PROJECT

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TITLE

# Heavy Ion Effects in Opto-Couplers

EUROPEAN SPACE AGENCY
CONTRACT REPORT

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**SUMMARY**

This report presents the Single Event Effects results from heavy ion tests of opto-coupler 66168 from Mii Optoelectronic. Large increase in SET cross section was observed for 90 degree compared to 0 degree of ion incident angle. For 90 degree, a SET cross-section of about 2.5E-5 $cm^2$ with a threshold LET of about 10 $MeV/mg/cm^2$ have been measured. Pulse duration's less than 100 ns with amplitudes of about 3 Volt have been recorded. For the highest LET studied (LET=29.4 MeV/mg/cm2) a few pulses of µs duration have been observed. These pulses have an amplitude of about 1 Volt. No concise explanation for these longer pulses can be given in the present study. The test results indicate that the SET response is mainly driven by the photo transistor.

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# 1. ABSTRACT

This report presents the Single Event Effects results from heavy ion tests of opto-coupler 66168 from Mii Optoelectronic. Large increase in SET cross section was observed for 90º compared to 0º of ion incident angle. For 90º degree, a SET cross-section of about 2.5E-5 $cm^2$ with a threshold LET of about 10 MeV/mg/$cm^2$ have been measured. Pulse duration's less than 100 ns with amplitudes of about 3 Volt have been recorded. For the highest LET studied (LET=29.4 MeV/mg/cm2) a few pulses of µs duration have been observed. These pulses have amplitude of about 1 Volt. No concise explanation for these longer pulses can be given in the present study. The test results indicate that the SET response is mainly driven by the photo transistor.

# 2. INTRODUCTION

Transients induced in opto-couplers by protons were identified as the cause of anomalies in the Hubble Space Telescope [1]. In laboratory tests transients from protons with duration of 20-60 ns were observed. The results were assumed to be proton recoil products in the large-area photo detector of the opto-coupler. The results showed an unexpected increase in cross section for incident angles above 80 degrees. Further studies [4] have shown that the large increase in SET cross section for protons at incident angles close to 90 degree is consistent with the increase in cross section that is expected when direct proton ionization begins to contribute.

In heavy ion experiments [3] of the same opto-couplers transient pulses with increasing duration exceeding 400 ns for long range particle has been observed. Simulations indicate that the ion range must exceed 50 µm to characterize the cross section and pulse duration in those devices. The studied types were all fabricated in sandwiched configuration with the LEDs mounted on a separate substrate above the photo detector.

The present paper investigates the effects of heavy ions on the 66168 opto-coupler from Mii Optoelectronics. This devise is a lateral coupled opto-coupler which require chemical disassembly of the coupling medium before testing. A first test was performed at the CYClotron of Louvain la Neuve (CYCLONE) in Belgium. The observed small number of pulses was interpreted as limited range for the heavy ions. The results presented in this report are from tests performed at the Cyclotron at the University of Jyväskylä in Finland, where the ion beam energies are higher.
This study was aimed to be the first in a series where opto-couplers commonly used in ESA projects should be tested using heavy ions.

# 3. OPTO-COUPLER STRUCTURE

## 3.1 Test Samples

Two test samples were opened and the opto-coupling medium was removed by using chemical solvent. Fig 3.1.1. show the inside of the package before and after the coupling medium has been removed. In Fig 3.1.2 a close up picture of the LED and the phototransistor is shown from the top (0° of incident angle) and from the side (90° of incident angle). The phototransistor base has the dimension 0,8 x 0,8 $mm^2$

| | |
|---|---|
| Part Type: | 66168 |
| Manufacturer: | Mii Optoelectronic Products Division |
| Date Code | “0017” |
| Quality: | JANTX |
| Sample #1; | LED and photo transistor with the coupling gel removed. |
| Sample #2; | Photo transistor without the LED and the coupling gel |

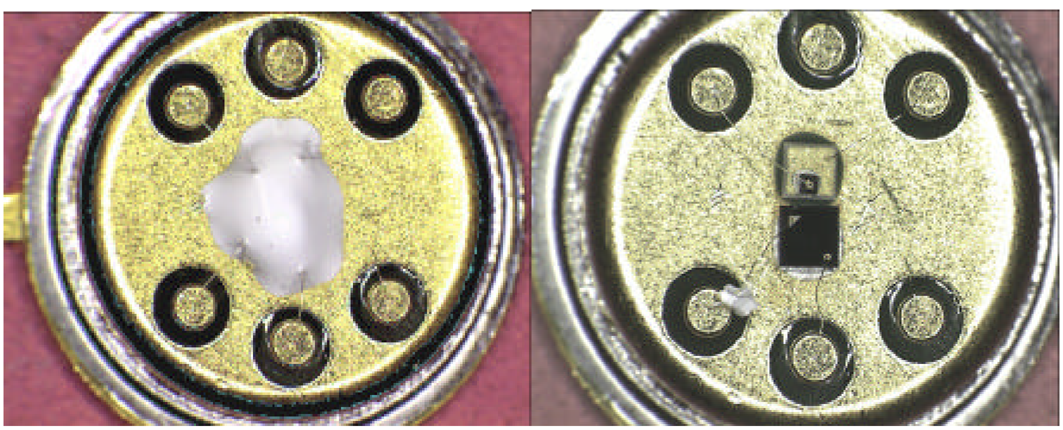

*Figure 3.1.1. Left, picture of the opened opto-coupler with light guiding gel. Right, same opto-coupler with the coupling gel removed*

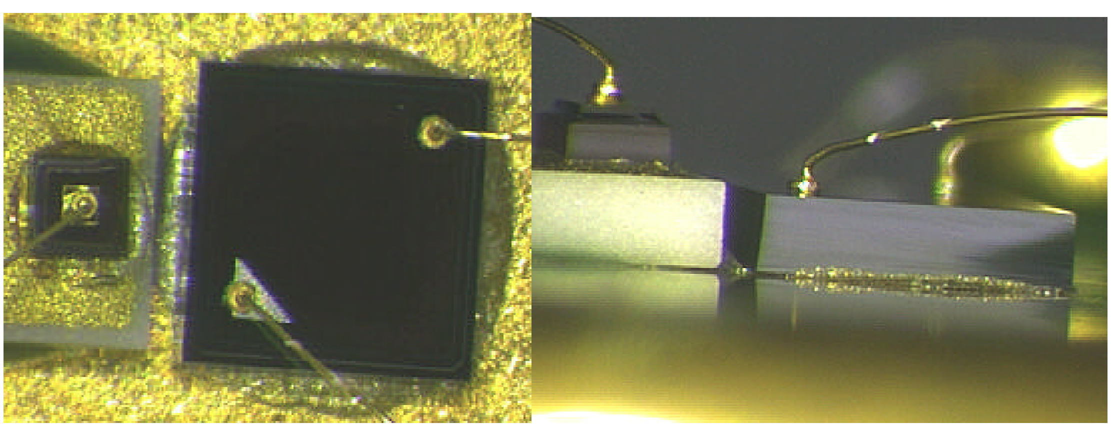

*Fig 3.1.2 Left; Close-up picture of the photo diode and the photo transistor from a 0° incident angle view. Right; The opto-coupler seen from 90° incident angle view. The coupling gel has been removed from the opto-coupler.*

## 3.2 Electrical Measurements of Prepared Samples

Electrical tests have been performed in order to verify if the photo transistor is sensitive for light from the LED without the light guiding gel. The LED emits light in the red region (700 nm). Two pulses with different durations (0.8 & 2.0 µs) generated by a pulse-generator were applied to the LED of sample #1. The result for the 2µs pulse measurement is shown in Fig 3.2.1. This indicates that the photo-transistor is sensitive for light without the gel. Electrical verification of sample #2 was performed to check the functionality

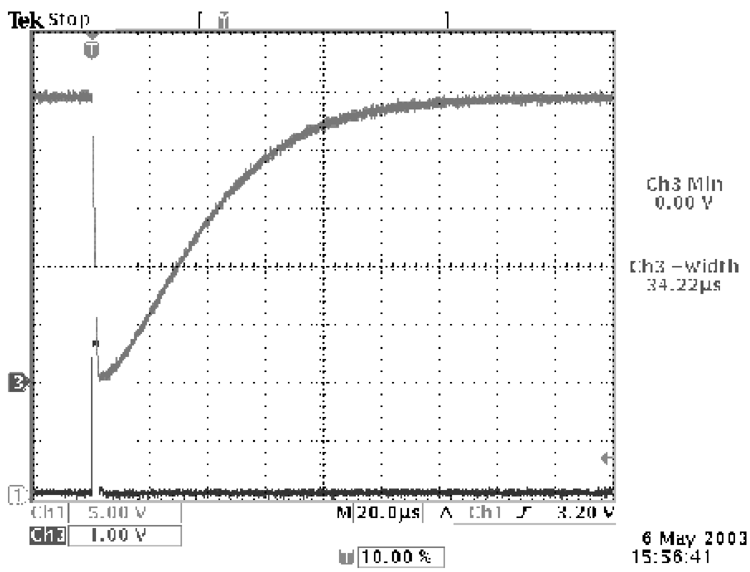


*Figure 3.2.1 Photo-transistor response with a 2 µs long electrical pulse applied to the LED in sample #1.*

# 4. TESTING TECHNIQUE

Single Event Transient (SET) pulses were measured with two oscilloscopes (Tektronix TDS3054, 500 MHz, 5GS/s), one oscilloscope for negative and one for positive SET pulses. For each SET event the pulse length and the pulse height were registered on a computer. Since the process time per SET event is about 20 ms, the flux of the heavy ion beam was adjusted to avoid dead time in the system. The test software was developed by use of “Labview software” for the GPIB communication between the computer and the oscilloscope. All results were stored as common ”Excel-files”.

## 4.1 Bias Condition and Test Set-ups

All devices were biased with +5 VDC and with the base terminal open on the transistors. The bias condition is such that the LED is off. Schematic drawings of the test set-ups are given in Figs 4.1.1 and 4.1.2 below for the two samples.

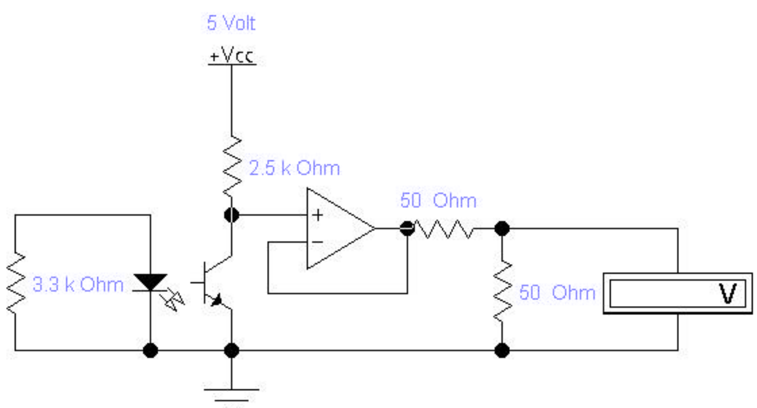


*Figure 4.1.1 Test set-up for sample #1 where the emitting diode and the photo transistor are working with the optical gel removed. The box to the right represents the oscilloscope*

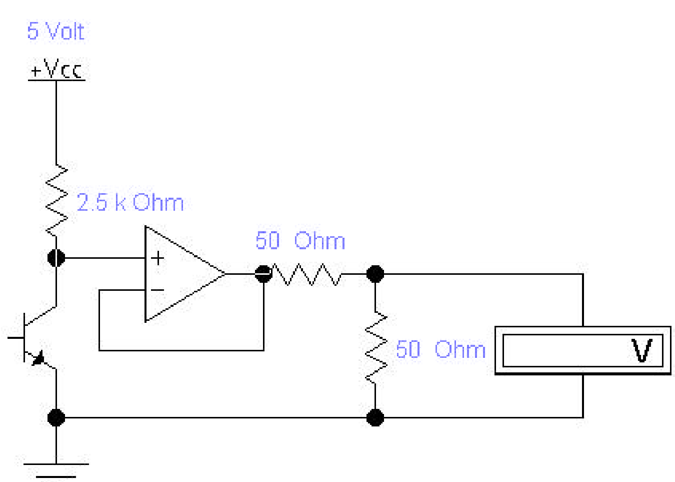


*Figure 4.1.2 Test set-up for sample #2 where the emitting diode and the optical gel are removed. The box to the right represents the oscilloscope.*

## 4.2 Pulse Parameter Definition

The pulse width is measured according to the oscilloscope specifications at the Full Width at Half Maximum (FWHM) of the measured amplitude.
The line driver output has a serial resistor of 50 ohm and the oscilloscope is set to 50 ohm input resistance, so the measured signal by the oscilloscope is one half of the input on the line driver. This means that all measured amplitudes are multiplied with a factor of 2.

## 4.3 Heavy Ion Test Facility

Heavy ion tests were performed both at the CYClotron of Louvain la Neuve (CYCLONE) in Belgium and at the Cyclotron at the University of Jyväskylä in Finland. The ions used at the two facilities are given in the Tables 4.1 and 4.2 below. Test data as ion beams, flux, fluence and number of SETs for the various test runs are given in Appendix A.

TABLE 4.1 HEAVY IONS USED AT LOUVAIN LA NEUVE IN BELGIUM

| **Element** | **Energy** MeV | **Range(Si)** µm | **LET value (Si)** [ MeV/mg/cm$^2$ ] |
|---|---|---|---|
| 84 Kr | 316 | 43 | 34 |

TABLE 4.2 HEAVY IONS USED AT JYVÄSKYLÄ IN FINLAND.

| **Element** | **Energy** MeV | **Range(Si)** µm | **LET value (Si)** [ MeV/mg/cm$^2$ ] |
|---|---|---|---|
| 30 Si | 280 | 127 | 7.1 |
| 56 Fe | 523 | 95 | 18 |
| 82 Kr | 766 | 93 | 29.4 |

# 5. RESULTS

## 5.1 Cross Section and Angle Dependence

The range of the ions at the Jyväskylä facility is believed to be long enough to make comparison experiments with the two samples in order to verify the influence of the photodiode on the SET behaviour.
The dependence of angle of incident was verified using $^{82}$Kr beam in 0° and 90°. The 90° angle was found to be about 100 times more sensitive than 0° for the photo transistor. The amount of SET generated by the LED can be observed in 0°, where the photo transistor is very insensitive. The complete opto-coupler (LED+photo transistor) was found to be a factor of 10 more sensitive in 90°. The results for the two samples are shown in Fig. 5.1.1. Similar results have earlier been reported for proton SET [1, 4].

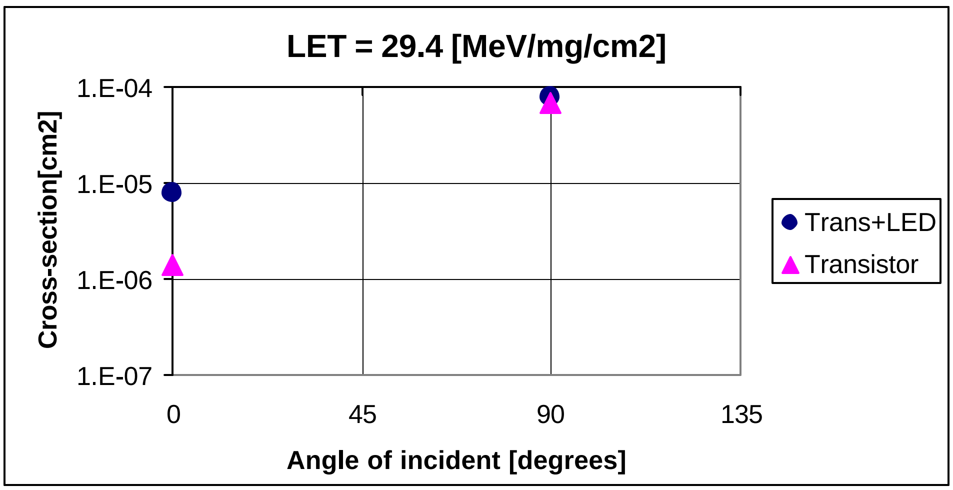


*Fig 5.1.1 Cross sections for 0° and 90° ion incident angle for LED+ photo transistor and for photo transistor alone. Note that at 0° the cross section for LED + photo transistor is a factor 10 times higher than for the photo transistor alone.*

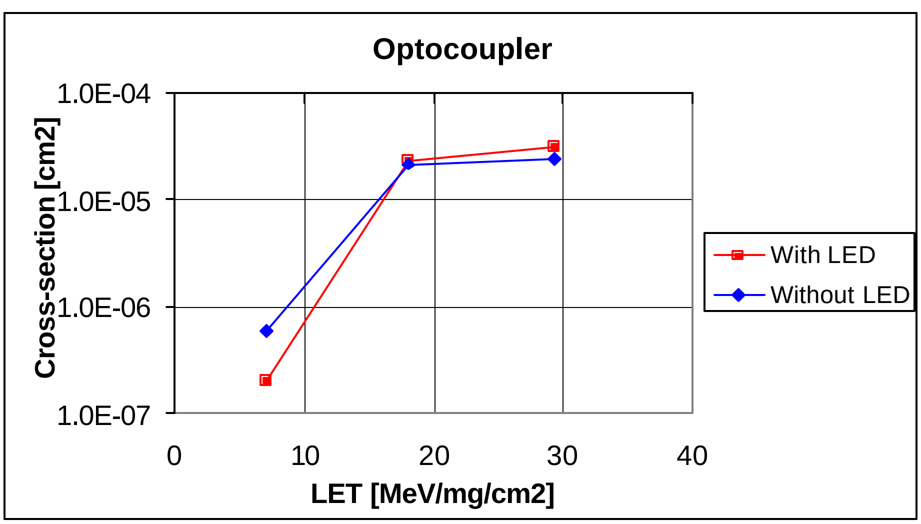


*Figure. 5.1.2 SET cross-section versus LET-value for the two samples with and without LED. At LET=7.1 MeVcm2/mg no SET was observed for sample #1 up to a fluence of 3,3E6 ions/cm2. The data point indicates the upper limit.*

The SET cross sections as a function of LET were only measured in the most sensitive angle 90° and the results are shown in Fig. 5.1.2. As can be seen from the figure, the photo transistor is the main contributor to the SET cross sections (sample #2 about the same cross section as sample #1). A small contribution from the LED to the SET cross section could be observed at the highest LET value 29,4 MeVcm2/mg.

### 5.1.1 Scatter Diagrams and Oscilloscope Images

All recorded SET pulses are negative, e.g. pulses going from the maximum output DC level at 5 Volt towards the ground level since the phototransistor are biased to the off state. As can be seen from the scatter diagrams below, the majority of the pulse lengths are shorter than 100ns with amplitudes varying from about 0.5 to 3.5 Volt. All presented results are from 90 degree incident angle.
For Kr ions with LET = 29.4 MeV/mg/cm$^2$, a few pulses have been observed with a durations in the range of µs.

## 5.2 Sample #1, LET 29. 4 MeV/mg/cm$^2$

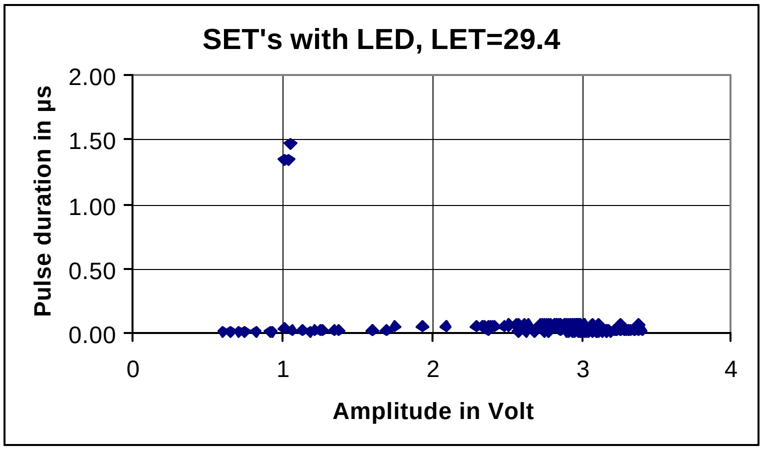


*Figure 5.2.1 Scatter diagram showing the SET pulse FWHM in µs versus the amplitude in Volt.*

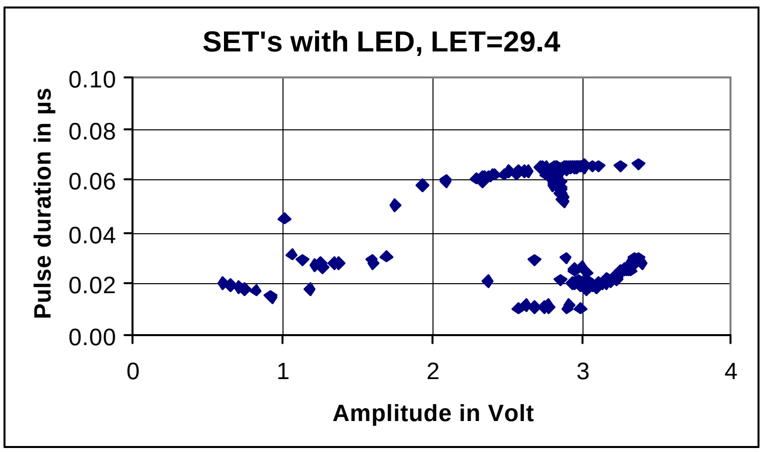


*Figure 5.2.2The same Scatter diagram as 5.2 but with the Y-scale enlarged.*

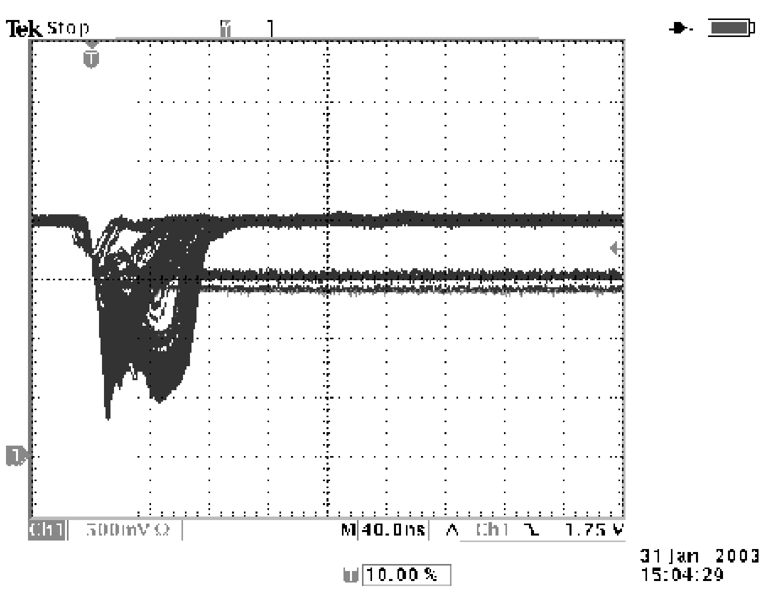


*Figure 5.2.3 Oscilloscope picture showing the SET pulses given in figure 5.2.1 and 5.2.2.*

## 5.3 Sample #2 for LET= 29.4 MeV/mg/cm²

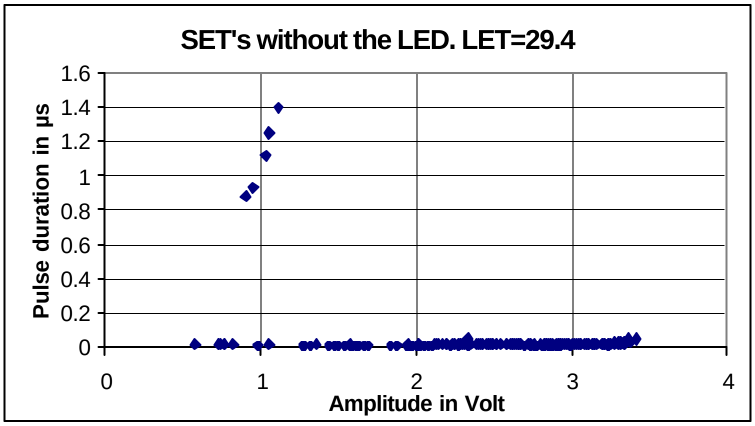


*Figure 5.3.1 Scatter diagram showing SET pulse FWHM in µs versus the amplitude in Volt.*

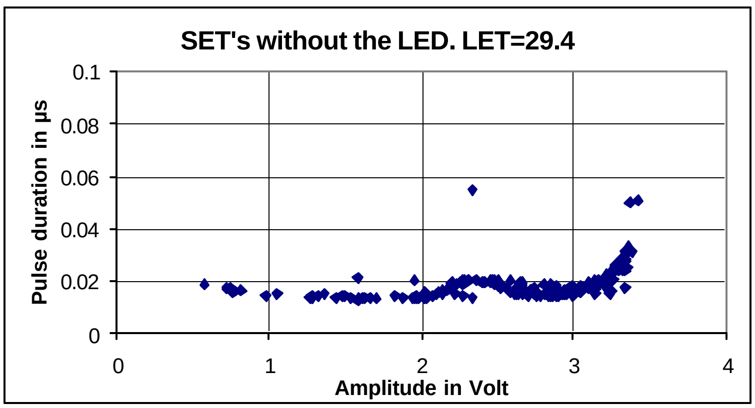


*Figure 5.3.2 The same Scatter diagram as 5.3.1 but with the Y-scale enlarged.*

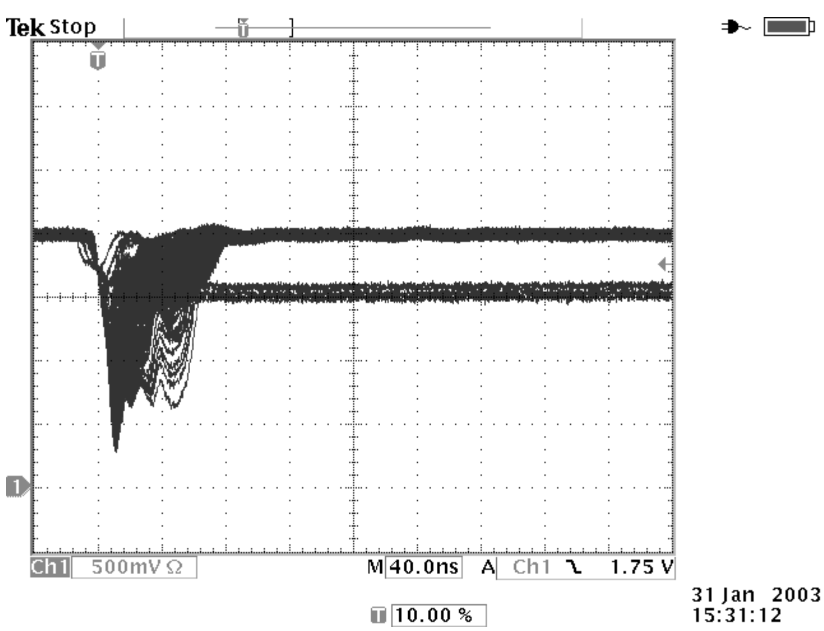


*Figure 5.3.3 Oscilloscope picture showing the SET pulses given in figure 5.3.1 and 5.3.2*

## 5.4 Sample #1 for LET = 18 MeV/mg/cm²

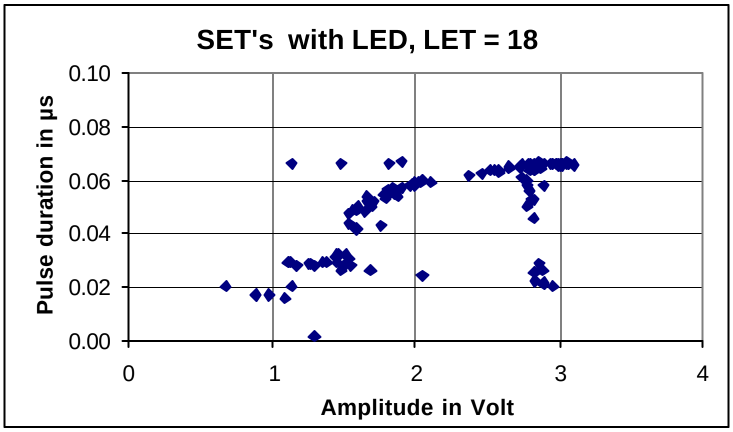


*Figure 5.4.1 Scatter diagram showing SET pulse FWHM in µs versus the amplitude in Volt.*

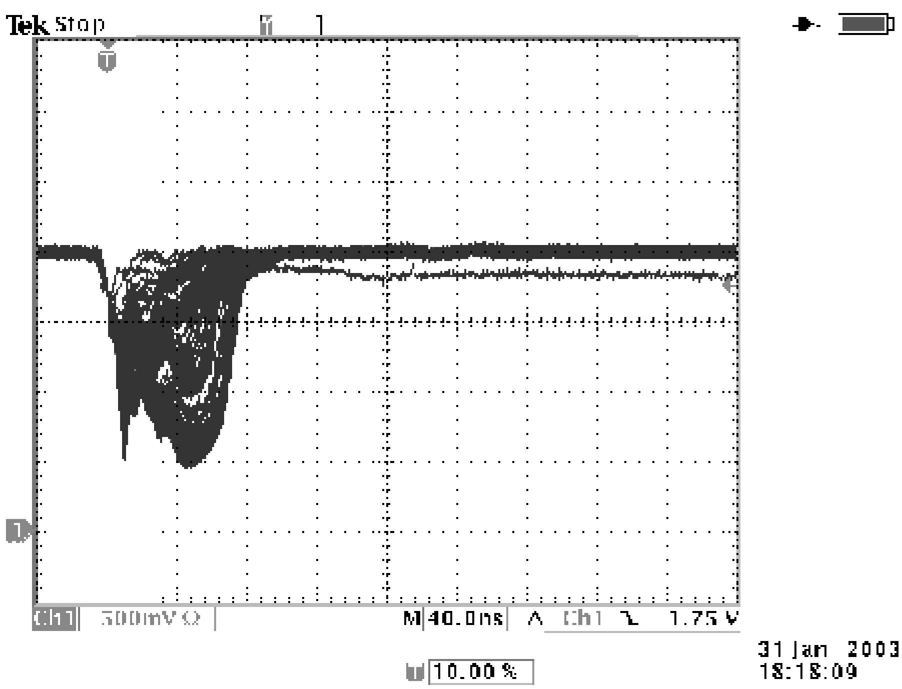


*Figure 5.4.2 Oscilloscope picture showing the SET pulses given in figure 5.4.1*

## 5.5 Sample #2 for LET = 18 MeV/mg/cm$^2$

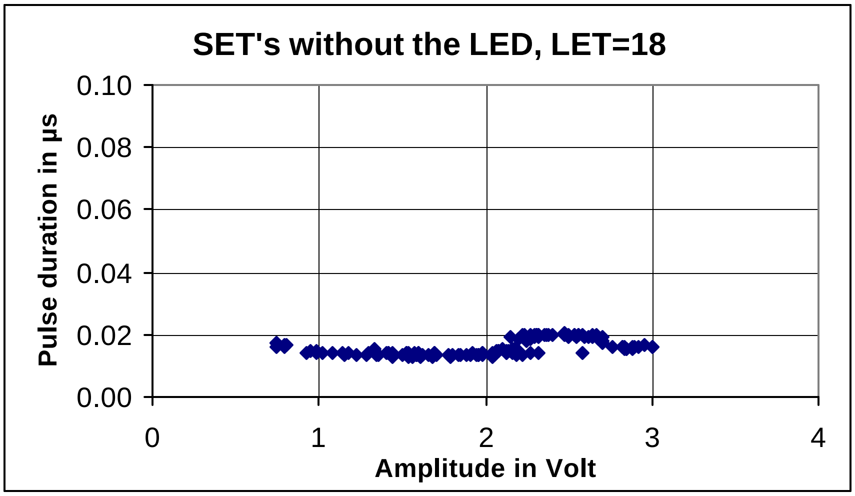


*Figure 5.5.1 Scatter diagram showing SET pulse FWHM in µs versus the amplitude in Volt.*

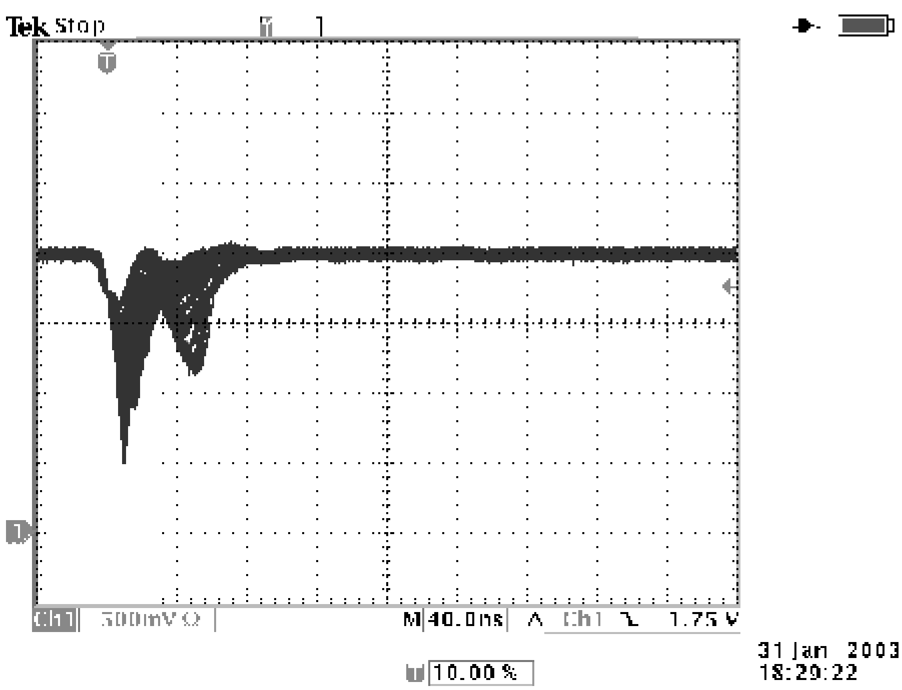


*Figure 5.5.2Oscilloscope picture showing the SET pulses given in figure 5.5.1*

## 6. DISCUSSIONS

Both amplitude and pulse width have to be considered when describing transients from linear devices. At low LET values (Si, LET=7,1 MeVcm2/mg ), a short single pulse shape and width were observed in the majority of test runs. For higher LET values, the pulse width associated with the dominant response increases along with the relative numbers of pulses from the dominant distribution. The original sharp short width pulse observed for low LET values are for higher LET ions followed by “ringing pulses” of higher amplitudes and larger widths. This trend seems to have reached a constant level at LET = 18 MeVcm2/mg, which in the present study indicate the threshold LET value for this device type. There are basically no difference in pulse shape at 90 degree incident angle between sample #1 ( LED + photo transistor) and sample #2 (phototransistor only) indicating that the SET response is generated by the photo transistor. In a previous study [3] “double pulses” were observed when irradiation was done at angles. The wide pulse shapes were interpreted as a superposition of pulse widths due to responses of diffused charge from the photo transistor.

All test runs have been performed in 90 degree incident angle due to the large probability. However, the results shown in Fig 5.1.1 indicate that zero degree incident angles has a cross section which is 10 times higher for LED + photo transistor than for photo transistor alone. This point to the fact that the LED have influence on the cross section even if it is not comparable with the cross section at 90 degree for the photo transistor.

Computer calculations of the time response of photo detector response made by Dodd et at al [5] have shown that a significant fraction of the diffused charge is collected in time periods below 150 ns when long range ions are used. This is in line with the observed results with an upper limit of about 100 ns for almost all pulses. Charge collections measurements of the photo transistor of 4N49 opto-coupler [3] indicate that the effective collection depth of this device is about 44 um. Thus, the gradual increase in width of the dominant response, associated with the photo transistor, is consistent with that charges are collected over extended time periods.

In the present study there are no means of determining the origins of the observed pulse shapes. At and above the threshold LET (around 10-18 MeVcm2/mg), the overall pulse shape seems to be a composition of several pulses making up the total pulse width. Nominal incident ion beam indicate very little of the “multi-shaped” pulses. This may be a result of the very low probability of SET in the transistor base at normal incident angle (a few SETs in E7 ions/cm2)

On each test run with a fluency of a few E6 ions/cm2, two to three SET pulses of microsecond duration were observed. The amplitude of these pulses are always around 1 V. The amplitude and for opto-coupler extremely long SET pulse duration suggest that these pulses are some type of disturbances. This has not been experimentally verified.

## 7. CONCLUSION

A SET cross-section of about 2.5E-5 $cm^2$ with a threshold LET of about 10 MeV/mg/$cm^2$ have been measured. Pulse duration's less than 100 ns with amplitudes of about 3 Volt have been recorded. For the highest LET studied (LET=29.4 MeV/mg/cm2) a few pulses of µs duration have been observed. These pulses have amplitude of about 1 Volt.
No concise explanation for these longer pulses can be given in the present study.
The test results indicate that the SET response is mainly driven by the photo transistor.

A SET test survey is recommended of all opto-coupler devices used in European projects in order to verify that all used types are free from heavy ion anomalies.

## 8. REFERENCES

[1] K.A. LaBel et.al "Proton-Induced Transients in Optocouplers: In-Flight Anomalies, Ground Irradiation Test, Mitigation and Implications" IEEE Trans. Nucl. Sci., 44, p1895, December 1997

[2] K.A. LaBel et.al "A Compendium of Recent Opto-coupler Radiation Test Data"

[3] A.H.Johnston et.al. Single-Event Upset Effects in Optocouplers, IEEE Trans. Nucl. Sci. 45(6), 2867 (1998)

[4] A.H.Johnston et.al "Angular and Enargy Dependence of Proton Upset in Optocouplers, IEEE Trans. Nucl. Sci., 46(6), 1335 (1999)

[5] P.E.Dodd et al "Three Dimensional Simulation of Charge Collection andMultiple-Bit Upset in Si Devices", IEEE Trans. Nucl. Sci. 41, 2005 (1994)

## 9. Appendix

Raw data from the test runs.

| *RUN#* | *ION* | *LET* | *FLUENCE* | *Flux* | *Sample* | *Angle of incident* | *Neg. pulses* |
|---|---|---|---|---|---|---|---|
| 1 | Kr | 29.4 | 1.00E+07 | 15k | 1 | 0 | 78 |
| 2 | Kr | 29.4 | 1.00E+07 | 15k | 2 | 0 | 14 |
| 3 | Kr | 29.4 | 1.93E+06 | 15k | 2 | 90 | 115 |
| 4 | Kr | 29.4 | 1.65E+06 | 15k | 1 | 90 | 137 |
| 5 | Kr | 29.4 | 2.18E+06 | 15k | 1 | 90 | 183 |
| 6 | Kr | 29.4 | 1.13E+06 | 15k | 1 | 90 | 70 |
| 7 | Kr | 29.4 | 3.21E+06 | 15k | 1 | 90 | 257 |
| 8 | Kr | 29.4 | 3.63E+06 | 15k | 2 | 90 | 240 |
| 9 | Si | 7.1 | 5.68E+06 | 9.5k | 2 | 90 | 0 |
| 10 | Si | 7.1 | 4.59E+06 | 9.5k | 1 | 90 | 0 |
| 11 | Si | 7.1 | 8,46E+06 | 9.5k | 1 | 90 | 0 |
| 12 | Si | 7.1 | 3.36E+06 | 9.5k | 2 | 90 | 5 |
| 13 | Fe | 18.0 | 2.02E+06 | 7k | 1 | 90 | 123 |
| 14 | Fe | 18.0 | 2.64E+06 | 7k | 2 | 90 | 144 |
| 15 | Fe | 23.5 | 5.41E+06 | 7k | 2 | 53 | 10 |
| 16 | Fe | 23.5 | 7.63E+06 | 7k | 1 | 53 | 21 |