monitoring

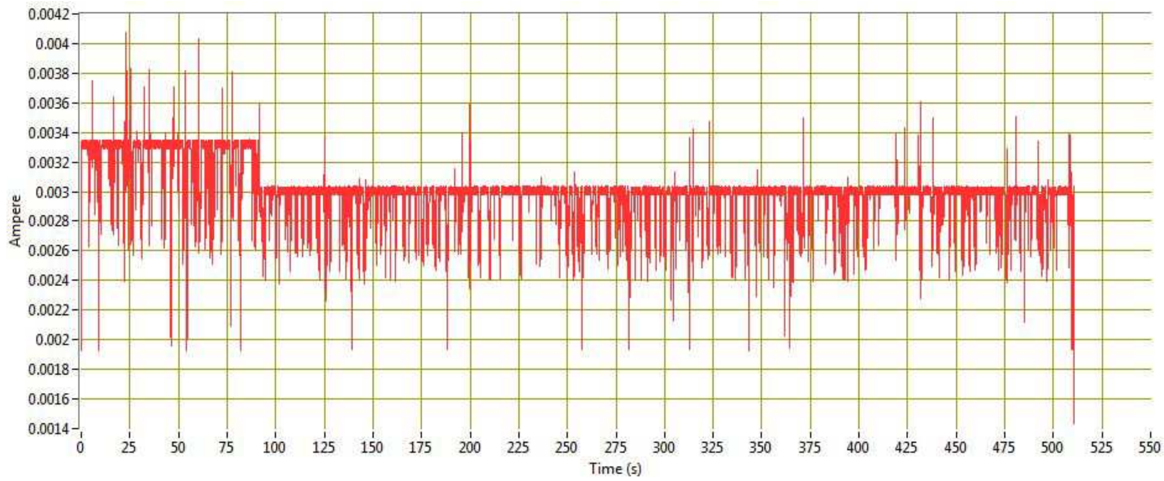


Figure A-51: Run No. 51 supply current monitoring

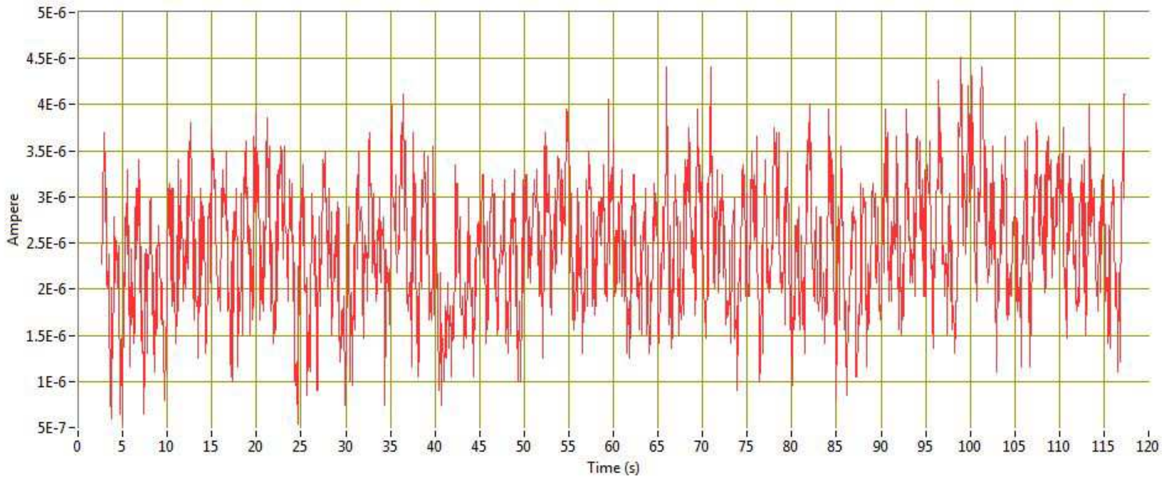


Figure A-52: Run No. 52 supply current monitoring

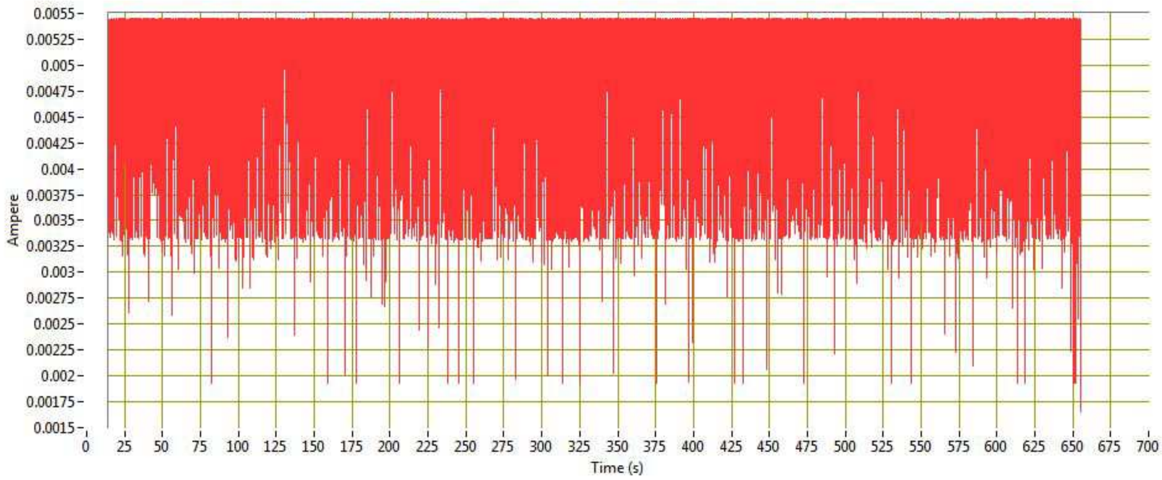
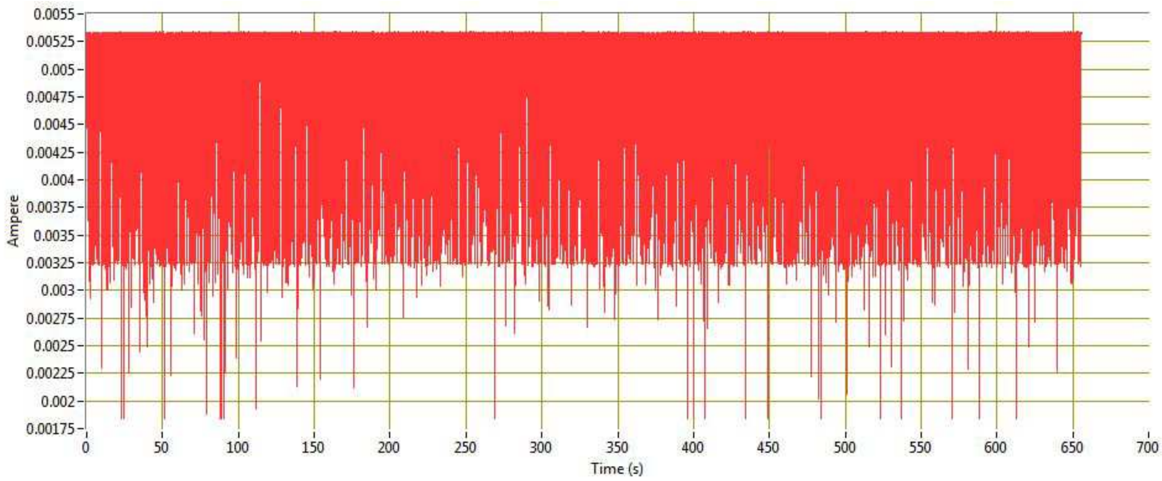


Figure A-53: Run No. 53 supply current monitoring



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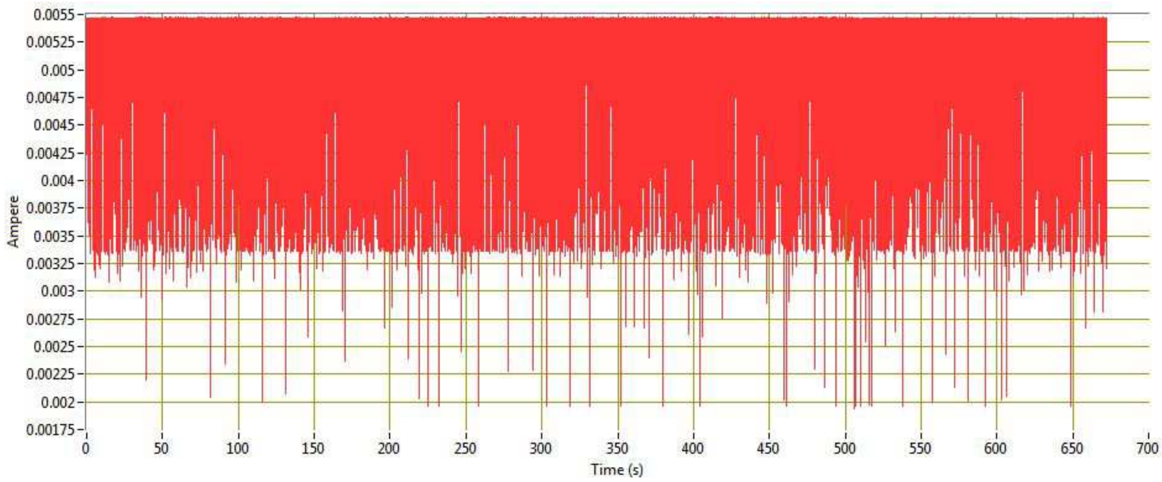

Figure A-55: Run No. 55 supply current monitoring

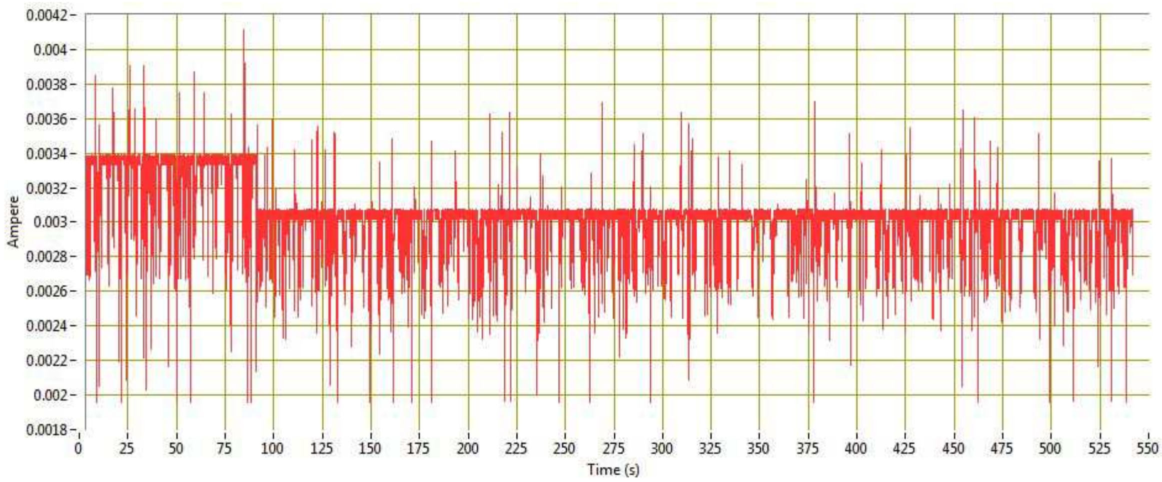

Figure A-56: Run No. 56 supply current monitoring

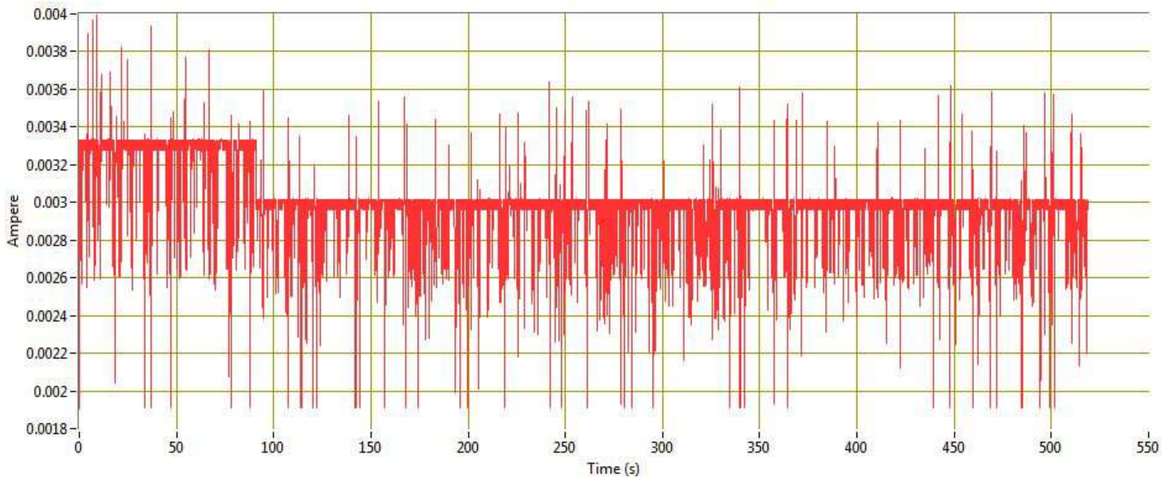

Figure A-57: Run No. 57 supply current monitoring

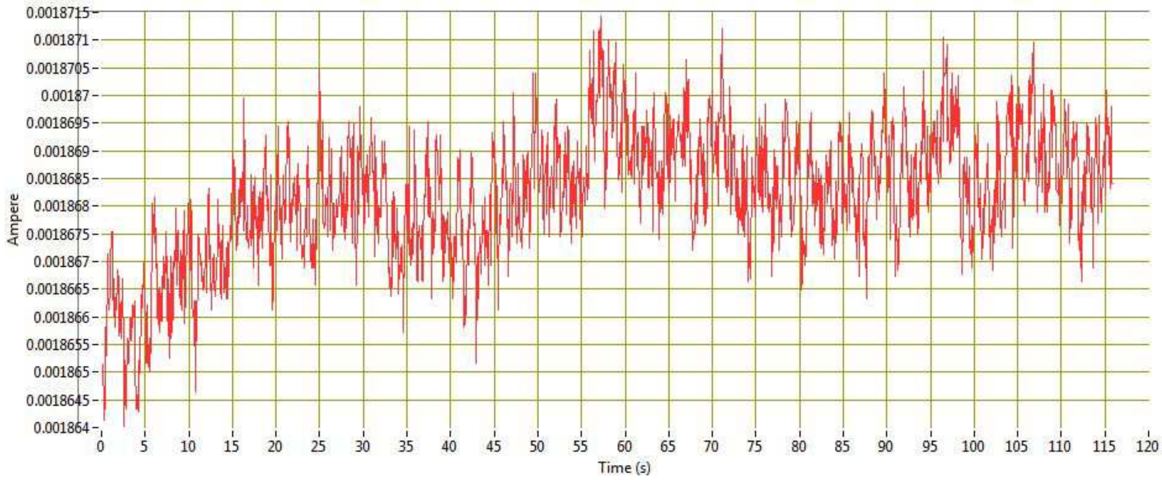

Figure A-58: Run No. 58 supply current monitoring

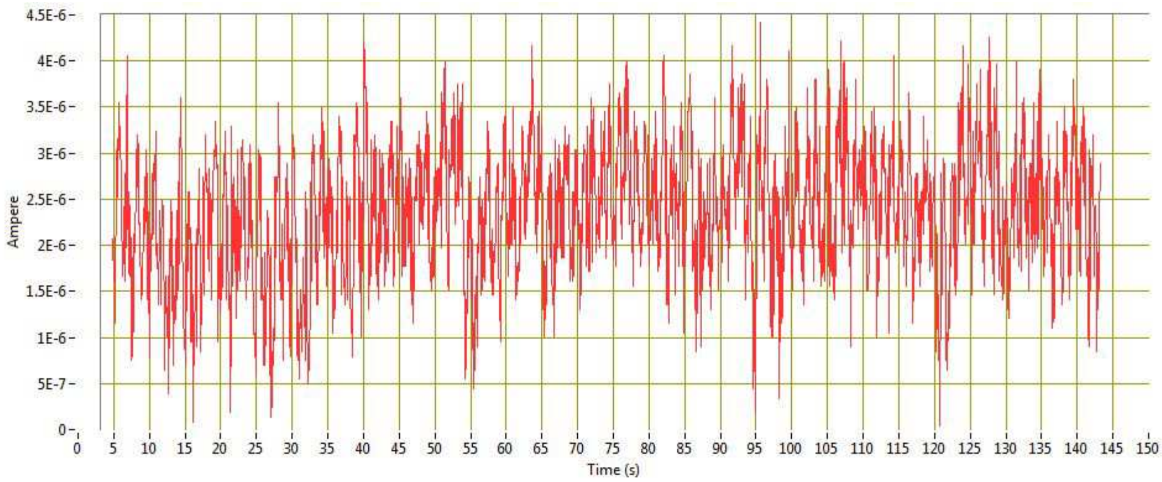

Figure A-59: Run No. 59 supply current monitoring

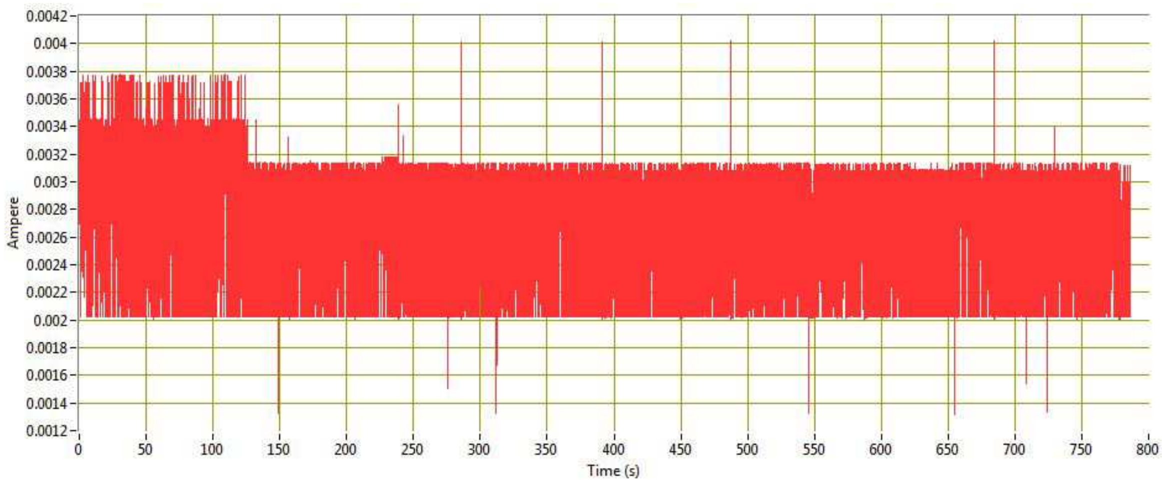

Figure A-60: Run No. 60 supply current monitoring

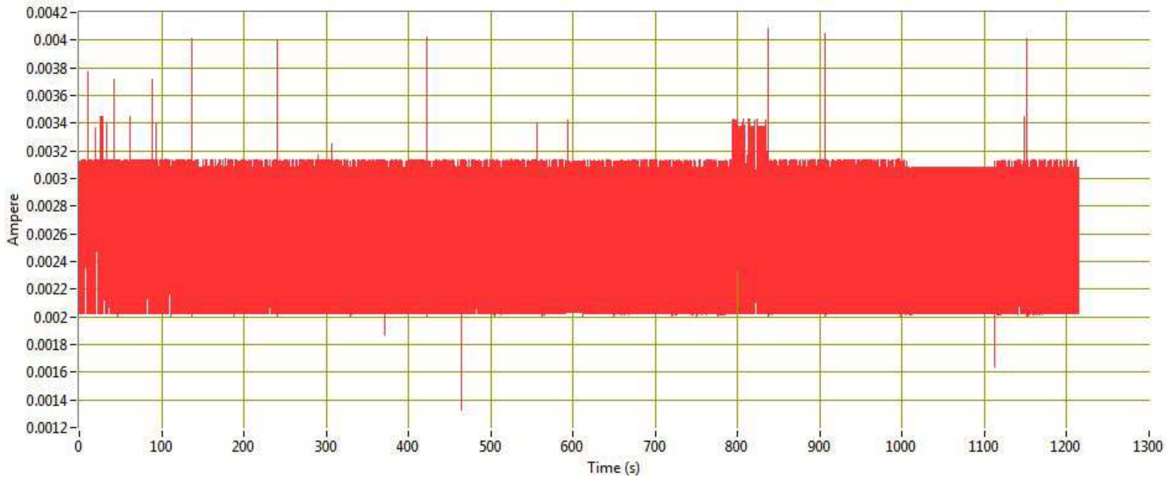

Figure A-61: Run No. 61 supply current monitoring