Radiation test of 8 bit Microcontrollers ATmega128 & AT90CAN128

A.Schüttauf *Astrium Space Transportation GmbH*, *Member IEEE*, S.Rakers, *Astrium Space Transportation GmbH*, C.Daniel *Astrium Space Transportation GmbH*

***Abstract*---We have performed heavy ion tests of the ATmega128 and AT90CAN128 micro controller. These COTS devices have shown a quite different sensitivity to SEL/SEU errors, where the current consumption showed a step like behaviour. Detailed measurements, analyses and on-orbit rates are presented.**

I. INTRODUCTION

THE usage of commercial off the shelf components (COTS) in space environment has become unavoidable since many semiconductor manufacturers have discontinued offering dedicated space or military grade components. Especially the availability of "state of the art" microcontrollers for space applications at a reasonable price is limited. The typically used 80C32 controller does often not match the nowadays needed performance and interface capabilities for modern payloads. In this framework we tested two general-purpose 8-bit microcontrollers (ATMEL ATmega128-AU16, AT90CAN128-AU16) in a heavy ion radiation test to assess their SEL/SEU sensitivity.

These high performance low power 8-bit microcontrollers provide 128kBytes in-system programmable flash memory, 4kBytes EEPROM and 4kBytes internal SRAM. They use an advanced RISC architecture up to 16 MIPS. Further built-in features are a master/slave TWI serial interface (I²C bus interface), an 8-channel, 10-bit AD converter with programmable gain set used for the inputs of primary current and temperature signals, and 53 digital I/O lines. The basic functional difference between the two microcontrollers is the CAN-bus interface, which only the AT90CAN128 offers.

II. TEST ENVIRONMENT

Tests with heavy ions have been carried out at the JYFL cyclotron in Jyväskylä/Finland where a LET range of 2 – 62 MeV $mg^{-1}cm^{2}$ is available.

In Figure 1 we show the setup used during the test. The Device Under Test (DUT) board was placed inside the vacuum chamber holding 2 piggy-boards with three microcontrollers on top for each derivate. Further the DUT board provided:

- Three power lines for the heaters
- One power line for the microcontroller DUTs (piggy pack) and the temperature sensor
- A temperature out signal for the digital voltmeter.

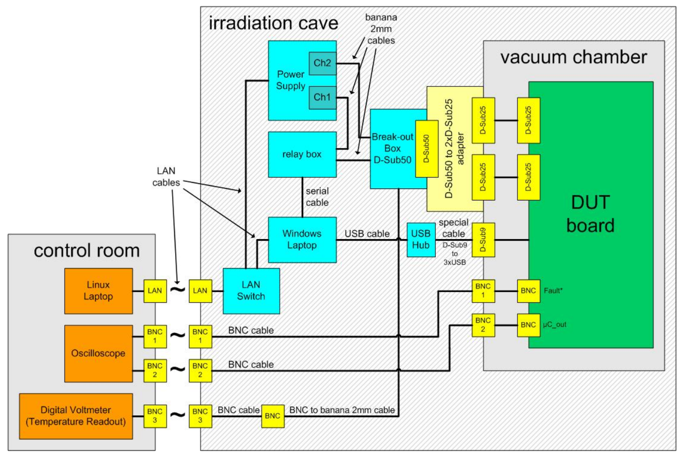

Figure 1: Radiation setup used for the test at Jyväskylä/ Finland.

Outside the vacuum chamber was a power supply, a windows laptop, a Break-out box (BOB), a relay box, an USB Hub and a LAN switch. The BOB is connected to an 8-port relay box and the relay box is connected to the power supply. The relay box is controlled by the Windows laptop. In this way up to eight DUTs can be powered controlled by the windows laptop without changing the wiring at the BOB.

The power supply provides two channels:

- Channel 1: Power supply for the DUT. This power supply is controlled via an Ethernet interface to a Laptop in the control room. This power supply has a fast over-voltage cut-off switch which is triggered by a latch-up. The software automatically resets the fuse after the latch-up is quenched.
- Channel 2: Power supply for the heaters. All samples are heated to 80°C during testing. The supply sits in the same mainframe like the DUT power supply and is also fully remote controllable.

A. SEU test application

During the irradiation the microcontrollers AT90CAN128 and ATmega128 executed permanently a memory test program to detect SEUs. In a sequence the flash memory (128 kB), the EEPROM (4 kB) and the RAM (4 kB) was filled with pseudo random pattern. In this endless loop

978-1-4244-8404-1/10/$26.00 ©2010 IEEE

various memory areas are compared with the previously generated pseudo random pattern. The duty cycle of this test was 95% for Flash, 2.5% for EEPROM and 2.5 % for RAM. In case of a negative result of the comparison the program indicates the fault by one signal (positive edge) " µC_out ". Due to this the memory fault is overwritten by the program with the correct pattern and the comparison process is continued. The watchdog of the different microcontrollers is enabled and the timeout is typically 0.26 s (256K cycles).

The test program was placed in the boot-loader area of the flash memory, which was not included in the comparison process. An oscilloscope outside the irradiation chamber was used to count the transients appearing on the "fault & µC_out" line and the fault pulses generated by the microcontroller.

B. SEU results

The SEU cross sections are presented in Figure 2 for the ATmega128 (upper) and AT90CAN 128 (lower) were the error-bars include the statistic and systematic errors. For the Weibull fit we assumed a vanishing cross section at 10% of the Krypton LET (32.1 MeVcm^{-2} mg^{-1}). The parameters of these fits are noted in Tab. 1. A comparison between the two microcontrollers shows, that the AT90CAN128 has a 3 orders of magnitude higher SEU saturation cross section (8.0 10^{-2} cm^2) than the ATmega128 (1.11 10^{-5} cm^2).

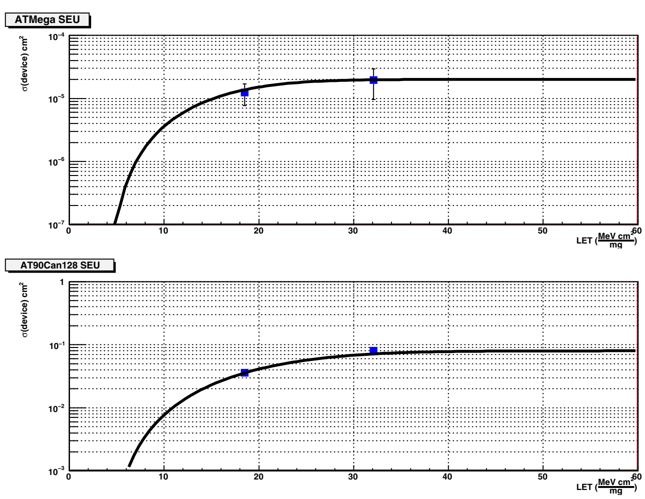

Figure 2: ATmega128 and AT90CAN128 SEU cross sections (cm^2 /device) versus the LET (MeVcm^{-2}mg^{-1})

C. Latch-up test application

During the irradiation the SELs were determined by a current threshold of the individual DUTs. All measurements were performed using a heating device for each DUT to a temperature of 80 °C.

D. SEL results

The microcontroller setup consists out of 4 devices powered by a mezzanine board, 3 for the irradiation test and 1 as a reference sample. The power for the mezzanine board was supplied by a standalone low voltage power supply. For the analysis we attributed similar power consumption to each microcontroller type and subtracted 75% of the measured current consumption during the non-irradiating phase. The Latch-up condition was fulfilled when a microcontroller passed during irradiation a fixed current threshold (I_{thr}) which was set at the power supply [3].

The fluence, needed to calculate the cross section, was individually dead-time corrected. To estimate the systematic uncertainty of this correction we compared the reconstructed with a fixed (3 s) dead-time per Latch-up. This systematic error for the cross section is below 1 % and folded into the statistical error.

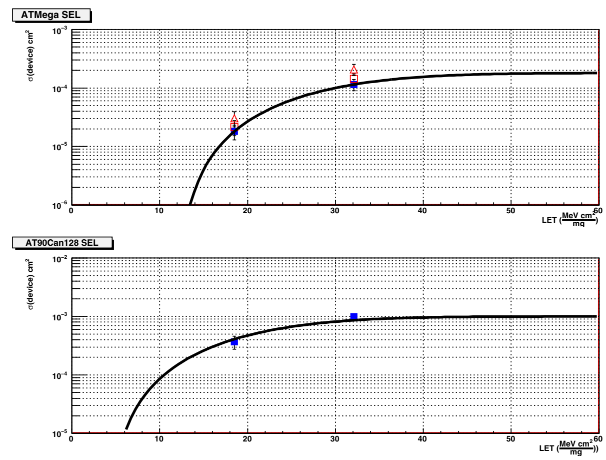

Figure 3: ATmega128 (upper) and AT90CAN128 (lower) SEL cross sections (cm^2) plotted versus the LET (MeVcm^{-2}mg^{-1}). For the ATmega128 we show on top the cross section enhancement by reducing the Latch-up threshold (I_{Thr}) to 0.3 and 0.2 (A) using open squares and triangles, respectively.

In the Figure 3 we present the measurement for the Latch-up test together with a Weibull fit though the data for the ATmega128 (upper plot) and AT90CAN (lower plot). Both microcontrollers were tested with Iron and Krypton ions at a fluence of 10^6 and 10^4 respectively. To perform the Weibull fit we assumed a vanishing Latch-up cross section at 30 % (ATmega128) and 10 % (AT90CAN128) of the Krypton LET (32.2 MeVcm-2 mg-1). The saturation cross section resulting from the Weibull fit shows, that the Latch-up probability differ by one order of magnitude (ATmega128 1.18 10^{-4} cm^2, AT90CAN128 1.0 10^{-3} cm^2). Comparing the SEL and SEU saturation cross sections it follows that the ATmega128 has an order of magnitude and the AT90CAN128 a two orders of magnitude lower sensitivity to Latch-ups.

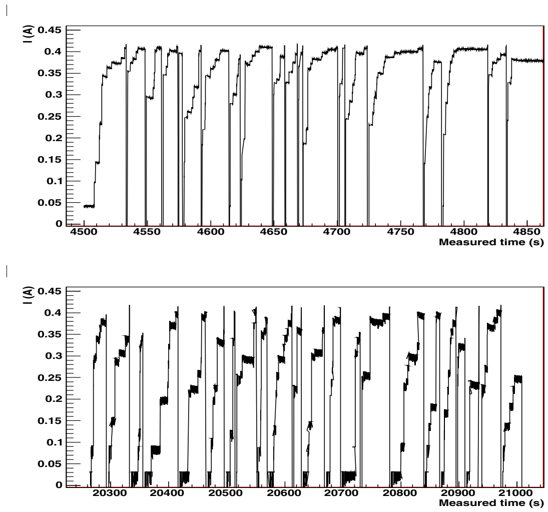

Figure 4: The ATmega128 (upper) and AT90CAN128 (lower) current (I) distribution depending on the irradiation time in seconds (s). The current is corrected for the offset introduced by the 3 additional microcontrollers on the piggy-board (not irradiated).

To determine the cross section in relation to the Latch-up threshold (I_{thr}) the current measurement was used (Figure 4) to calculate the electrical energy spectrum for each microcontroller individually. By integrating this spectrum for different current settings and normalizing it to the measured current spectrum, we were able to correct the fluence of each microcontroller individually. To minimize the statistical error we used all measurements at a given LET. The microcontroller dependent cross section enhancement factor is shown in Figure 5. for two different LET settings (18,2;32,2 MeV cm-2 mg-1). This factor has a hyperbolic dependence towards lower thresholds with a microcontroller dependent maximum (6-8). As a side remark it has to be pointed out, that the enhancement factor is insensitive to the LET of the irradiating particle. Therefore we can fold this function with the measured cross section to get an estimate for the Latch-up enhancement towards lower thresholds (I_{thr}).The reason to lower this threshold is based on the "step like" current distributions (Figure 4) during the irradiation of both microcontrollers and the limiting DC currents for the ATmega128 and AT90CAN128 with 200-400 and 200 mA respectively. These different thresholds can partially explain their different Latch-up cross sections. The overall trend for the current consumption during irradiation is presented in Figure 4, were the ATmega128 has "plateau like" behaviour before the Latch-up condition is fulfilled the AT90CAN128 tends to have "step like" behaviour which sets in at lower currents.

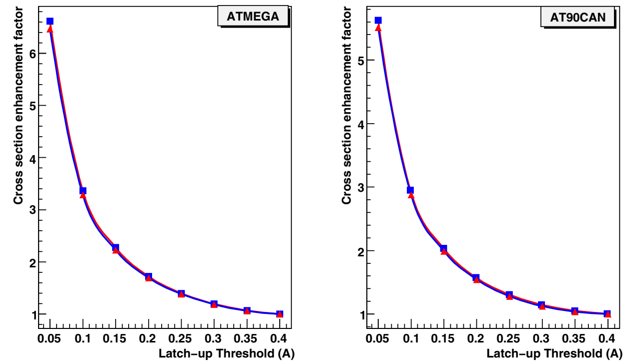

Figure 5: The cross section enhancement factor in relation to the applied Latch-up threshold I_{thr} (A) for the ATmega128 (left) and AT90CAN128 (right). The red triangles represent the calculation for the Iron LET and the blue squares for the Krypton LET.

E. Fit parameters

The data from the ATmega128 and AT90CAN128 microcontrollers have been fitted by Weibull distributions.

Table 1 shows the resulting fit parameters.

TABLE 1: WEIBULL FIT PARAMETERS FOR THE ATMEGA128 AND AT90CAN128 MICROCONTROLLER.

ATmega128 SEU	W [MeV cm^{-2} mg^{-1}]	13,49
	S	2,0
	L0 [MeV cm^{-2} mg^{-1}]	4,0
	σ0 [cm^2]	2.0E-05
AT90CAN128 SEU	W [MeV cm^{-2} mg^{-1}]	18,8
	S	2,0
	L0 [MeV cm^{-2} mg^{-1}]	4,0
	σ0 [cm^2]	8,00E-02
ATmega128 Latch-up	W [MeV cm^{-2} mg^{-1}]	20,1
	S	2,0
	L0 [MeV cm^{-2} mg^{-1}]	12,0
	σ0 [cm^2]	1,8E-04
AT90CAN128 Latch-up	W [MeV cm^{-2} mg^{-1}]	20,1
	S	2,0
	L0 [MeV cm^{-2} mg^{-1}]	4,0
	σ0 [cm^2]	1,0E-03

F. In orbit calculations

The data has been folded with the particle fluxes in the International Space Station (ISS) environment given in [1] for 500 and 100 mils shielding.

TABLE 2: UNDER NOMINAL CONDITIONS WITH 500 MILS SHIELDING, THE ATMEGA128 WILL LATCH ONCE IN 1310 YEARS AND THE AT90CAN128 ONCE IN 57 YEARS. THE SEU RATE FOR THE ATMEGA128 WILL BE ONCE IN 1630 YEARS AND FOR THE AT90CAN128 ONCE IN 7 MONTH.

ISS LEO 500 mils				
Function	**Nominal**	**Maximum Flare Peak**	**Max.Fl. Orbit average**	**Unit**
Latch-up ATmega	2,09 10-6	5,42 10-4	7,87 10-5	Day^{-1}
Latch-up AT90CAN	4,76 10-5	1,29 10-4	1,63 10-3	Day^{-1}
SEU ATmega	1,68 10-6	4,56 10-4	5,61 10-5	Day^{-1}
SEU AT90CAN	4,17 10-3	1,13	1,43 10-1	Day^{-1}

TABLE 3: UNDER NOMINAL CONDITIONS WITH 100 MILS SHIELDING, THE ATMEGA WILL LATCH ONCE IN 481 YEARS AND THE AT90CAN ONCE IN 24 YEARS. THE SEU RATE FOR THE ATMEGA128 WILL BE ONCE IN 690 YEARS AND FOR THE AT90CAN128 ONCE IN 3 MONTH.

ISS LEO 100 mils				
Function	**Nominal**	**Maximum Flare Peak**	**Max.Fl. Orbit average**	**Unit**
Latch-up ATmega	5,69 10-6	1,07 10-1	1,76 10-2	Day^{-1}
Latch-up AT90CAN	1,14 10-4	1,92 10-4	2,73 10-3	Day^{-1}
SEU ATmega	3,97 10-6	6,44 10-2	8,22 10-3	Day^{-1}
SEU AT90CAN	1,0 10-2	168	23,8	Day^{-1}

For a geostationary orbit at 38000 km with 0 ^{o} inclination and 100 mils shielding the following results were reached using the SPACERAD program with the CRÈME space weather conditions (M1, M2, and M3).

TABLE 4 CONSIDERING ONLY THE GALACTIC COMPONENT IN THE CREME CODE (M1), THE ATMEGA WILL LATCH ONCE IN 24 YEARS AND THE AT90CAN ONCE IN 1.5 YEARS. THE SEU RATE FOR THE ATMEGA WILL BE ONCE IN 56 YEARS AND FOR THE AT90CAN ONCE IN 1 MONTH.

GEO 100 mils				
Function	**CRÈME M1**	**CRÈME M2**	**CRÈME M3**	**Unit**
Latch-up ATmega	1,12 10-4	1,07 10-4	1,77 10-4	Day^{-1}
Latch-up AT90CAN	1.61 10-3	1,57 10-3	2,60 10-3	Day^{-1}
SEU ATmega	4,84 10-5	4,62 10-5	7,65 10-5	Day^{-1}
SEU AT90CAN	1,78 10-2	1,37 10-1	2,26 10-1	Day^{-1}

I. SUMMARY & CONCLUSION

A radiation test was performed using Iron and Krypton ions at a LET of 18.5 and 32.1 $MeVcm^{-2}mg^{-1}$. For the ATmega128 microcontroller we measured a Latch-up rate (SEL) of once in 481 years and for the AT90CAN128 a Latch-up rate of once in 24 years. A similar pattern was found for the SEU-tests where the ATmega128 has a rate of once in 690 years and the AT90CAN128 once in 3 month. Both SEEs rates are calculated for 100 mils aluminum shielding at an inclination of 51° and 400 km under quiet solar conditions.

This significant difference between the 2 microcontrollers was not expected from their electrical and technological properties. Comparing the thermal and electrical properties of the ATmega128 (-40-125 ^{o} C, 200-400 mA) and the AT90CAN128 we can point towards the difference, that the AT90CAN128 has the smaller temperature range -40-85 ^{o} C and a lower DC current limit 200 mA, except the CAN-bus interface. Additionally the current consumptions for both microcontrollers showed "step like" time dependence (Figure 2). This effect points towards a slow charging of sensitive structures or "Micro Latch Ups". During this behavior the microcontrollers did not show any degradation in terms of performance or reliability.

To minimize the overall power consumption of the microcontrollers we developed a method to determine a cross section enhancement factor in relation to the applied Latch-up threshold (I_{thr}). This method uses the current measurement (Figure 2) during irradiation to determine the electrical energy spectrum for each microcontroller individually. In first order the derived functions are independent on the LET of the ion species and show a hyperbolic shape towards smaller threshold currents (Figure 3). For both microcontrollers we determined for low current thresholds (I_{thr}< 50 mA) a cross section enhancement of ~10. As a result we recommend for the ATmega128 a Latch-up threshold of 150-200 mA which would enhance the cross sections by a factor 2.0-2.5, but keeps the current consumption well below the DC limit of 400 mA. For the AT90CAN128 this method leads to the conclusion that this microcontroller should not be used for space application due to its high Latch-up and SEU rates.

References

[1] NASA SSP30512, Space Station Ionizing Radiation Design Environment

[2] NASA SSP30513, Space Station Ionizing Radiation Environment Effects Test and Analysis Techniques

[3] ASTRIUM Space Transportation, SPAICE-RIBRE-TN-0018 Radiation Test Report