Characterizations of OP-Amps response to heavy ion irradiation

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This work has been performed on ESA/ESTEC contract

Abstract

Four different types of OP-amplifiers in comparator mode have been investigated for their response against heavy ion irradiation. Obtained differences between the OP-amplifiers are explained by the differences in the electrical parameters.
One of the OP-amplifiers is compared with results obtained with the device operating in a voltage regulator application.

I. Introduction

The four OP-amplifiers are:
LM124 from National Semiconductor,
RH1014 from Linear Technology,
LM124 from Texas Instruments,
OP27 from Analog Devices.
All four were tested under the same conditions supplied from a single voltage supply of +15 Volt, see Figure 1 below. To verify the sensitivity due to the delta-input voltage two different input delta voltages have been used, see table 1.

Table1 Bias conditions for the OP-amplifiers.

Input bias			
ΔVin (V)	**V+ (V)**	**V- (V)**	**Vout (V)**
0.15	**2.65**	**2.50**	**12**
5	**7.43**	**2.50**	**12**

Table 2 Heavy used ions at Jyväskylä in Finland. (foil = 0.5µm Au foil in the beam.)

Ion	Ener-gy [MeV]	Tilt Angle [deg]	LET value [MeV/mg/cm^2]	Range [µm]
Si	280	48	11	
Si	280	60	14	127
Fe	523	0	18	95
Fe	523	40	24	
Fe	523	52	29	
Kr	766	0	29	93
Kr ,foil		0	30	
Kr ,foil		40	40	
Kr	766	48	44	
Kr ,foil		50	47	
Kr	766	60	59	

The heavy ion tests have been performed at the CYCLotron la Neuve in Belgium and at the Cyclotron at the University of Jyväskylä in Finland. The facilities heavy ion cocktails are presented in Tables 2 and 3.

Table 3 Heavy ions used at Lovain la Neuve in Belgium

Ion	Energy MeV	Tilt Angle [deg]	LET value [MeV/mg/cm^2]
Ar	150	0	14
Ar	150	40	18.7
Ar	150	54	24
Kr	316	0	34
Kr	316	41	45

II. Test samples

Table 4 summarizes the data for the used test samples. In those cases where the test samples have four integrated amplifiers in each package, only one of the amplifiers has been tested.

Table4 Test sample data

Type	LM124	RH1014	LM124	OP27A
Manufacturer	National Sem.	Linear Tech.	Texas Instr.	Analog Dev.
D.C	9652	9651	0207	0021
Pack.	DIL-14	FP-14	FP-14	TO99
Quality	Class S	Class S	MIL Temp	Class S
Slew rate[V/µs]	0.5	0.2	0.5	2.8
Amplf. per pack.	4	4	4	1

II. 5-Vollt regulator setup

In a 5-Volt regulator set-up the OP-amplifier LM124NS was irradiated and the output respond from the regulator was measured at test-point TP1 in Figure 2. In this application LM124NS operates in a linear mode to regulate the transistor output level to 5 V. The +input is connected to a reference, 2.5 volt zener diode (RH1009) and the other –input senses the output voltage via the voltage divider
R2 & R3.

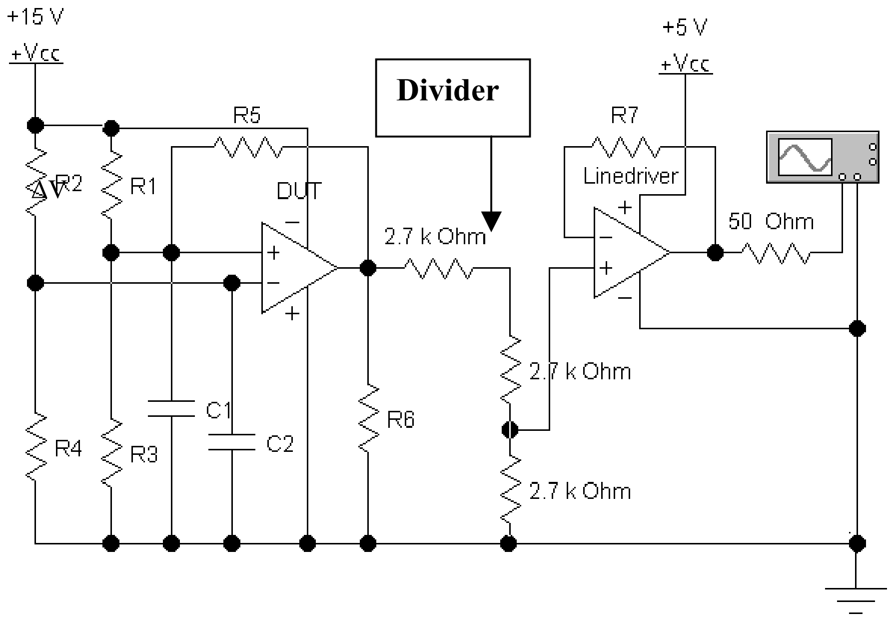

Fig. 1 Schematic drawing of the comparator test setup. The resistance dividers R1/R2 and R3/R4 maintain input voltage differences. The box to the right represents the oscilloscope with 50 Ω input resistance. R1 = 26.1 kΩ or 5.72 kΩ, R2 = 26.1 kΩ, R3 = 5.62 kΩ, R4 = 5.23 kΩ, R5 = 562 kΩ,

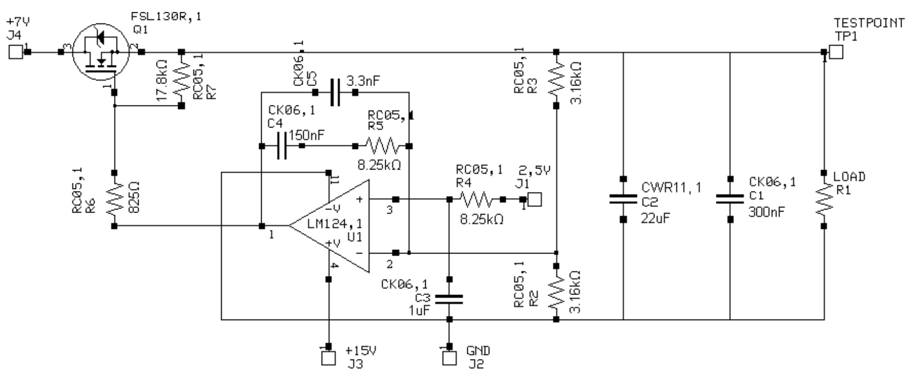

Fig. 2 Schematic drawing of the 5-volt regulator setup. The "load R1" is 115Ω.

III. Definition of the measured SET

The negative SET pulse amplitude is measured from the nominal DC level down to the lowest value as shown in Figure 3. The pulse duration is measured with the oscilloscope at the Full Width at Half Maximum (FWHM). So the total pulse length at the trigger level is about 80% longer in most of the images from the oscilloscope. After the line driver shown in figure 1 is the signal divided with 2, 50Ω out from the line driver and 50Ω as input resistance on the oscilloscope. Because of the "Divider" on the output from the comparator in figure 1, is the signal one third in on the line driver.
The vertical rising slope up to nominal DC level marked in the Figure 3 with "1", has afterwards been found to depend on the line-driver.

A voltage supply loss to the drivers made them not fully operational "rail-to-rail". This has later been confirmed with tests in our laboratory.

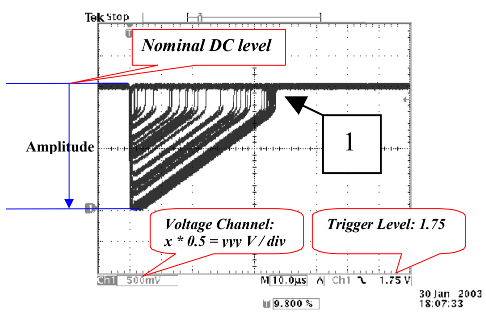

Fig. 3 Definition of the SET pulse amplitude

IV. RESULTS

A. LM124NS

No significant differences in the cross section have been observed between the two delta-input voltages, see Figure 4. From earlier investigations it has been found out that the ΔV_{IN} has little effect on the transient sensitivity, only that the lower ΔV_{IN} has little higher SET sensitivity [1]. The scatter diagrams in Figure 5 show the distribution of the pulse length versus the amplitude. SETs with amplitudes between 5 and up to 11-Volt correlate with the pulse length. The oscilloscope image shows pulse duration up to 45 µs, see Figure 6.

B. RH1014

The most considerable results from RH1014 are the long pulse lengths. Pulse duration up to 280 µs have been observed, see Figures 8 & 9. The cross-section is lower for this "rad hard" component compared to LM124NS and LM124TI, except at LET = 59 MeV/mg/cm^2 seen in Figure 8. Also here does not the cross-section show significant differences between the two delta-input voltages. Otherwise, the pulse duration was found to be about 30% longer for the lower delta input voltage of 0.2 V.

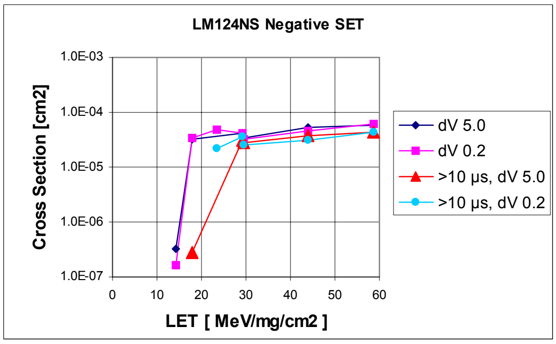

Fig. 4 SET cross-section vs. LET-value for all SETs and for the SETs longer than 10 µs are given for delta input voltages respectively.

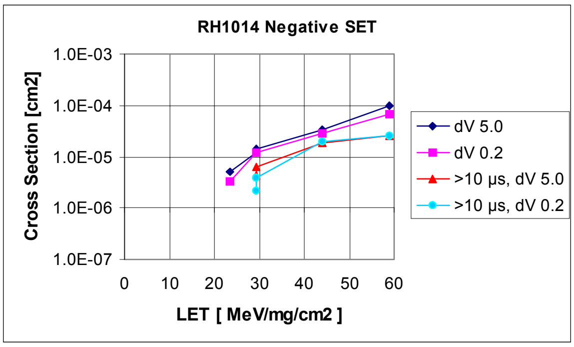

Fig. 7 SET cross-section vs. LET-value for all SETs and for the SETs longer than 10 µs are given for delta input voltages respectively.

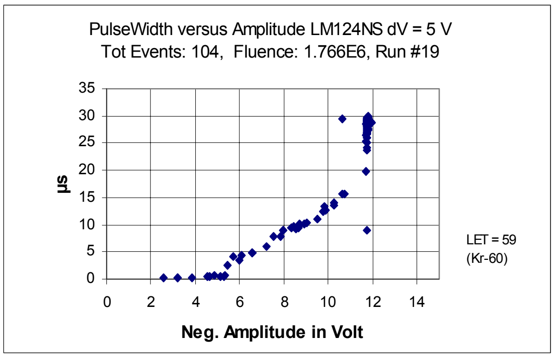

Fig. 5 Scatter diagram showing the pulse length at FWHM vs. the amplitude, ΔV_{in} = 5V.

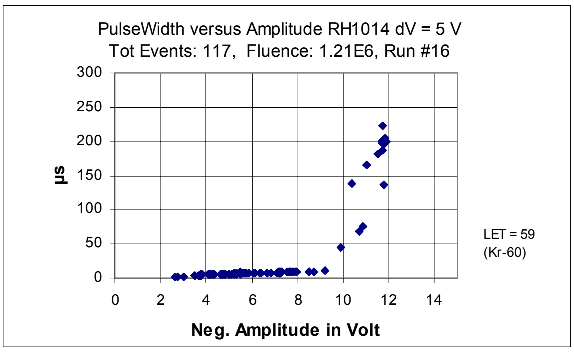

Fig. 8 Scatter diagram showing the pulse length at FWHM vs. the amplitude, ΔV_{in} = 5V.

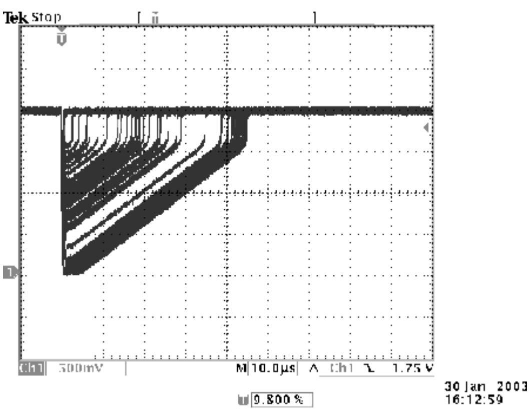

Fig. 6 Oscilloscope image of the SET's given in figure 2. X-scale = 10 µs/div. (LM124NS)

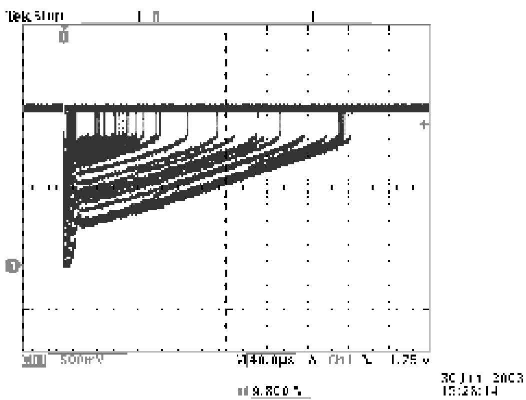

Fig. 9 Oscilloscope image of the SET's given in figure 4. X-scale = 40 µs/div. (RH1014)

C. LM124TI

LM124 from Texas Instruments have a cross-section very similar to LM124 from National Semiconductor. A major difference compared to the other two above is the shorter pulse lengths. The longest pulse duration is measured to be about 25 µs. See Figures 11 to 12 below.

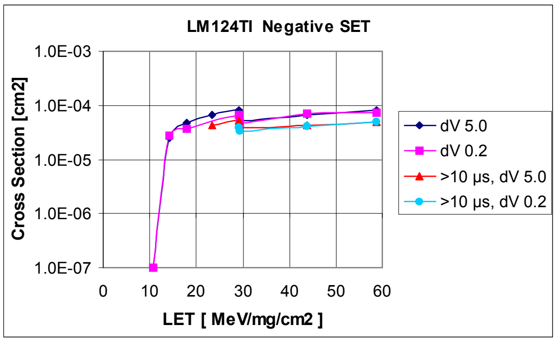

Fig. 10 SET cross-section vs. LET-value for all SETs and for the SETs longer than 10 µs are given for delta input voltages respectively.

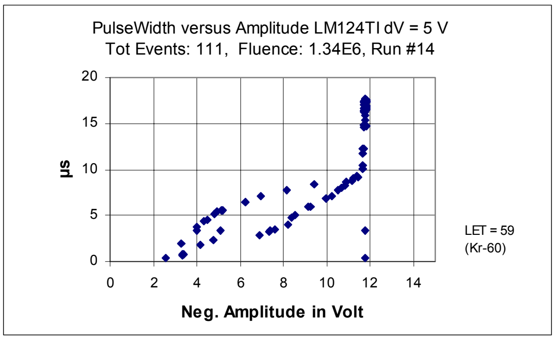

Fig. 11 Scatter diagram showing the pulse length at FWHM vs. the amplitude, ΔV_{in} = 5V.

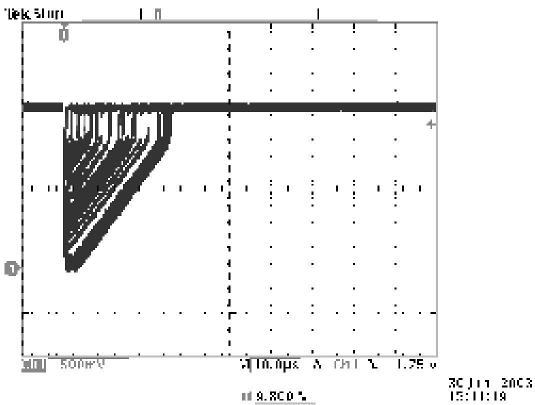

Fig. 12 Oscilloscope image of the SET's given in figure 8. X-scale = 10 µs/div. (LM124TI)

D. OP27

Op27 from Analog Devices indicate being almost insensitive for heavy ions. This OP-amplifier show a complete different response compared to the other three, see Figures 14-16. The largest measured amplitude was about 5 Volt and the longest pulse duration to about 50 ns.

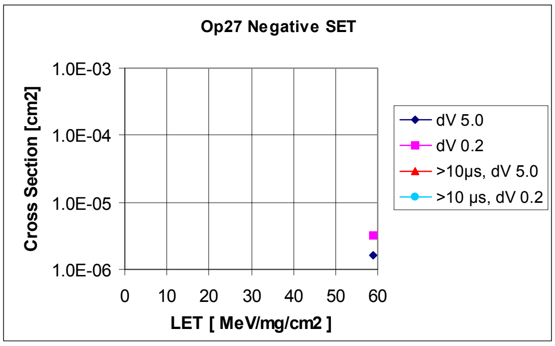

Fig. 13 SET cross-section vs. LET-value for all SETs and for the SETs longer than 10 µs are given for delta input voltage respectively.

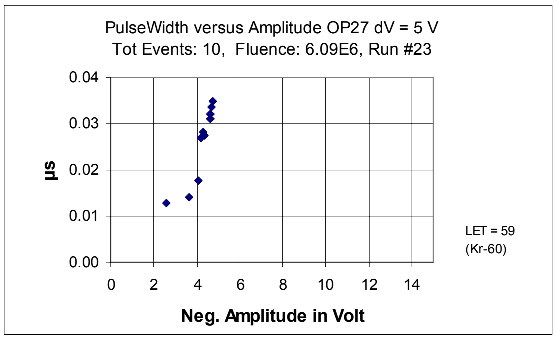

Fig. 14 Scatter diagram showing the pulse length at FWHM vs. the amplitude, ΔV_{in} = 5V.

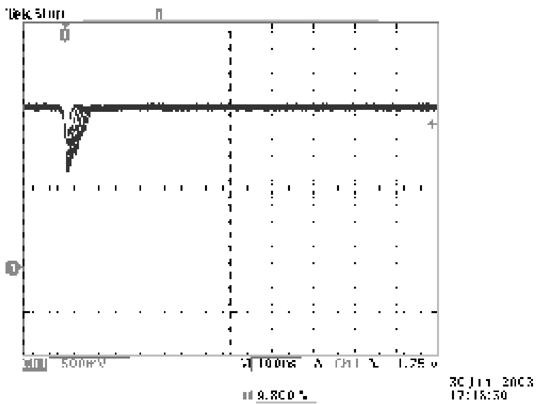

Fig. 15 Oscilloscope image of the SET's given in figure 11. X-scale = 100 ns/div. (OP27)

V. Discussions

Such parameters as Slew-Rate (SR) and the output current sink will explain the pulse shape. Two parts of the pulse are discussed and each part refers to figure 17.

1/ When a SET occur, the output stage chip sinks the existing capacitive charge. As an example, the current sink is typical 15 mA, the capacitive output load is approximately 15 pF and the capacitor is charged to 12 Volt. With these numbers the fall-time will be 12 ns.

2/ The inclination of the straight positive slope depends on the OP-amplifiers SR. From Figure 16 is the SR measured to be 0.23 V/µs, which is somewhat lower compared to the typical specification 0.5 V/µs.

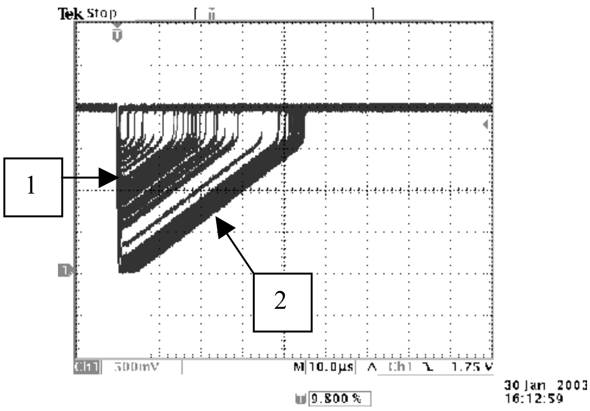

Fig. 16 LM124NS from a test run. The numbers in the figure refer to the text above

The Slew-Rate values in Table 2 are:
SR1 is determined from the SET oscilloscope images.
SR2 is post-irradiation measured values with a component tester.
SR3 is according to typical specification.

The theory above fits well for LM124 from both manufacturers. RH1014 have a difference of 10 times between specification and measured SR1 and at post-irradiation measurement the component was out of function. For OP27 it is very little of recorded test data.

Table 3 Slew Rate values. Sr1 from the SET oscilloscope images, SR2 post-irradiation measurements and SR3 acc. to specification.

Device	SR1 [V/µs]	SR2 [V/µs]	SR3 [V/µs]
LM124NS	0.23	0.22	0.5
RH1014	0.024		0.2
LM124TI	0.40	0.40	0.5
OP27	5.0	2.5	2.8

VI. Results from the 5 volt regulator

In the 5-Volt regulator application set-up the cross-section was determined to 3.68E-4 cm^2 for LET = 30.3 MeV/mg/cm^2. This value is somewhat lower compared to the test of LM124NS in the comparator mode, but this could be explained by the dead time in measure instruments. During that run was the flux too high, which gave as increase of the percentage dead time. This influenced also the distribution of the recorded data, but the tendency is seen in the figure 18 below, the pulse lengths and amplitudes correlate. Pulses greater than 0.1 Volt has duration between 50 to 80 µs, where the pulse amplitude correlates with the pulse duration. Maximum pulse duration of about 240 µs as in figure 17 correspond to the discharging time of the capacitor C2 in figure 2 from 5.5 to 5 Volt.
Negative pulses were not expected, since the RC time is about 2.5 ms and a negative SET is about 30 µs see figure 16, which will be a drop of about 60 mV (see figure 2, C2 = 22 µF and R1 = 115 Ω).

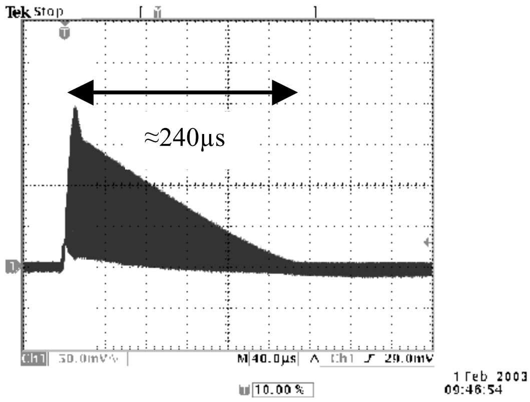

Fig. 17 Oscilloscope picture showing the positive going SET pulses.

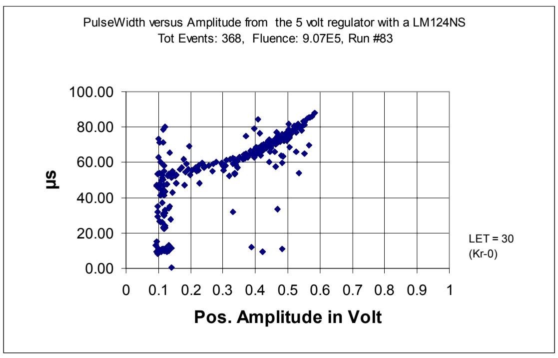

Fig 18 Scatter diagram showing positive pulse length at FWHF in µs vs. amplitude in Volt,

A PSpice simulation of this regulator shown in Figure 19 shows a similar pulse shape as to the observed positive pulses shown in figure 17.

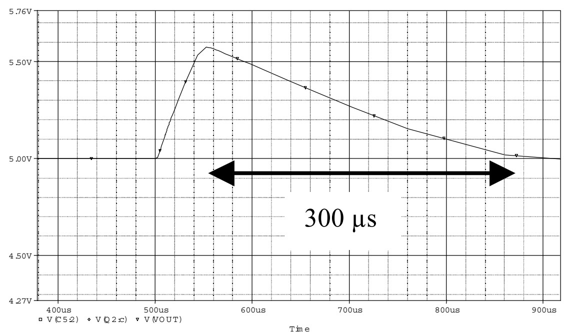

Fig. 19 Result from a PSpice simulation of the 5-Volt regulator.

VII. Conclusions

Results from this investigation have shown that the OP-Amplifier OP27 is most resistant to heavy ion irradiation. The other three, LM124NS, RH1014 and LM124TI show a similar sensitivity for heavy ion irradiation. Between the two LM124 OP-Amplifiers there are only minor differences between them such as the pulse duration and the threshold LET value which is somewhat lower for LM124TI. The rad hard device RH1014 has even a lower threshold LET value, but the pulse duration showed to be much longer for this component. Low or high delta input voltage on the OP-Amplifiers have not shown any significant differences in the cross-section, which is in accordance with earlier investigations by C. Poivey et al [1].
With help of known electrical parameters for an OP-Amplifier the response for heavy ion irradiation more or less can be predicted, especially regarding the pulse duration.
To avoid most problems it looks like that OP27 seems to be the best choice to use in space environment.

VIII. Acknowledgements

The authors would like to acknowledge the help from the staff at Heavy ion facility at Jyväskylä in Finland and at the CYClotron of Louvain la Neuve in Belgium The authors would also like to thank Design Engineer John Simonsson at Saab Ericsson Space AB for his help in the PSpice simulation and System Design Manager Anders Boström and Analysis Laboratory Manager for all interesting and fruitful discussions.

IX. References

[1] C. Poivey, J.W. Howard, S. Buchner, K. A. Label, J. D. Forney, H. S. Kim and A. Assad. “Development of a Test Methodology for Single Event Transients (SET) in Linear Devices”, NASA publications, 2001.