HIREL EXPERTISE HIREX ENGINEERING

# ESA-QCA0004S-C

## RADIATION TEST REPORT

**Heavy Ions Testing of**

**RH1078**

**Dual, Single Supply,**

**Precision Op Amp**

**from Linear Technology**

ESA Purchase Order No 181635 dated 13/08/98

European Space Agency Contract Report

The work described in this report was done under ESA contract.
Responsibility for the contents resides in the author or organization that prepared it


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# I. INTRODUCTION

This report presents the results of a heavy ion Single Event Effects (SEEs) test program carried out for the XMM project on Linear technology RH1078 Dual,Single Supply, Precision Op Amp. Hirel devices were tested at the European Heavy Ion Irradiation Facility (HIF) at Cyclone, Université Catholique de Louvain, Belgium.
The main aims of these tests were to assess the RH1078 susceptibility to Single Event Upsets (SEUs) using :

(a) a test configuration equivalent to TERMA design used on XMM: In this application, an over-voltage protection is realized using the two DUT amplifiers. First one is used as the limit comparator while the second one forms a bistable latch which can power off the supply. In SEE testing configuration, a time delay circuit allows for automatic reset. Furthermore, thanks to a relay switch, it was possible to assess the efficiency of a add-on capacitor transient filter to prevent subsequent latching.

(b) a component oriented test configuration, i.e. as a stand-alone Closed Loop Amplifier.

Tests were performed in such a way that the SEU cross sections can be plotted over a wide LET range in order to allow computation of the SEU rates in XMM orbit.

This work was performed for ESA/ESTEC under Purchase Order No 181635 dated 13/08/98.

# II. APPLICABLE DOCUMENTS

The following documents are applicable:

- XMM SOW QCA/RHS-98XMM01.DOC July 98, Issue 0 (e-mail dated June 25, 98), Radiation SEE Testing of RH1078M, LM139, UC1842 and UC1707 for XMM.
- Proposal for SEE Testing of RH1078M, LM139, UC1842, UC1707 for XMM - Hirex Doc No HRX/98.3568 Issue 1, dated July 2, 1998 -

## II.1 REFERENCE DOCUMENTS

- Linear Technology, RH1078 data sheet.
- Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100
- The Heavy Ion Irradiation Facility at CYCLONE, UCL document, Centre de Recherches du Cyclotron (IEEE NSREC'96, Workshop Record, Indian Wells, California, 1996)

## III. DEVICE INFORMATION

### III.1 DEVICE DESCRIPTION

Dual, single supply, precision Op Amp.

### III.2 PROCUREMENT OF TEST SAMPLES

5 hirel samples have been procured by ESA.

### III.3 PREPARATION OF SAMPLES

3 devices with the following numbers #008, #009, #215have been delidded by ESA. No sample has been mechanically damaged during this operation.

### III.4 SAMPLES CHECK OUT

A functional test sequence has been performed on delidded samples to check that devices have not been degraded by the delidding operation.

### III.5 DEVICE DESCRIPTION

Description of the devices is as follows:

| | |
|---|---|
| Part type : | RH1078 |
| Manufacturer : | Linear Technology |
| Package : | Cerdip DIL-8 |
| Quality Level : | Hirel |
| Date Code : | 9638A |
| Serial Number : | #008, #009, #215, #217, #336 |
| Die Technology : | Bipolar |
| Top Marking: | XMIG0067<br>01BR |
| Die Size : | 2.45 mm x 2.25 mm approximately |
| Die Marking : | 1987 |
| Tested samples : | 2 ( #008, #215) |

External and Internal Photos are shown in Figure III-1.

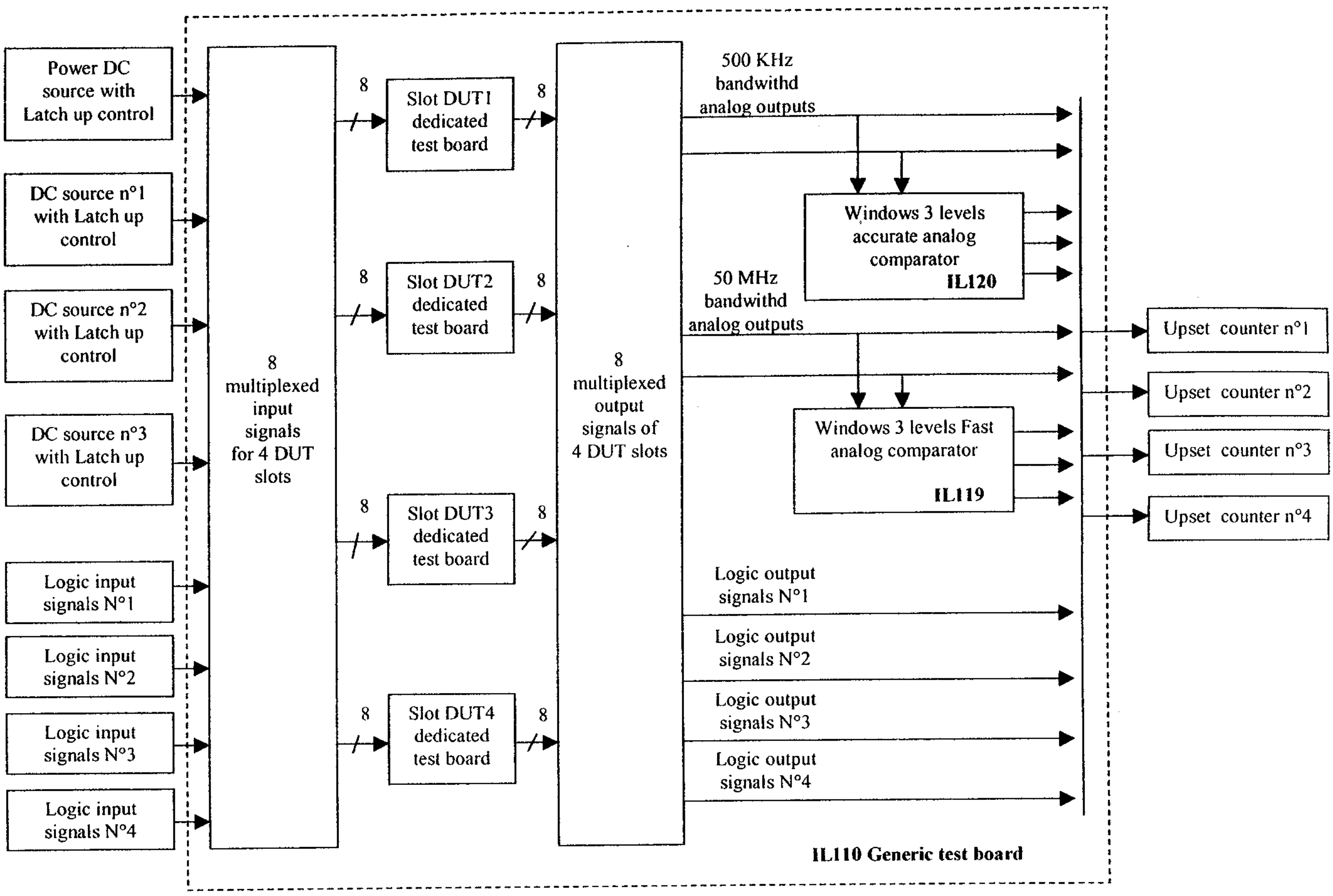



**Figure IV-2 - Mother board synoptic**

### IV.2.2 DUT Test board description

The device under test is mounted on a specific board support which is plugged onto the motherboard.
Mechanical outlines : 141 mm x 50 mm, wrapping or printed circuit board with two 20 pins connectors.
According to test set up and device operating conditions, the test board can accept the mounting of :

- The DUT package with beam positioning constraints ( unique for Louvain facilities)
- The golden chip
- The pattern generator
- any interface circuit such as buffer, latches ...
- a standalone micro controller if necessary...

Note : Beam focus diameter is limited to maximum 25 mm, to prevent the exposure of others devices which might be sensitive.

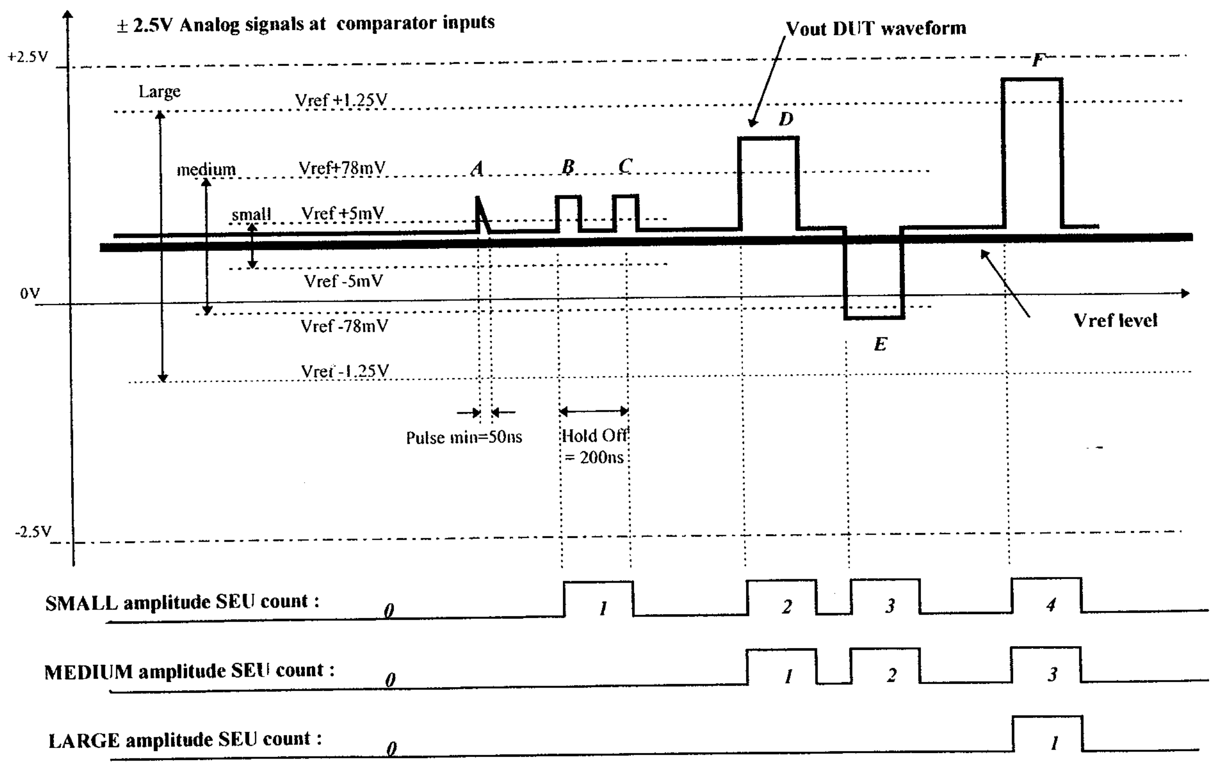
## IV.2.3 Three Windows analog comparator

Each window uses pre-defined levels centered around the awaited working point :

- The SMALL window uses the lowest levels compatible with the hardware limitation ( offset, noise ...)
- The LARGE window is for counting major DUT output perturbations : Vout max /2 or DAC MSB...
- The MEDIUM window has been defined using a geometric progression between SMALL and LARGE

To illustrate how it works, the here after figure gives an example of timing diagram :
Both DUT and Ref working point can vary within the ±2.5V allowed input range (+1V in the example).
6 transient pulses can be seen on the DUT Vout record :

- Pulse A will not be counted as its width is shorter than Pulse min parameter
- Pulse B and C : Only B will be counted as the time between B and C is less than the Hold Off parameter (this prevents of multiple counting in case of large degraded transient)
- Pulse D and E : Both pulses will be counted as the comparator works whatever polarity.
- Pulse F is an example of large event . It can be noticed that a large event is also counted as a medium and a small as well.




The use of this principle allows for straightforward analysis of the test data, at run time. So, it is easy react on beam conditions and adjust to obtain proper data. When preparing the report, it also shortens the subsequent run recorded data analysis exercise.
Lastly, using 3 different levels at a time reduces the number of run needed for the device characterization

## IV.3 TEST CONFIGURATIONS

Two test configurations have been used :

- First one is equivalent to a design implemented on XMM, called "TERMA Design" in the present report, where the dual amplifier is configured as a latched command: first amplifier is used as a comparator which will trig a flip of the bistable element formed by the second amplifier, when the comparator input level exceeds a given threshold. Command re-initialization requires a power off-power-on cycle of the equipment.

- Second configuration is the amplifier function itself where the amplifier is used in a closed loop configuration with a large differential gain.

### IV.3.1 TERMA Design

TERMA Application :

- Both DUT amplifiers are used with saturated outputs as comparators.
- The first comparator is used to detect a power supply over-voltage, using input voltages around 4V.
- The second comparator is used to realize a bi-stable flip-flop, with saturated input levels.
- The normal state of the flip-flop is the ON state.
- ON and OFF command are available in the application.

Test principle :

- The variable input level of the comparator is generated with a programmable source.
- The fixed reference level is generated using the same divider bridge as the one used in the actual application, in order to reproduce the interdependency of both DUT amplifiers, since the flip-flop uses a reference point coming from the divider bridge of the comparator.
- Each input is connected to a resistor bridge (divider by 10) and de-coupling capacitors which present an impedance equivalent to the one used in the actual application.
- A reset command is implemented allowing continuous testing of the component without switching off the power supply after each upset.
- A time delay circuit is added for automatic reset of the latch, after a wait state of 1ms in order to observe transient upsets and permanent upsets.
- DUT power supply has been designed in the same way than in the actual application, i.e. with a 6.2 V zener diode which clamps the supply voltage when a state change occurs.

Types of events detected :

- Transient upset limited to the comparator.
- Comparator or latch upset leading to a latch change.

Functional Check :

A 100µs @ 1Hz signal modifying one of the input and allowing activation of counting function.

Design change to improve upset tolerance :

Implementation of a RC filter in the amplifier feedback used as a flip-flop allows for the introduction of a wait state during the locking phase.

Different test set-up conditions :

Two different set-up conditions have been used and corresponding bias figures are given in the here below table :

| Test board | | Signal definition | Signal state | Set up 1 | Set up 2 |
|---|---|---|---|---|---|
| | | | | Close to trig. | Far from trig. |
| DC source | PVI | DUT supply | 15V, 3.6mA | 5mA limit threshold | |
| DC source | VI1 | Line voltage input | trig. level | 4.1V | 3.6V |
| | | | | | |
| | | | | | |
| Scope chan 1 | FO1 | Latch output | 6V to 0V | 2V / Div | |
| Scope chan 2 | FO2 | Comparator output | 6V to 0V | 2V / Div | |
| | | | | | |
| Counter 1 | FO1 | Latch output | 6V to 0V | Trig @ 4V ↓ | |
| Counter 2 | FO2 | Comparator output | 6V to 0V | Trig @ 4V ↓ | |
| Counter 3 | LO1 | Latched SEU | Logic level | Trig @2.5V ↑ | |

Note : actual differential input level is computed as follow: (4.15V) – (line)
with 4.15V = resistor divider from Zener 6.2V + hysteresis effect

**Table IV-1 - TERMA Design Test Conditions**

# VIRGO design / LM139 test set up

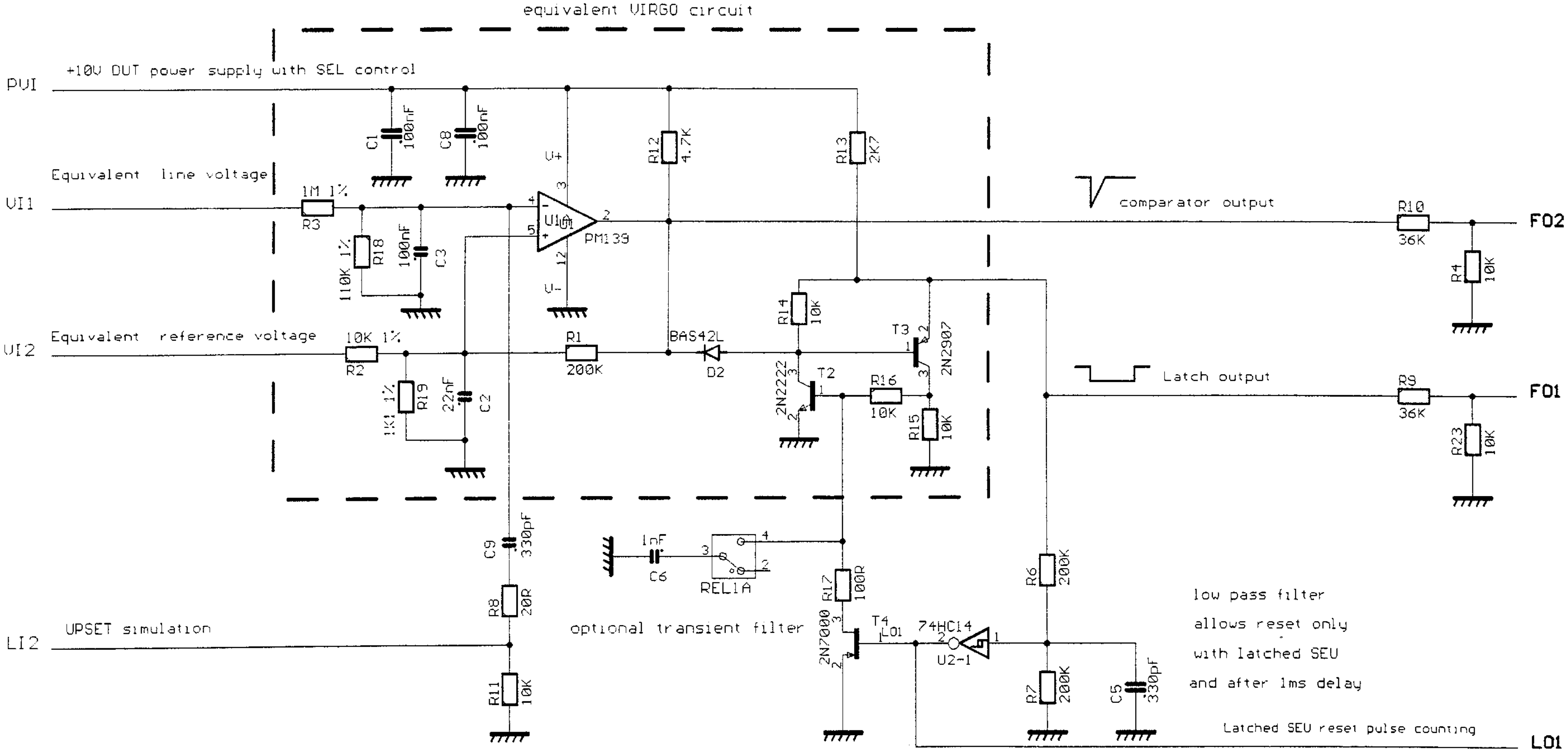



**Figure IV-3 – LM339 Virgo Design Synoptic**

### IV.3.2 Comparator Application

Test principle :

The comparator input levels are generated using two programmable sources.

Types of events detected :

Comparator output is at +10 Volts in absence of event.
Transients are detected and counted into two different bins :

- Large errors, corresponding to the 2 Volts threshold : Comparator output transients with an amplitude higher than 8 volts are counted.
- Small errors, corresponding to the 8 Volts threshold : Comparator output transients with an amplitude higher than 2 volts (thus, include the large errors) are counted.

Functional Check :

A 100µs @ 1Hz signal modifying the reference threshold and allowing activation of counting function.

Different test set-up conditions :

Two different set-up conditions have been used and corresponding bias figures are given in the here below table :

| Test board | | Signal definition | Signal state | Set-up Cond. 1 | Set-up Cond. 2 |
|---|---|---|---|---|---|
| | | | Close to GND | Half supply CMV | |
| DC source | PVI | DUT supply | 10V, 1.6mA | 5mA limit threshold | |
| DC source | VI1 | + input | | 100mV | 7.08V |
| DC source | VI2 | - input | | 50mV | 7.02V |
| | | | | | |
| Scope chan 1 | FO1 | Comparator output | 10V to 0V | 5V / Div | |
| | | | | | |
| | | | | | |
| Counter 1 | FO1 | small | 10V to 0V | Trig @ 8V ↓ | |
| Counter 2 | FO2 | large | 10V to 0V | Trig @ 2V ↓ | |

Note : Actual differential input level is calculated as follow : (+input) – (-input)

**Table IV-2 – LM339 Comparator Test Conditions**

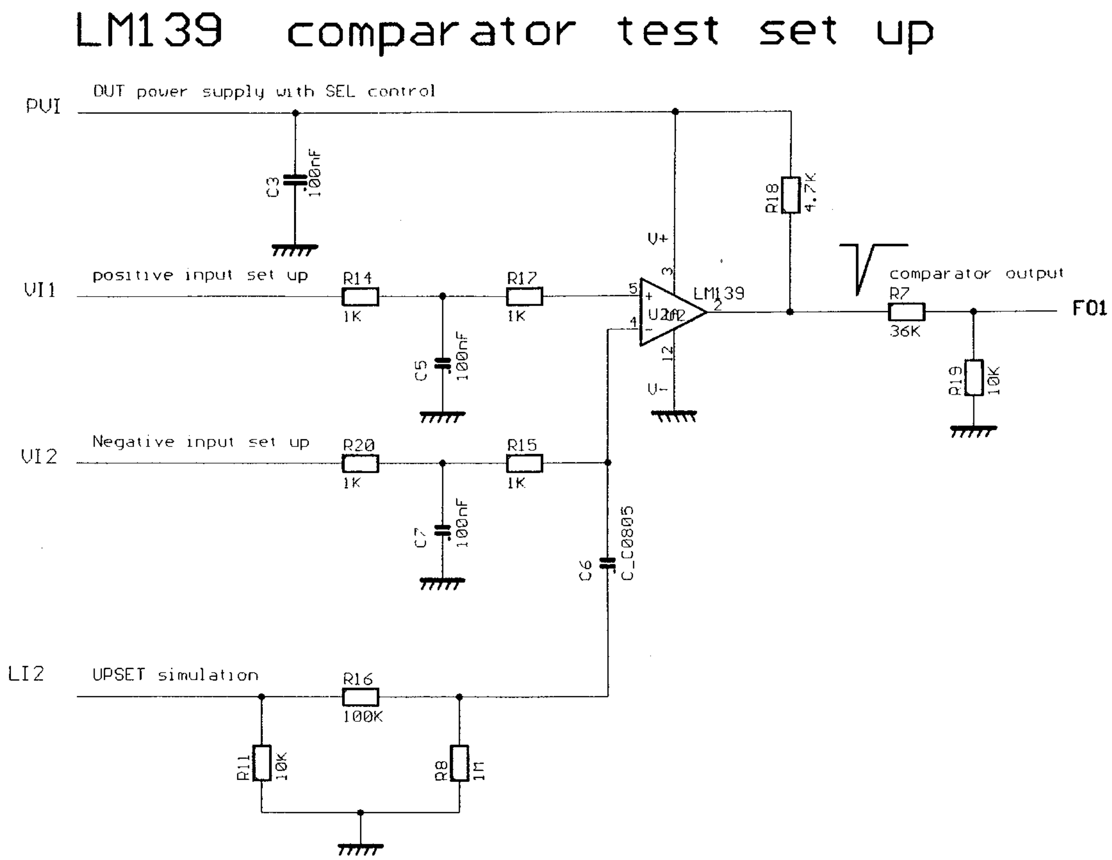



**Figure IV-4 – LM339 Comparator Test Synoptic**

# V. TEST FACILITIES

Test at the cyclotron accelerator was performed at Université de Louvain (UCL) in Louvain la neuve (Belgium) under HIREX Engineering responsibility.
4 delidded samples were irradiated.

## V.1 BEAM SOURCE

In collaboration with the European Space Agency (ESA), the needed equipment for single events studies using heavy ions has been built and installed on the HIF beam line in the experimental hall of Louvain-la-Neuve cyclotron.
CYCLONE is a multi particle, variable energy, cyclotron capable of accelerating protons (up to 75 MeV), alpha particles and heavy ions. For the heavy ions, the covered energy range is between 0.6 MeV/AMU and 27.5 MeV/AMU. For these ions, the maximal energy can be determined by the formula :

$$110\ Q^2/M$$

where Q is the ion charge state, and M is the mass in Atomic Mass Units.

The heavy ions are produced in a double stage Electron Cyclotron Resonance (ECR) source. Such a source allows to produce highly charged ions and ion "cocktails". These are composed of ions with the same or very close M/Q ratios. The cocktail ions are injected in the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency. This method is very convenient for a quick change of ion (in a few minutes) which is equivalent to a LET variation.

## V.2 BEAM SET-UP

### V.2.1 Ion Beam Selection

The LET range was obtained by changing the ion species and incident energy and changing the angle of incidence between the beam and the chip, Table VI-2, Table VI-3 and Table VI-4 provide the ions which were used to determine the LET threshold and the asymptotic cross section within the LET range for this heavy ion characterization. In addition ion energy, LET, range and tilt angle are also provided for each test run.

### V.2.2 Flux Range

Particle flux could be varied from few hundred ions/cm²/sec up to a ten thousand ions/cm²/sec under normal operations (tilt 0°).

### V.2.3 Particle Fluence Levels

Fluence level was comprised between 3 x10E5 and 1 x10E6 ions/cm²

### V.2.4 Dosimetry

The current UCL Cyclotron dosimetry system and procedures were used.

### V.2.5 Accumulated Total Dose

Table VI-2 to Table VI-4 provide for each run the equivalent total dose (rad(Si)) received by each device under test.
For each device, the total amount is below 10 x10E+03 rads.

### V.2.6 Test Temperature Range

All the tests performed were conducted at ambient temperature.

# VI. RESULTS

Virgo test configuration :

As mentioned in paragraph IV.3.1, the effect of Single Event Upset was monitored and counted at three different locations of the test circuit :

- At the output of the comparator, see F01 line in Figure IV-3, (which is the only device irradiated on the board),
- At the output of the latch to see any transient propagated by the comparator, see F02 line in Figure IV-3.
- If the latch state has changed permanently, a third counter is incremented after a time delay period of 100 ms, see L01 line in Figure IV-3.

Table VI-2and Table VI-3 give the test results using the Virgo configuration respectively without the filtering capacitor and with this capacitor added.

The main result from the run using the first test configuration is that every transient detected at the comparator output is also detected at the latch output and in absence of the filtering capacitor, the latch state changes permanently.

In Table VI-3, it can be seen that the add-on filter with a capacitor of 1nF is efficient as no latched SEU errors could be detected anymore (No more permanent latch state change).

Comparator test configuration :

In this configuration and in absence of event, the output comparator is fixed to +10 volts and transients errors, which will switch the comparator output towards zero, will be detected with two different threshold levels :

- Large error : transient signal amplitude higher than the 8 volts threshold,
- Small error : transient signal amplitude signal higher than the 2 volts threshold

Table VI-4 give the test results using the comparator configuration.

The main result from all runs is that most of the transients fall in the large error category.

Test results comparison :

Four samples have been tested and results are very consistent.
Comparison between the two test configurations, i.e. Virgo (comparator errors) and the stand-alone comparator (small errors), is provided in Figure VI-1 where the number of errors have been averaged on the two samples. Table VI-1 provides the corresponding figures.
It can be noted a strong effect of the tilt angle in the error cross-section

Lastly typical waveforms observed with the scope are provided in Figure VI-2, Figure VI-3, Figure VI-4, in the following respective configurations, Virgo, Virgo with 1nF filtering capacitor and lastly, comparator configuration.

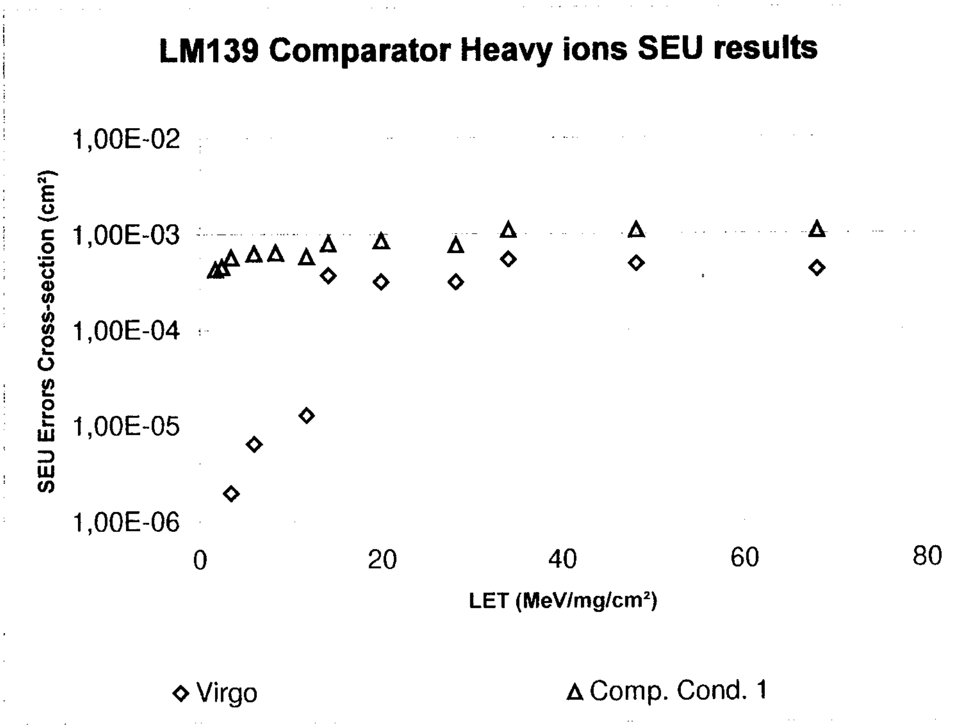



**Figure VI-1 – LM339 comparator SEU Error cross-section per device**

| LET (MeV/mg/cm²) | SEU Cross-section per device (cm²) | |
|---|---|---|
| | Virgo | Comp. Cond. 1 |
| 1,7 | | 4,26E-04 |
| 2.4 | | 4,52E-04 |
| 3,4 | 2,00E-06 | 5,68E-04 |
| 5,9 | 6,50E-06 | 6,25E-04 |
| 8,3 | | 6,35E-04 |
| 11,7 | 1,30E-05 | 5,84E-04 |
| 14,1 | 3,72E-04 | 7,99E-04 |
| 19,9 | 3,20E-04 | 8,56E-04 |
| 28,2 | 3,13E-04 | 7,62E-04 |
| 34 | 5,40E-04 | 1,10E-03 |
| 48,1 | 4,88E-04 | 1,09E-03 |
| 68 | 4,23E-04 | 1,07E-03 |

**Table VI-1 – LM339 SEU error cross-section versus LET**

**Table VI-2 – Test results on SGS Thomson LM339 using Virgo configuration**
**Test T007 Virgo Condition 1**

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Comparator | Errors Latch | Errors Latched SEU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00247 | T007 | S025 | I003 | 27/09/98 | 0 | 34 | 67 | - | 4,48 E+03 | 8,49 E+02 | 3,00 E+05 | - | 164 | 164 | 164 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S025 | #1 | LM339D1 | 9836 | SGS Thomson |
| S026 | #2 | LM339D1 | 9836 | SGS Thomson |
| S027 | #3 | LM339D1 | 9836 | SGS Thomson |
| S028 | #4 | LM339D1 | 9836 | SGS Thomson |

| | | | | |
|---|---|---|---|---|
| **Note** | Condition 1 : | VI1 | Reference voltage input | 300mV |
| | | VI2 | Line voltage input | 290mV |

**Table VI-3 – Test results on SGS Thomson LM339 using Virgo configuration**
**Test T009 Virgo Condition 1 plus 1nF filtering capacitor**

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Comparator | Errors Latch | Errors Latched SEU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00099 | T009 | S026 | I004 | 25/09/98 | 0 | 14,1 | 93 | - | 5,38 E+03 | 1,83 E+02 | 5,00 E+05 | - | 186 | 185 | 0 |
| R00100 | T009 | S026 | I004 | 25/09/98 | 45 | 19,94 | 119 | - | 4,20 E+03 | 3,43 E+02 | 5,00 E+05 | - | 154 | 154 | 0 |
| R00101 | T009 | S026 | I004 | 25/09/98 | 60 | 28,2 | 154 | - | 3,25 E+03 | 5,69 E+02 | 5,00 E+05 | - | 146 | 143 | 0 |
| R00102 | T009 | S025 | I004 | 25/09/98 | 0 | 14,1 | 68 | - | 7,35 E+03 | 1,13 E+02 | 5,00 E+05 | - | 186 | 186 | 0 |
| R00103 | T009 | S025 | I004 | 25/09/98 | 45 | 19,94 | 108 | - | 4,63 E+03 | 2,72 E+02 | 5,00 E+05 | - | 166 | 166 | 0 |
| R00104 | T009 | S025 | I004 | 25/09/98 | 60 | 28,2 | 168 | - | 2,98 E+03 | 4,98 E+02 | 5,00 E+05 | - | 167 | 166 | 0 |
| R00105 | T009 | S025 | I005 | 25/09/98 | 60 | 11,7 | 231 | - | 2,18 E+03 | 5,92 E+02 | 5,03 E+05 | - | 8 | 6 | 0 |
| R00106 | T009 | S026 | I005 | 25/09/98 | 60 | 11,7 | 355 | - | 2,82 E+03 | 7,56 E+02 | 1,00 E+06 | - | 10 | 9 | 0 |
| R00107 | T009 | S026 | I005 | 25/09/98 | 0 | 5,85 | 120 | - | 8,33 E+03 | 8,49 E+02 | 1,00 E+06 | - | 7 | 6 | 0 |
| R00108 | T009 | S025 | I005 | 25/09/98 | 0 | 5,85 | 125 | - | 8,00 E+03 | 6,86 E+02 | 1,00 E+06 | - | 6 | 5 | 0 |
| R00248 | T009 | S025 | I003 | 27/09/98 | 0 | 34 | 65 | - | 4,62 E+03 | 1,01 E+03 | 3,00 E+05 | - | 177 | 176 | 0 |
| R00249 | T009 | S025 | I003 | 27/09/98 | 45 | 48,08 | 92 | - | 3,26 E+03 | 1,24 E+03 | 3,00 E+05 | - | 148 | 147 | 0 |
| R00250 | T009 | S025 | I003 | 27/09/98 | 60 | 68 | 113 | - | 2,65 E+03 | 1,57 E+03 | 3,00 E+05 | - | 114 | 114 | 0 |
| R00251 | T009 | S026 | I003 | 27/09/98 | 60 | 68 | 133 | - | 2,26 E+03 | 1,18 E+03 | 3,00 E+05 | - | 140 | 140 | 0 |
| R00252 | T009 | S026 | I003 | 27/09/98 | 45 | 48,08 | 91 | - | 3,30 E+03 | 1,41 E+03 | 3,00 E+05 | - | 145 | 143 | 0 |
| R00253 | T009 | S026 | I003 | 27/09/98 | 0 | 34 | 64 | - | 4,69 E+03 | 1,57 E+03 | 3,00 E+05 | - | 147 | 147 | 0 |
| R00302 | T009 | S026 | I007 | 27/09/98 | 60 | 3,4 | 109 | - | 4,59 E+03 | 2,32 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |
| R00303 | T009 | S025 | I007 | 27/09/98 | 60 | 3,4 | 100 | - | 5,00 E+03 | 2,32 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S025 | #1 | LM339D1 | 9836 | SGS Thomson |
| S026 | #2 | LM339D1 | 9836 | SGS Thomson |
| S027 | #3 | LM339D1 | 9836 | SGS Thomson |
| S028 | #4 | LM339D1 | 9836 | SGS Thomson |

**Note** Condition 1 : VI1 Reference voltage input 300mV
VI2 Line voltage input 290mV

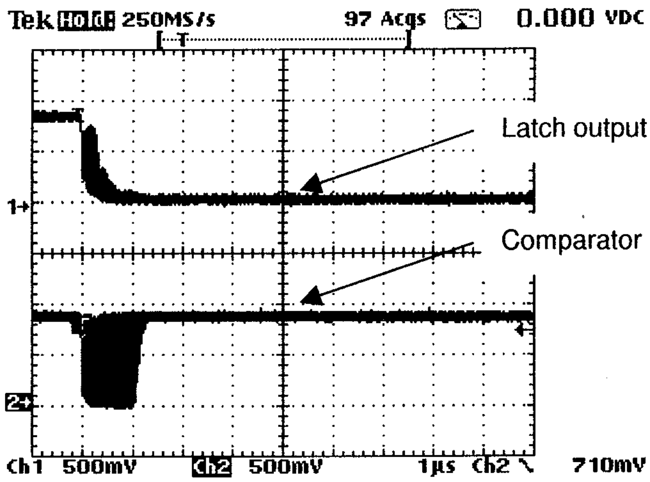
## Table VI-4 - Results on SGS Thomson LM339 using comparator configuration
## Test T010 – Comparator Condition 1

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Small | Errors Large |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00092 | T010 | S028 | I004 | 25/09/98 | 0 | 14,1 | 103 | - | 4,85 E+03 | 1,13 E+02 | 5,00 E+05 | - | 414 | 414 |
| R00093 | T010 | S028 | I004 | 25/09/98 | 45 | 19,94 | 148 | - | 3,38 E+03 | 2,72 E+02 | 5,00 E+05 | - | 436 | 430 |
| R00094 | T010 | S028 | I004 | 25/09/98 | 60 | 28,2 | 188 | - | 2,66 E+03 | 4,98 E+02 | 5,00 E+05 | - | 342 | 332 |
| R00095 | T010 | S027 | I004 | 25/09/98 | 0 | 14,1 | 102 | - | 4,90 E+03 | 1,13 E+02 | 5,00 E+05 | - | 385 | 382 |
| R00096 | T010 | S027 | I004 | 25/09/98 | 45 | 19,94 | 137 | - | 3,65 E+03 | 2,72 E+02 | 5,00 E+05 | - | 420 | 419 |
| R00097 | T010 | S027 | I004 | 25/09/98 | 60 | 28,2 | 200 | - | 2,50 E+03 | 4,98 E+02 | 5,00 E+05 | - | 420 | 403 |
| R00109 | T010 | S027 | I005 | 25/09/98 | 60 | 11,7 | 169 | - | 2,96 E+03 | 5,92 E+02 | 5,00 E+05 | - | 294 | 286 |
| R00110 | T010 | S027 | I005 | 25/09/98 | 45 | 8,27 | 296 | - | 2,61 E+03 | 6,94 E+02 | 7,72 E+05 | - | 508 | 496 |
| R00111 | T010 | S027 | I005 | 25/09/98 | 0 | 5,85 | 167 | - | 2,99 E+03 | 7,40 E+02 | 5,00 E+05 | - | 324 | 311 |
| R00112 | T010 | S028 | I005 | 25/09/98 | 0 | 5,85 | 124 | - | 4,03 E+03 | 5,45 E+02 | 5,00 E+05 | - | 301 | 289 |
| R00113 | T010 | S028 | I005 | 25/09/98 | 45 | 8,27 | 109 | - | 4,59 E+03 | 6,11 E+02 | 5,00 E+05 | - | 306 | 303 |
| R00114 | T010 | S028 | I005 | 25/09/98 | 60 | 11,7 | 167 | - | 2,99 E+03 | 7,04 E+02 | 5,00 E+05 | - | 290 | 276 |
| R00260 | T010 | S026 | I003 | 27/09/98 | 0 | 34 | 71 | - | 4,23 E+03 | 1,73 E+03 | 3,00 E+05 | - | 325 | 265 |
| R00261 | T010 | S026 | I003 | 27/09/98 | 45 | 48,08 | 102 | - | 2,94 E+03 | 1,96 E+03 | 3,00 E+05 | - | 358 | 294 |
| R00262 | T010 | S026 | I003 | 27/09/98 | 60 | 68 | 143 | - | 2,10 E+03 | 2,29 E+03 | 3,00 E+05 | - | 320 | 279 |
| R00263 | T010 | S025 | I003 | 27/09/98 | 60 | 68 | 145 | - | 2,07 E+03 | 1,90 E+03 | 3,00 E+05 | - | 322 | 281 |
| R00264 | T010 | S025 | I003 | 27/09/98 | 45 | 48,08 | 105 | - | 2,86 E+03 | 2,13 E+03 | 3,00 E+05 | - | 297 | 243 |
| R00265 | T010 | S025 | I003 | 27/09/98 | 0 | 34 | 71 | - | 4,23 E+03 | 2,29 E+03 | 3,00 E+05 | - | 334 | 280 |
| R00296 | T010 | S028 | I007 | 27/09/98 | 0 | 1,7 | 66 | - | 7,58 E+03 | 7,18 E+02 | 5,00 E+05 | - | 212 | 209 |
| R00297 | T010 | S028 | I007 | 27/09/98 | 45 | 2,4 | 93 | - | 5,38 E+03 | 7,37 E+02 | 5,00 E+05 | - | 241 | 234 |
| R00298 | T010 | S028 | I007 | 27/09/98 | 60 | 3,4 | 128 | - | 3,91 E+03 | 7,64 E+02 | 5,00 E+05 | - | 291 | 261 |
| R00299 | T010 | S027 | I007 | 27/09/98 | 60 | 3,4 | 75 | - | 6,67 E+03 | 7,68 E+02 | 5,00 E+05 | - | 277 | 253 |
| R00300 | T010 | S027 | I007 | 27/09/98 | 45 | 2,4 | 80 | - | 6,25 E+03 | 7,87 E+02 | 5,00 E+05 | - | 211 | 209 |
| R00301 | T010 | S027 | I007 | 27/09/98 | 0 | 1,7 | 55 | - | 9,09 E+03 | 8,00 E+02 | 5,00 E+05 | - | 214 | 211 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

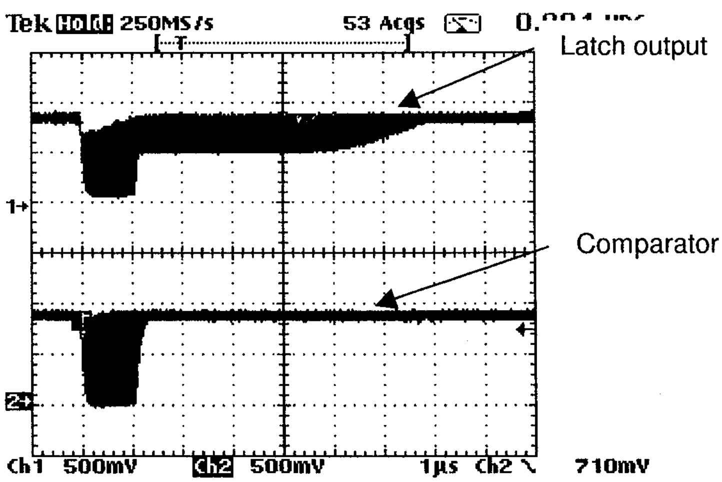
| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S025 | #1 | LM339D1 | 9836 | SGS Thomson |
| S026 | #2 | LM339D1 | 9836 | SGS Thomson |
| S027 | #3 | LM339D1 | 9836 | SGS Thomson |
| S028 | #4 | LM339D1 | 9836 | SGS Thomson |

**Note** Condition 1 : VI1 + input 100mV
VI2 - input 50mV



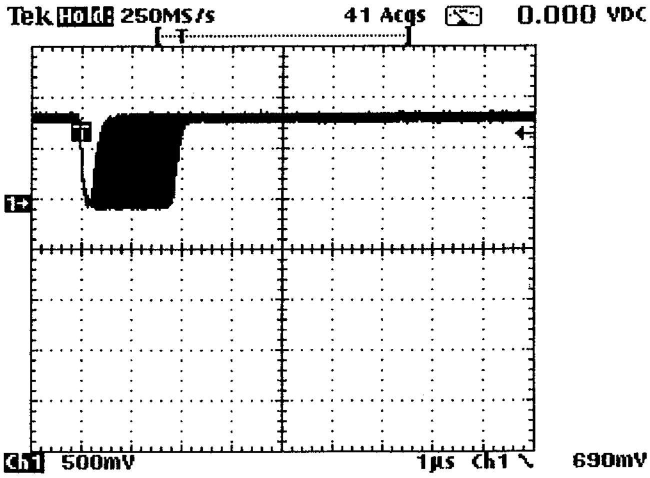

**(5V/div 2µs)**
In this case, the change of the latch state can be observed

**Figure VI-2 – Typical Waveform, Virgo configuration without filter capacitor**




**(5V/div 2µs)**
This scope record shows that the latch output change does not latch thanks to the filtering capacitor

**Figure VI-3 – Typical Waveform, Virgo configuration with 1nF capacitor filter**




**(5V/div 1µs)**
This scope record shows the envelop of SEU pulses of different transient duration

**Figure VI-4 – Typical Waveform, Comparator configuration**

## VII. CONCLUSION

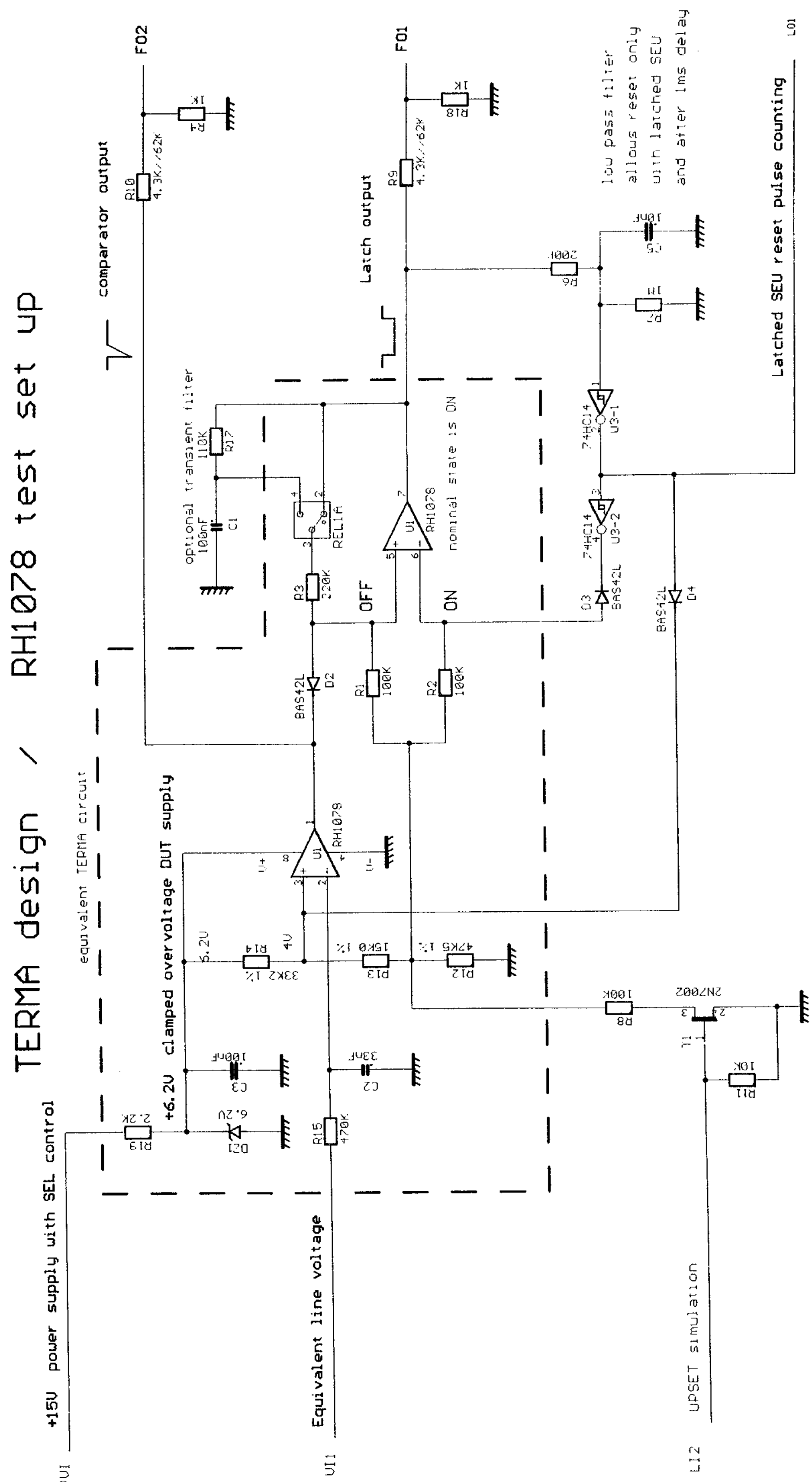
SEU test have been conducted on LM339D1 Quad Voltage Comparator from SGS Thomson, using the heavy ions available at the University of Louvain facility.

SEU susceptibility was obtained through the error cross section versus LET curve for two different test configurations.

The effect of a capacitor filter applied in the Virgo equivalent configuration has been assessed and drastic improvement has been obtained.

With these results, upset predictions on XMM orbit, can be performed for each error type and the risk associated with the present Virgo design can be assessed.

**Figure IV-3 – RH1078 TERMA Design Synoptic**



IV.3.2 Closed Loop Amplifier Application

Test principle :

Systematic detection of upsets occurring at the inputs stage of the component which is supposed to be the more sensitive part of the circuit, requires the use of a close loop working point :
- The input differential voltage is equal to zero, and thus in a linear equilibrium around threshold,
- Large gain (100) to allow for sufficient sensitivity.

Types of events detected :

The detection of events will be done with an analog window comparator system, the principle of which is given in paragraph IV.2.3 :

- Small error which corresponds to a transient upset of small amplitude
- Medium error which corresponds to a transient upset of medium amplitude
- Large error which corresponds to a transient upset of large amplitude

Functional Check :

A 100µs @ 1Hz signal modifying one of the input and allowing activation of counting function.

Different test set-up conditions :

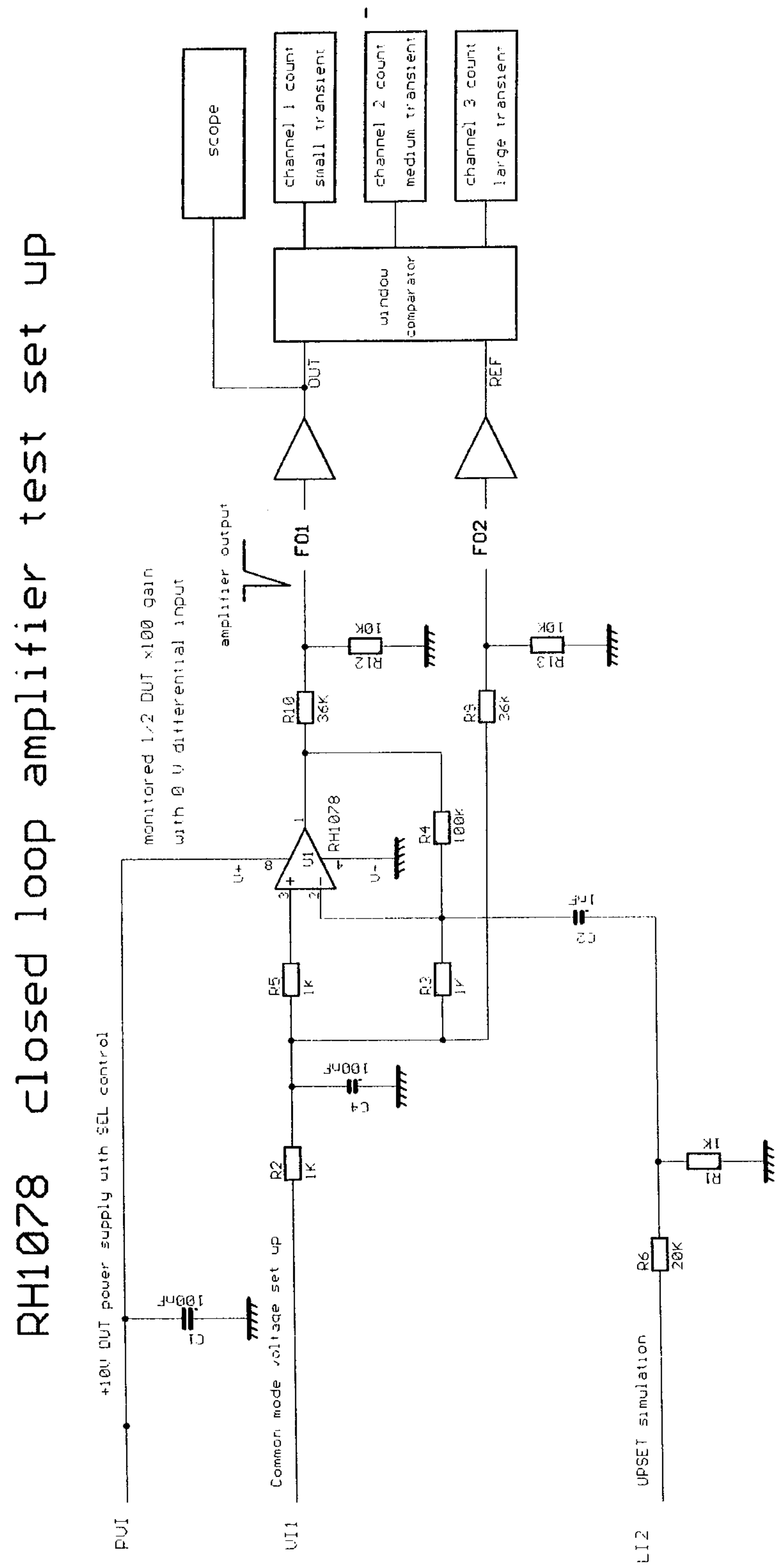
Two different set-up conditions have been used and corresponding bias figures are given in the here below table :

| **Test board** | | **Signal definition** | **Signal state** | **Set up 1** | **Set up 2** |
|---|---|---|---|---|---|
| | | | | **Closed to GND** | **Half supply CMV** |
| DC source | PVI | DUT supply | 15V 3.6mA | 5mA limit threshold | |
| DC source | VI1 | Common mode voltage | | 0.5V | 4.5V |
| | | | | | |
| | | | | | |
| Scope chan 1 | | output | CMV | Scope 200mV /Div<br>=> DUT = 2V / Div | |
| | | | | | |
| | | | | | |
| Counter 1 | LO1 | small | | Trig @ 50mV ↓↑ | |
| Counter 2 | LO2 | medium | | Trig @ 400mV ↓↑ | |
| Counter 3 | LO3 | large | | Trig @ 6.25V ↓↑ | |

Note : output DC level is equal to input common mode level

**Table IV-2 – RH1078 Closed Loop Amplifier Test Conditions**

**Figure IV-4 – RH1078 Closed Loop Amplifier Test Synoptic**



## V. TEST FACILITIES

Test at the cyclotron accelerator was performed at Université de Louvain (UCL) in Louvain la neuve (Belgium) under HIREX Engineering responsibility.
2 delidded samples were irradiated.

### V.1 BEAM SOURCE

In collaboration with the European Space Agency (ESA), the needed equipment for single events studies using heavy ions has been built and installed on the HIF beam line in the experimental hall of Louvain-la-Neuve cyclotron.
CYCLONE is a multi particle, variable energy, cyclotron capable of accelerating protons (up to 75 MeV), alpha particles and heavy ions. For the heavy ions, the covered energy range is between 0.6 MeV/AMU and 27.5 MeV/AMU. For these ions, the maximal energy can be determined by the formula :

$$110\ Q^2/M$$

where Q is the ion charge state, and M is the mass in Atomic Mass Units.

The heavy ions are produced in a double stage Electron Cyclotron Resonance (ECR) source. Such a source allows to produce highly charged ions and ion "cocktails". These are composed of ions with the same or very close M/Q ratios. The cocktail ions are injected in the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency. This method is very convenient for a quick change of ion (in a few minutes) which is equivalent to a LET variation.

### V.2 BEAM SET-UP

#### V.2.1 Ion Beam Selection

The LET range was obtained by changing the ion species and incident energy and changing the angle of incidence between the beam and the chip.
For each run, information is provided on the beam characteristics in the detailed results tables provided in paragraph VI.

#### V.2.2 Flux Range

Particle flux could be varied from few hundred ions/cm²/sec up to a ten thousand ions/cm²/sec under normal operations (tilt 0°).

#### V.2.3 Particle Fluence Levels

Fluence level was comprised between 3 x10E5 and 1 x10E6 ions/cm²

#### V.2.4 Dosimetry

The current UCL Cyclotron dosimetry system and procedures were used.

#### V.2.5 Accumulated Total Dose

For each run, the equivalent dose figure received during the run and the computed cumulated dose received by the DUT sample, are provided in the detailed results tables of paragraph VI.

#### V.2.6 Test Temperature Range

All the tests performed were conducted at ambient temperature.

# VI. RESULTS

TERMA Design

As mentioned in paragraph IV.3.1, the effect of Single Event Upset was monitored and counted at three different locations of the test circuit :

- Comparator error : At the output of the comparator, see F01 line in Figure IV-3,
- Latch error : At the output of the latch to see any transient propagated by the comparator, see F02 line in Figure IV-3,.
- Latched SEU error : If the latch state has changed permanently, a third counter is incremented after a time delay period of 100 ms, see L01 line in Figure IV-3.

It must be noted that in this case, both the comparator formed by the first DUT amplifier and the latch formed by the second DUT amplifier, are exposed to the beam.

Results are presented in Table VI-3 and Table VI-4 give the results the two working operating conditions which are described in Table IV-1.
These two tables show that a large fraction of the transients detected at the comparator output or / and at the latch output, will induce a permanent latch change, i.e. a latched SEU error.
On the contrary, it can be seen in Table VI-5 which give the results obtained when the 1nF filter capacitor is switched on, that, in that case, no more latched SEU error is counted.

Corresponding SEU error cross-sections per device versus LET, are plotted in Figure VI-2 and Figure VI-2 for the two different working operating conditions.

Amplifier test configuration :

As described in details in paragraph IV.3.2, the effect of Single Event Upset was counted with the analog window comparator which count into three bins :

- small error : for transient amplitude higher than 50 mV,
- medium error : for transient amplitude higher than 400 mV
- large error : for transient amplitude higher than 6.25 V

Table VI-1 and Table VI-2 give the results for the two working operating conditions which are described in Table IV-2.
In these two tables, it can be seen that no large error has been counted as the threshold was fixed to a too high value.
It must be mentioned that the different runs were conducted using two diffrent boards and that on one of these board, a load resistor of 4.7 kΩ was used, which changed somewhat the working conditions. The impact can be seen in Figure VI-3, on the medium errors cross-sections values for the two different samples.

It can also be noted a strong influence of the tilt angle on the error cross-section.

Test results comparison :

Figure VI-4 compares the comparator error cross-sections for TERMA test configuration and amplifier test configuration.

Lastly, Figure VI-5 to Figure VI-13 give the waveform of typical events in the various test conditions.

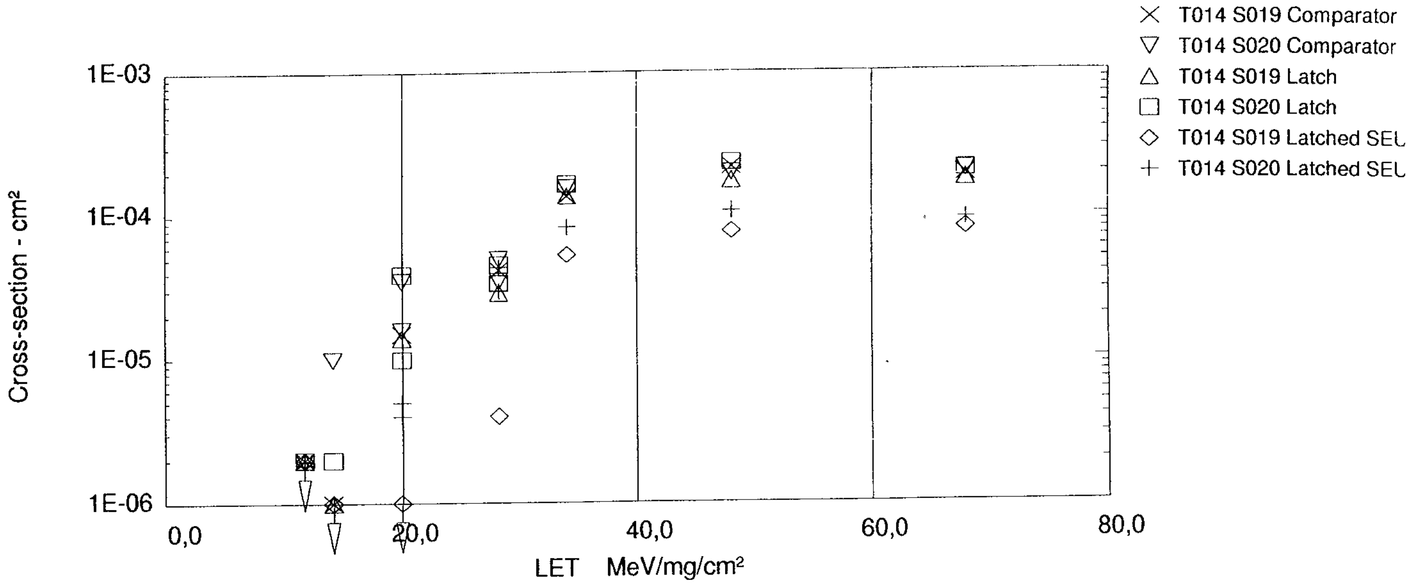



**Figure VI-1 – RH1078, TERMA design condition 1**

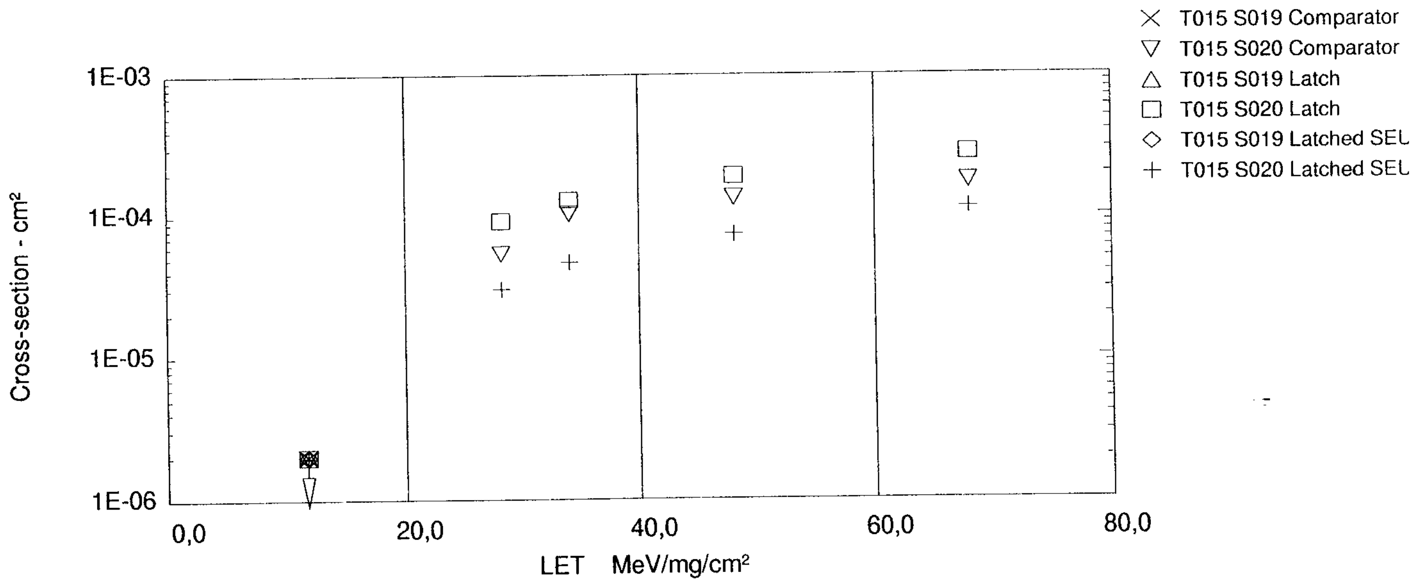



**Figure VI-2 – RH1078, TERMA design condition 2**

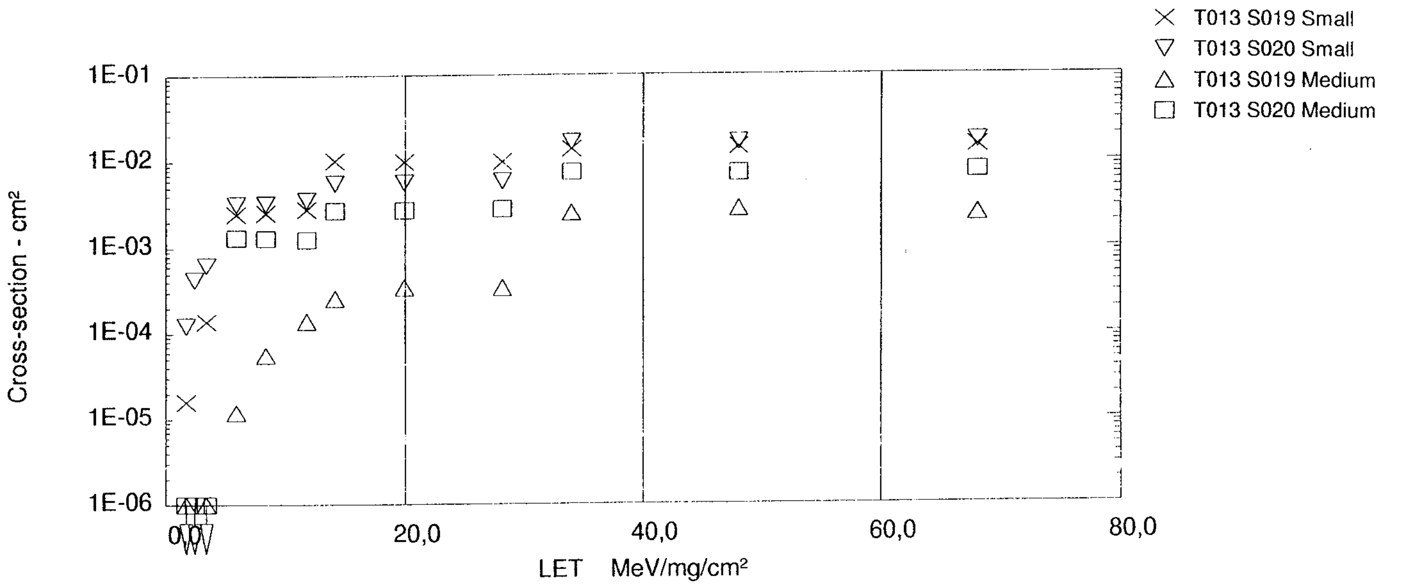
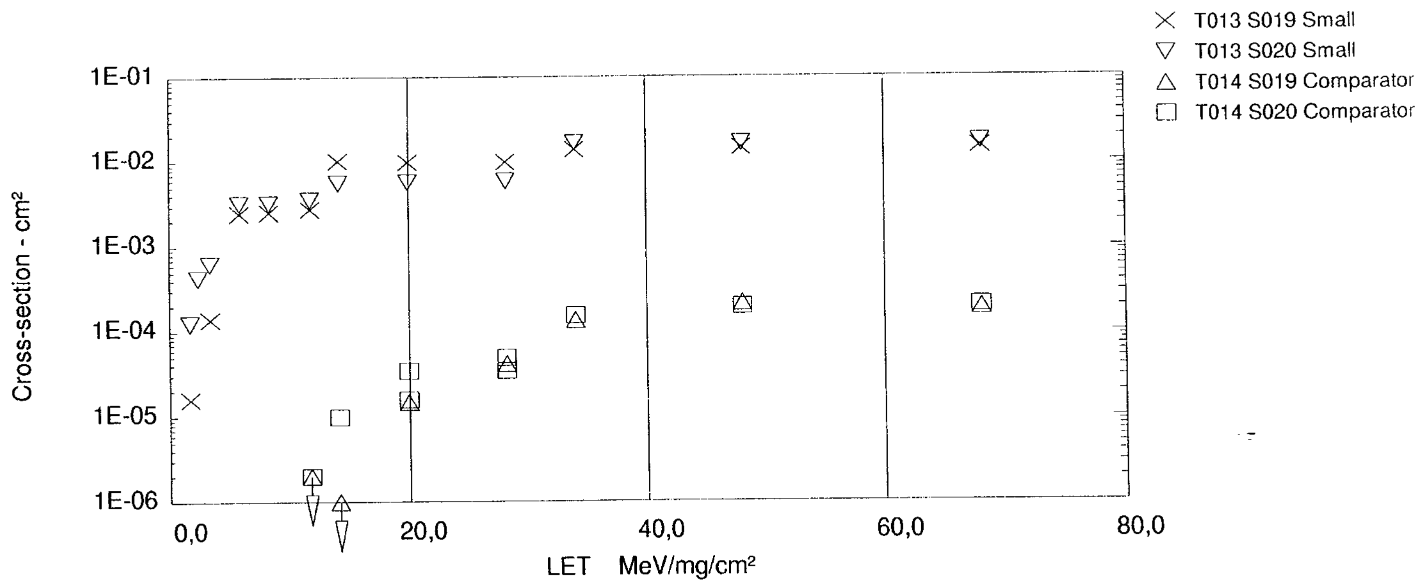



**Figure VI-3 – RH1078, Closed Loop Amplifier**




T013 = Closed loop Amplifier, T014 = Terma design, condition 1

**Figure VI-4 – RH1078, Comparison between the two test configurations**

**Table VI-1 – Test results on Linear Technology RH1078**
**Test T012 Closed Loop Amplifier Condition 1**

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Small | Medium | Large |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00076 | T012 | S020 | I004 | 25/09/98 | 0 | 14,1 | 103 | - | 4,85 E+03 | 3,32 E+03 | 5,00 E+05 | - | 1871 | 918 | 0 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S019 | #215 | RH1078 | 9638A | Linear Technology |
| S020 | #008 | RH1078 | 9638A | Linear Technology |

**Note** Condition 1 : Common mode voltage 0.5V

**Table VI-3 – Test results on Linear Technology RH1078 using TERMA configuration**
**Test T014 TERMA Condition 1**

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Comparator | Errors Latch | Errors Latched SEU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00056 | T014 | S020 | I004 | 25/09/98 | 60 | 28,2 | 105 | - | 4,78 E+03 | 3,39 E+02 | 5,02 E+05 | - | 25 | 23 | 22 |
| R00057 | T014 | S020 | I004 | 25/09/98 | 60 | 28,2 | 253 | - | 3,95 E+03 | 7,90 E+02 | 1,00 E+06 | - | 35 | 34 | 30 |
| R00058 | T014 | S020 | I004 | 25/09/98 | 45 | 19,94 | 192 | - | 5,21 E+03 | 1,11 E+03 | 1,00 E+06 | - | 16 | 10 | 4 |
| R00059 | T014 | S020 | I004 | 25/09/98 | 45 | 19,94 | 162 | - | 6,18 E+03 | 1,43 E+03 | 1,00 E+06 | - | 35 | 39 | 5 |
| R00060 | T014 | S020 | I004 | 25/09/98 | 0 | 14,1 | 105 | - | 9,52 E+03 | 1,65 E+03 | 1,00 E+06 | - | 10 | 2 | 0 |
| R00061 | T014 | S019 | I004 | 25/09/98 | 0 | 14,1 | 94 | - | 1,06 E+04 | 2,26 E+02 | 1,00 E+06 | - | 0 | 0 | 0 |
| R00062 | T014 | S019 | I004 | 25/09/98 | 60 | 28,2 | 164 | - | 6,10 E+03 | 6,77 E+02 | 1,00 E+06 | - | 42 | 29 | 4 |
| R00063 | T014 | S019 | I004 | 25/09/98 | 45 | 19,94 | 108 | - | 9,26 E+03 | 9,96 E+02 | 1,00 E+06 | - | 15 | 14 | 0 |
| R00140 | T014 | S020 | I005 | 26/09/98 | 60 | 11,7 | 86 | - | 5,81 E+03 | 3,42 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |
| R00141 | T014 | S020 | I005 | 26/09/98 | 60 | 11,7 | 82 | - | 6,10 E+03 | 3,51 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |
| R00164 | T014 | S019 | I005 | 26/09/98 | 60 | 11,7 | 249 | - | 2,01 E+03 | 1,81 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |
| R00235 | T014 | S019 | I003 | 27/09/98 | 0 | 34 | 48 | - | 6,25 E+03 | 3,31 E+03 | 3,00 E+05 | - | 41 | 41 | 16 |
| R00236 | T014 | S019 | I003 | 27/09/98 | 45 | 48,08 | 67 | - | 4,48 E+03 | 3,54 E+03 | 3,00 E+05 | - | 65 | 52 | 23 |
| R00237 | T014 | S019 | I003 | 27/09/98 | 60 | 68 | 100 | - | 3,00 E+03 | 3,87 E+03 | 3,00 E+05 | - | 57 | 53 | 24 |
| R00238 | T014 | S019 | I003 | 27/09/98 | 60 | 68 | 105 | - | 2,86 E+03 | 4,20 E+03 | 3,00 E+05 | - | 60 | 54 | 15 |
| R00239 | T014 | S020 | I003 | 27/09/98 | 60 | 68 | 113 | - | 2,65 E+03 | 5,07 E+03 | 3,00 E+05 | - | 61 | 62 | 28 |
| R00240 | T014 | S020 | I003 | 27/09/98 | 45 | 48,08 | 79 | - | 3,80 E+03 | 5,30 E+03 | 3,00 E+05 | - | 59 | 70 | 32 |
| R00241 | T014 | S020 | I003 | 27/09/98 | 0 | 34 | 60 | - | 5,00 E+03 | 5,46 E+03 | 3,00 E+05 | - | 47 | 50 | 25 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S019 | #215 | RH1078 | 9638A | Linear Technology |
| S020 | #008 | RH1078 | 9638A | Linear Technology |

| **Note** | Condition 1 : | Line Voltage= 4.1V |
|---|---|---|

**Table VI-4 – Test results on Linear Technology RH1078 using TERMA configuration**
**Test T015 TERMA Condition 2**

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Comparator | Latch | Latched SEU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00064 | T015 | S020 | I004 | 25/09/98 | 60 | 28,2 | 168 | - | 5,95 E+03 | 2,11 E+03 | 1,00 E+06 | - | 54 | 92 | 30 |
| R00142 | T015 | S020 | I005 | 26/09/98 | 60 | 11,7 | 81 | - | 6,17 E+03 | 3,61 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |
| R00165 | T015 | S019 | I005 | 26/09/98 | 60 | 11,7 | 261 | - | 1,92 E+03 | 1,91 E+03 | 5,00 E+05 | - | 0 | 0 | 0 |
| R00242 | T015 | S020 | I003 | 27/09/98 | 0 | 34 | 57 | - | 5,26 E+03 | 5,62 E+03 | 3,00 E+05 | - | 31 | 39 | 14 |
| R00243 | T015 | S020 | I003 | 27/09/98 | 45 | 48,08 | 94 | - | 3,19 E+03 | 5,85 E+03 | 3,00 E+05 | - | 40 | 57 | 22 |
| R00244 | T015 | S020 | I003 | 27/09/98 | 60 | 68 | 126 | - | 2,38 E+03 | 6,18 E+03 | 3,00 E+05 | - | 52 | 83 | 34 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S019 | #215 | RH1078 | 9638A | Linear Technology |
| S020 | #008 | RH1078 | 9638A | Linear Technology |

**Note** Condition 2 : Line Voltage = 3.6V

**Table VI-5 – Test results on Linear Technology RH1078 using TERMA configuration**
**Test T015 TERMA Condition 2 plus capacitor filter added**

| Run ID No | Test ID No | Sample ID No | Ion ID No | Date | Angle ° | Eff. LET Mev/mg/cm² | Run Time sec | Eff. Time sec | Flux P/cm²/sec | TID per Sample Rads (Si) | Fluence P/cm² | Eff. Fluence P/cm² | Errors Comparator | Latch | Latched SEU |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R00245 | T015 | S020 | I003 | 27/09/98 | 60 | 68 | 131 | - | 2,29 E+03 | 6,51 E+03 | 3,00 E+05 | - | 43 | 69 | 0 |
| R00246 | T015 | S019 | I003 | 27/09/98 | 60 | 68 | 128 | - | 2,34 E+03 | 4,52 E+03 | 3,00 E+05 | - | 61 | 64 | 0 |

| Ion ID | Specy | Energy MeV | LET Mev/mg/cm² | Range µm |
|---|---|---|---|---|
| I004 | 40-Ar | 150 | 14,1 | 42 |
| I005 | 20-Ne | 78 | 5,85 | 45 |
| I003 | 84-Kr | 316 | 34 | 43 |
| I007 | 10-B | 41 | 1,7 | 80 |

| Sample ID | SN | Part Type | Date Code | Comments |
|---|---|---|---|---|
| S019 | #215 | RH1078 | 9638A | Linear Technology |
| S020 | #008 | RH1078 | 9638A | Linear Technology |

**Note** Condition 2 : Line Voltage = 3.6V

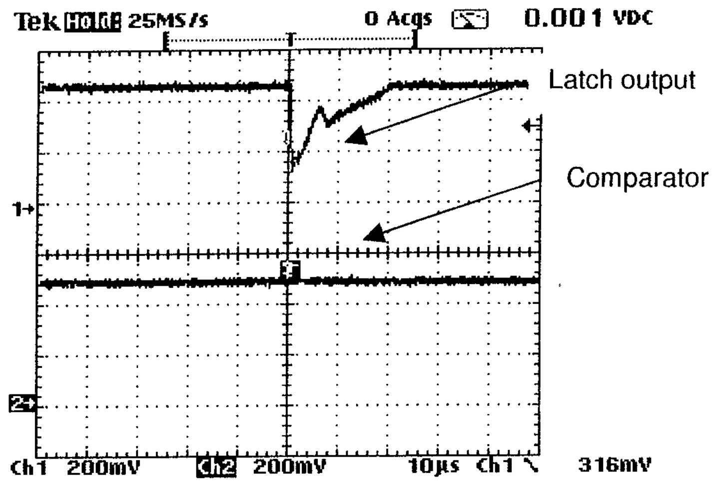



**Figure VI-5 – TERMA design, SEU at the latch output only**

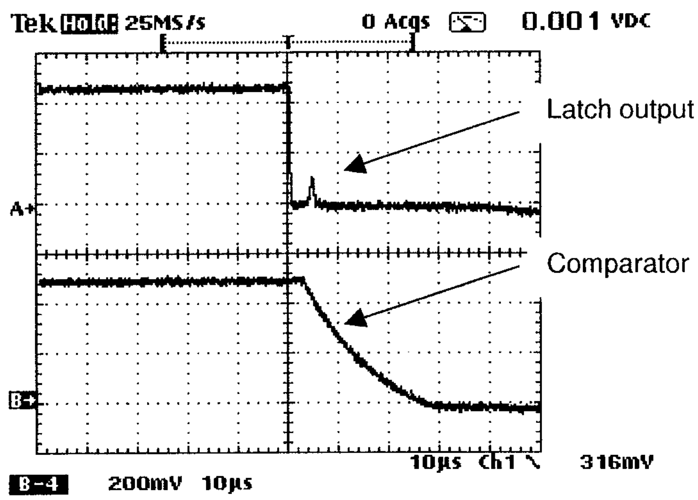
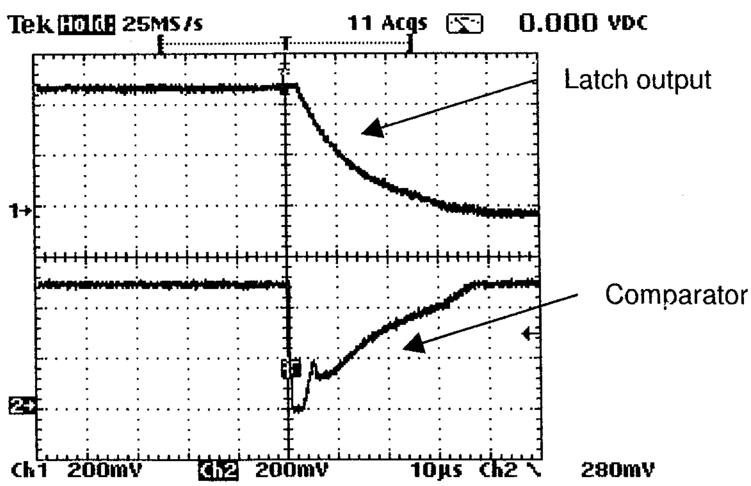
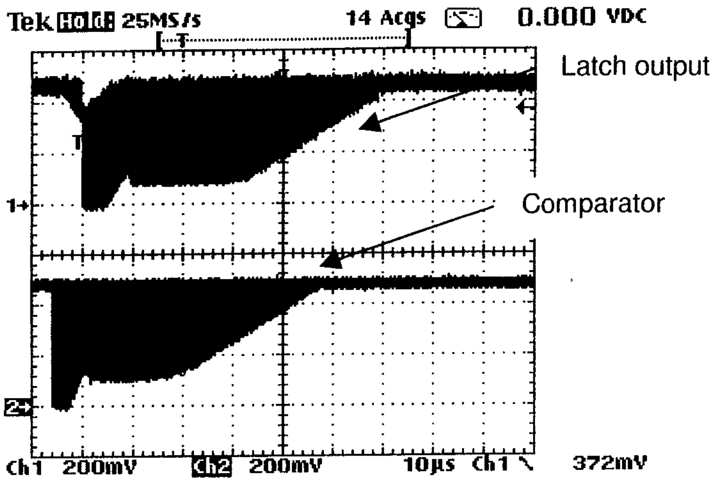



**Figure VI-6 - TERMA design, SEU at the latch output with a reaction on the comparator output**




. One can note the reaction of the latch change on the comparator output

**Figure VI-7 - TERMA design, SEU on comparator which induces a change in the latch state**




Transient Change at the latch output is not latched thanks to the filtering capacitor

**Figure VI-8 - TERMA design, filter added**

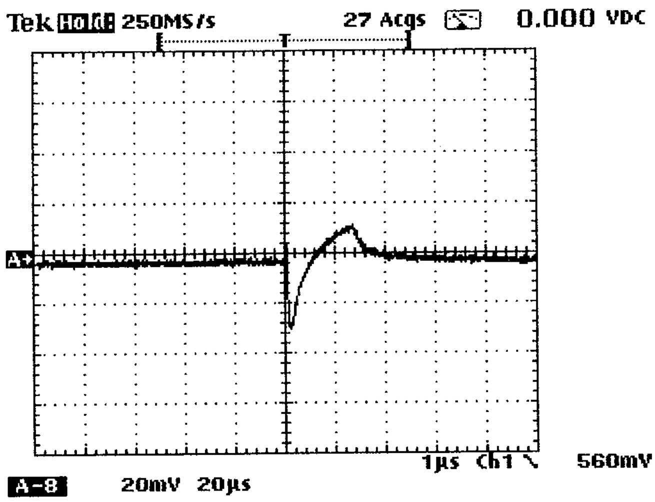



**Figure VI-9 – Closed loop amplifier, typical small event**

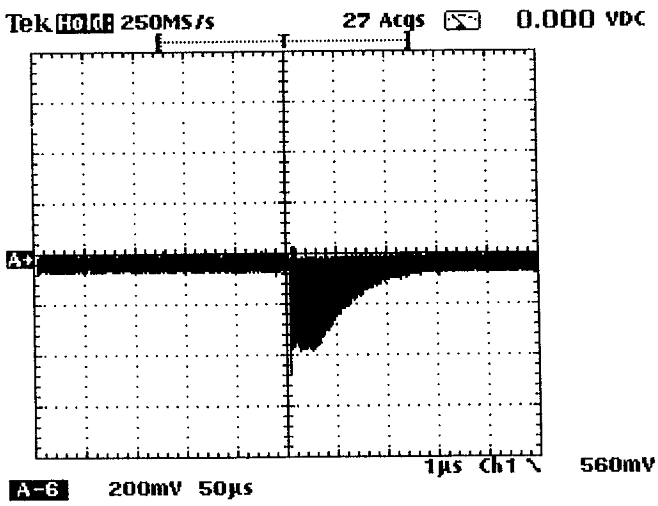



**Figure VI-10 - Closed loop amplifier, envelop of typical large events**

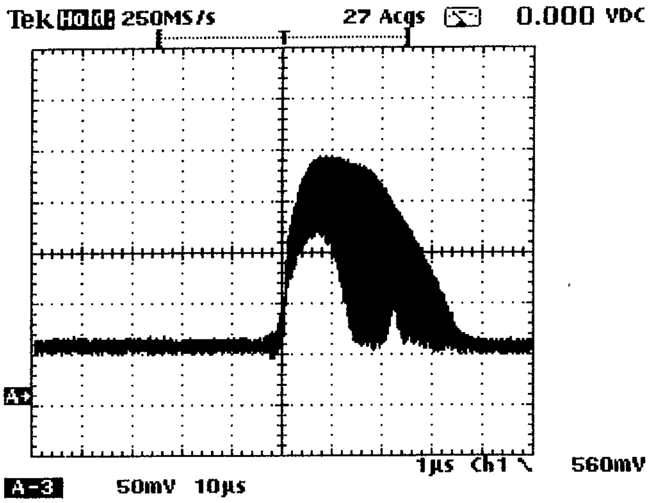



**Figure VI-11 - Closed loop amplifier, envelop of typical large events**

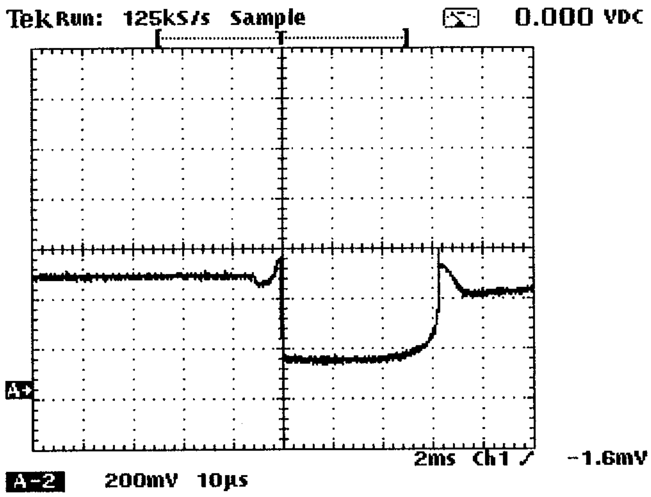



**Figure VI-12 - Closed loop amplifier, typical large event**

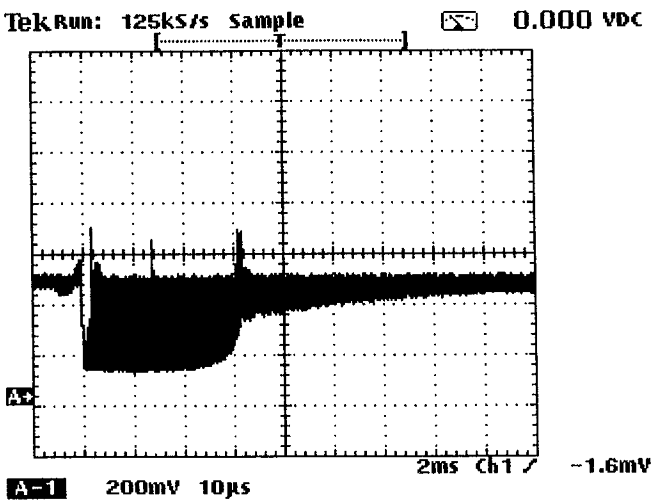



**Figure VI-13 - Closed loop amplifier, envelop of typical large events**

## VII. CONCLUSION

SEU test have been conducted on RH1078 Dual Single Supply, Precision Op Amp from Linear technology, using the heavy ions available at the University of Louvain facility.

SEU susceptibility was obtained through the error cross section versus LET curve for two different test configurations.

The effect of a capacitor filter applied in the Terma equivalent configuration has been assessed and drastic improvement has been obtained.

With these results, upset predictions on XMM orbit, can be performed for each error type and the risk associated with the present Virgo design can be assessed.