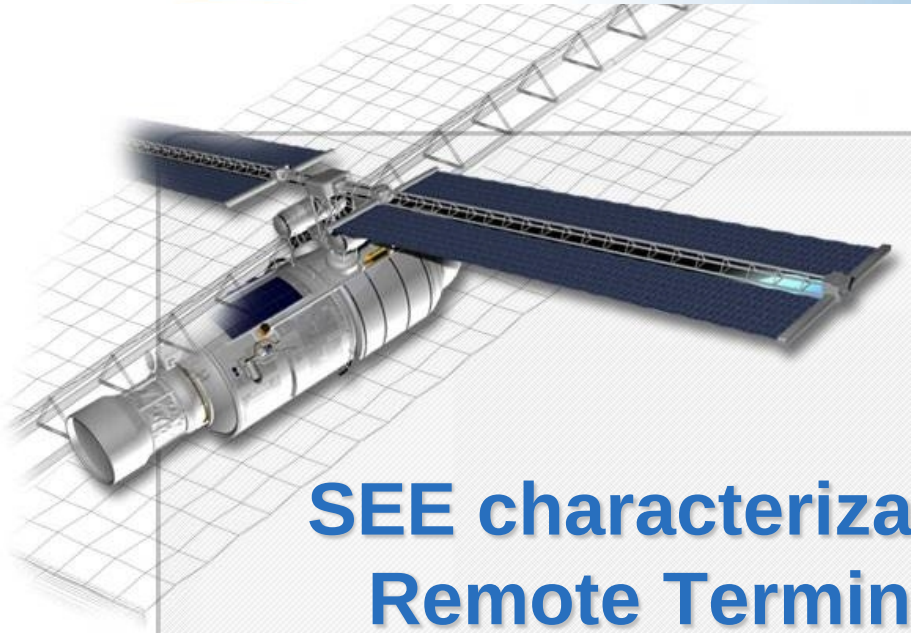


SEE characterization of SpaceWire Remote Terminal Control (RTC) AT7913 of ATMEL

Enoal LE GOULVEN, Pierre GARCIA, Alexandre ROUSSET, Ludovic PUYBUSQUE, Athina VAROTSOU

Outline

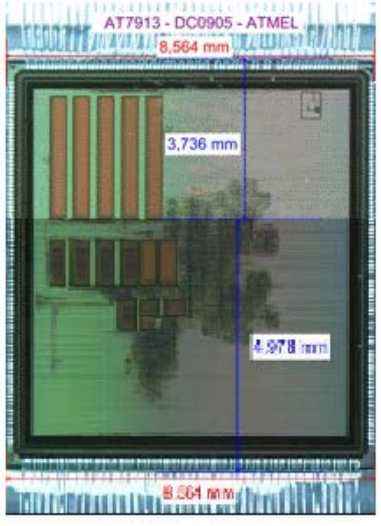
- **The project**
- **SEE tests**
  - Beam description
  - Device description
  - Test bench overview
  - For each function tested
    - Test method
    - Test results
- **Conclusion**

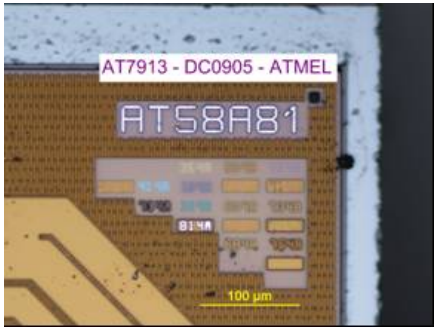
Aim of the project

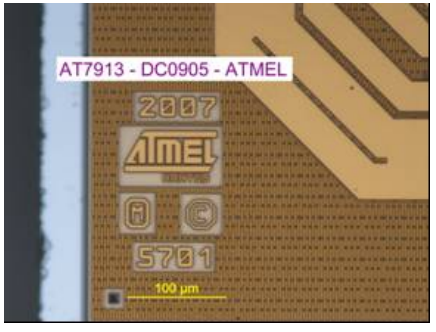
- The test has performed in response at request of European Space Agency
- The development has lasted several months
- 40 hours of beam facility have used, separated in two test campaigns.

SEE tests: Parts

PART IDENTIFICATION	
Type :	AT7913
Manufacturer :	ATMEL
Function :	SpaceWire Remote Terminal Controller
PARTS PROCUREMENT INFORMATIONS	
Packaging :	MCGA 349
Sample size:	2 irradiated samples







Beam description

Irradiation facility: U.C.L.

- At UCL, Heavy ions available are separated in two “Ion Cocktails”, one for the High LET (M/Q=5) and a second one for the High Range (M/Q=3.3). Here bellows are given the characteristics of each cocktail.
- The irradiations were performed with the heavy ion in yellow of High range cocktail and the High LET cocktail.

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg⁻¹)
$^{15}N^{3+}$	60	59	3.3
$^{20}Ne^{4+}$	78	45	6.4
$^{40}Ar^{8+}$	151	40	15.9
$^{84}Kr^{17+}$	305	39	40.4
$^{124}Xe^{25+}$	420	37	67.7

UCL cocktail M/Q=5

Ion	Energy (MeV)	Range (µm(Si))	LET (MeV.cm².mg⁻¹)
$^{13}C^{4+}$	131	292	1.1
$^{22}Ne^{7+}$	235	216	3
$^{40}Ar^{12+}$	372	117	10.2
$^{58}Ni^{18+}$	567	100	20.4
$^{83}Kr^{25+}$	756	92	32.6

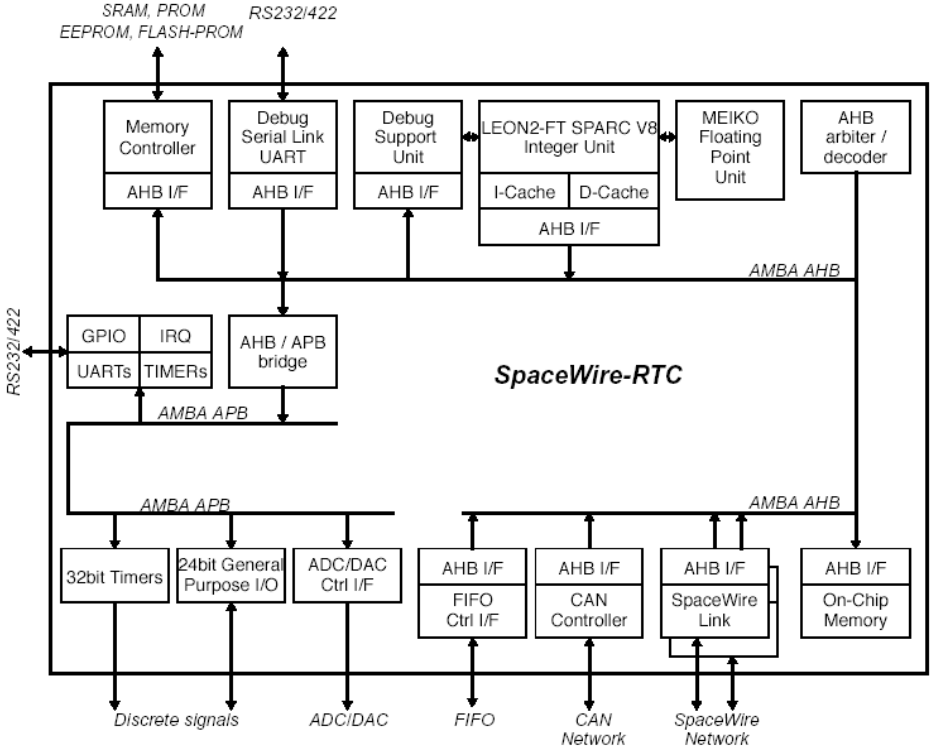
UCL cocktail M/Q=3.3

The DUT

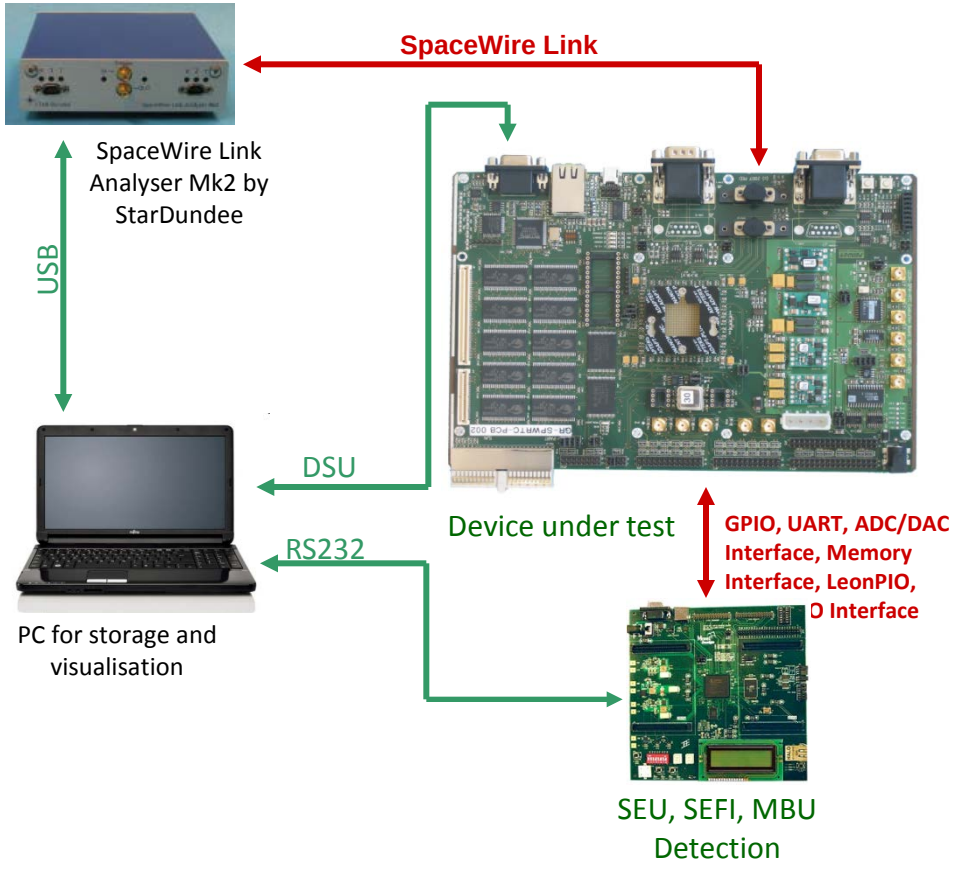
- The SpaceWire Remote Terminal Controller (RTC) is a bridge between the SpaceWire network and the CAN bus, providing a fully integrated system.

The functions tested are:

- an embedded microprocessor
- a FIFO interfeace
- a ADC/DAC interface
- a Memory Controller
- a UARTs port
- a 32-bit timers
- a General Purpose Input Output
- a On-Chip Memory
- a CAN bus controller
- a SpaceWire controller

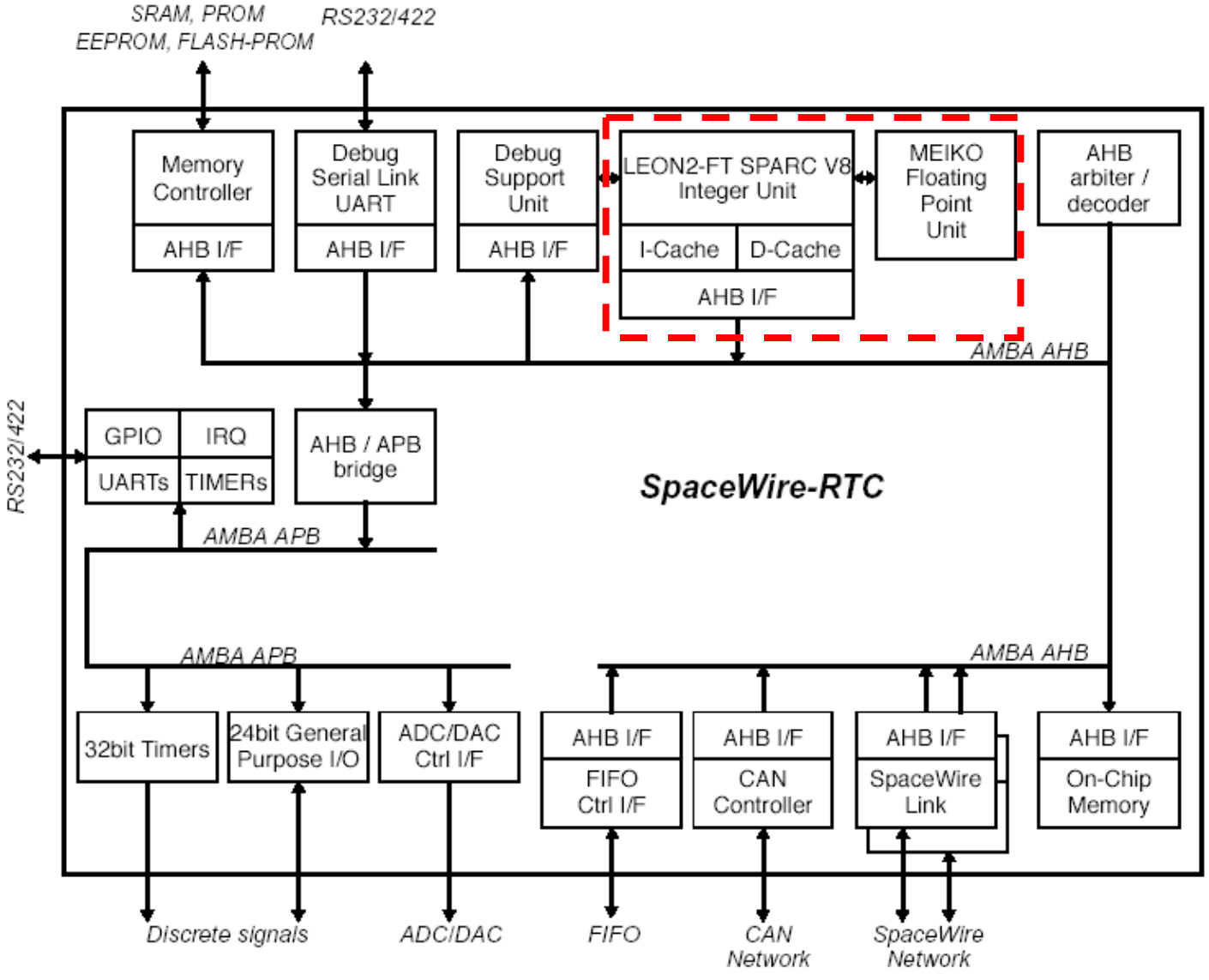


Test bench overview



* A test is terminated for a fluence of 10^6 .cm^{-2} is reached or 100 events are observed.

The LEON2-FT


SRAM, PROM
EEPROM, FLASH-PROM
RS232/422
Memory Controller
AHB I/F
Debug Serial Link UART
AHB I/F
Debug Support Unit
AHB I/F
LEON2-FT SPARC V8 Integer Unit
I-Cache
D-Cache
AHB I/F
MEIKO Floating Point Unit
AHB arbiter / decoder
AMBA AHB
RS232/422
GPIO
IRQ
UARTs
TIMERs
AHB / APB bridge
SpaceWire-RTC
AMBA APB
AMBA APB
AMBA AHB
32bit Timers
24bit General Purpose I/O
ADC/DAC Ctrl I/F
AHB I/F
FIFO Ctrl I/F
AHB I/F
CAN Controller
AHB I/F
SpaceWire Link
AHB I/F
On-Chip Memory
Discrete signals
ADC/DAC
FIFO
CAN Network
SpaceWire Network

Leon2-FT: Description

LEON2-FT Sparc V8 Processor

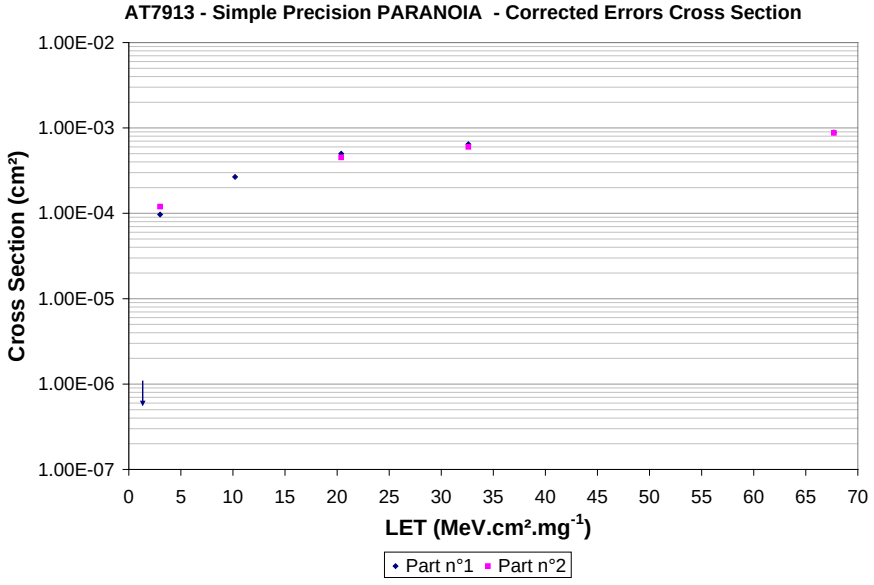
- 4K instruction caches / 4K data caches
- Meiko FPU
- Interrupt Controller
- Uart serial links
- 32-bit Timers
- Memory Controller
- General purpose IO
- Debug Support Unit (DSU)
- stage pipeline

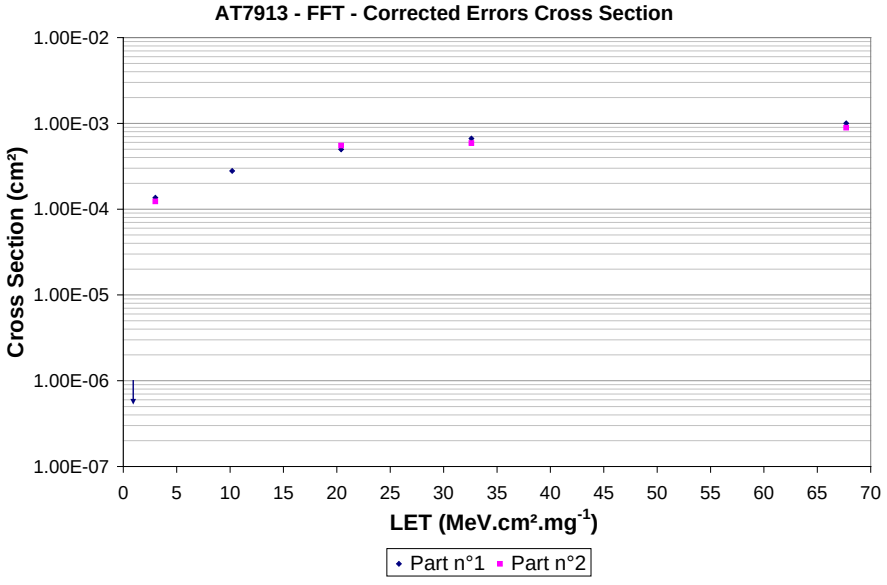
Leon2-FT: Test method

- Two target applications using in dynamic test PARANOÏA and FFT method:
  - For each test, the test bench provide this log :
    - **Number of successful/unsuccessful runs**
    - **Number of traps**
    - **Number of corrected/uncorrected errors**
- SEU statics tests comparison before/after irradiation of :
  - Registers
  - Cache memories (Instruction and Data)

Leon2-FT: Dynamic test results

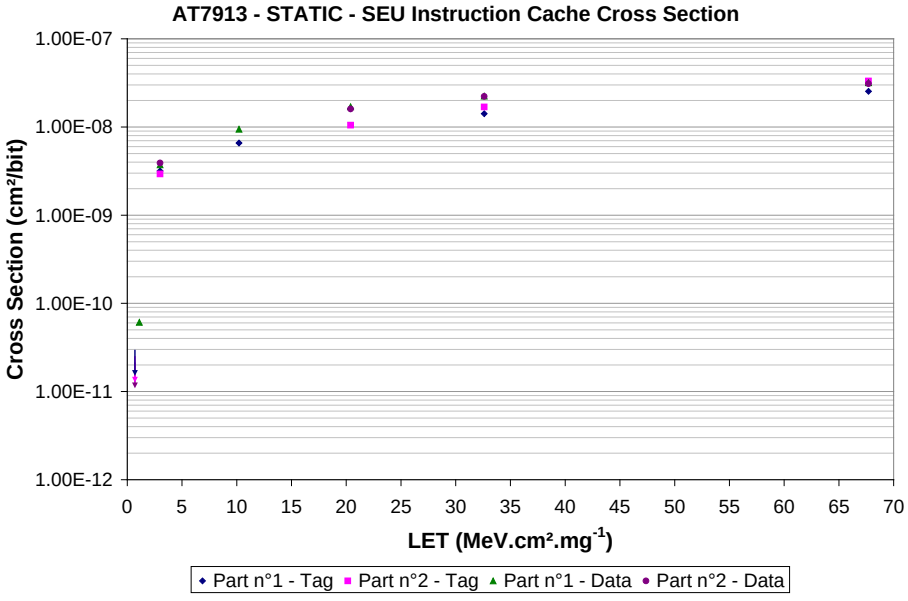
- SEE detected:
  - A majority of corrected errors
  - Few Traps
  - Few unsuccessful runs
- FFT and Paranoïa show the same sensitivity
- No lost of functionality which require OFF/ON of the power supply

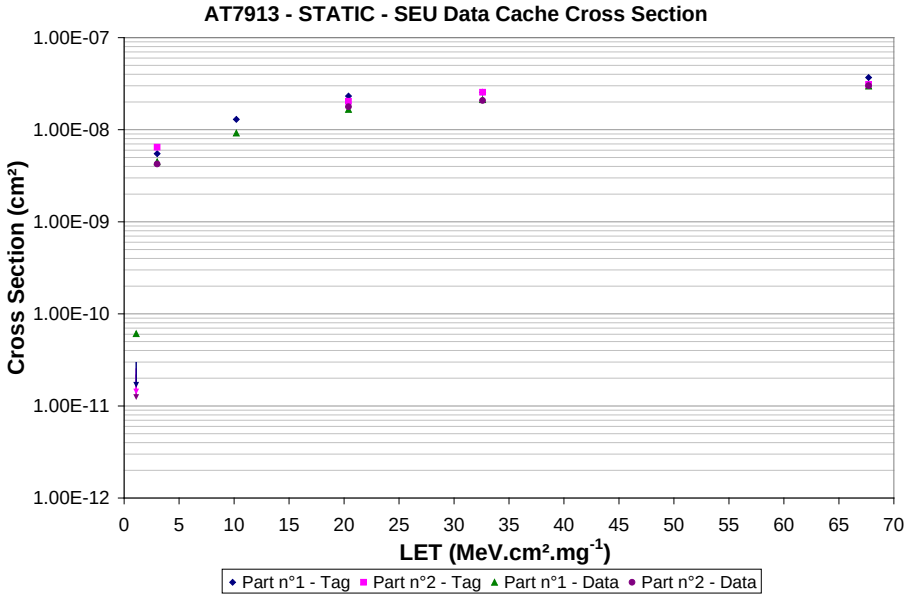




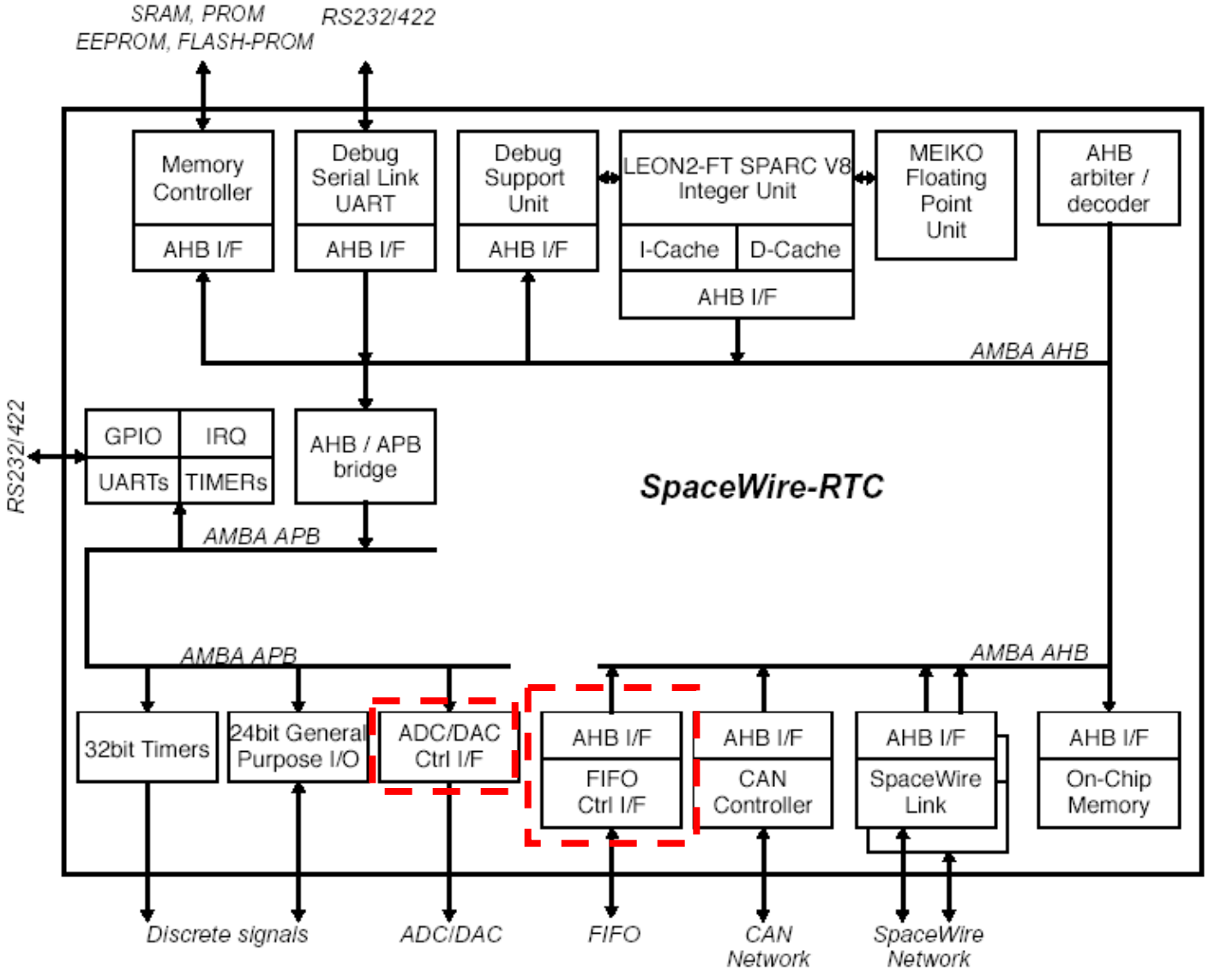
Leon2-FT: Static test results

- SEE detected:
  - SEU on Instruction and Data cache memories
  - Few SEU on Registers



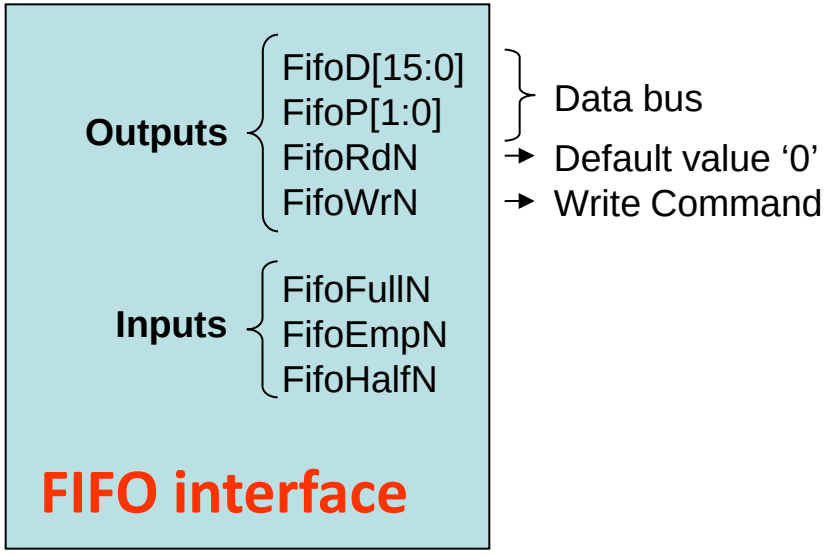


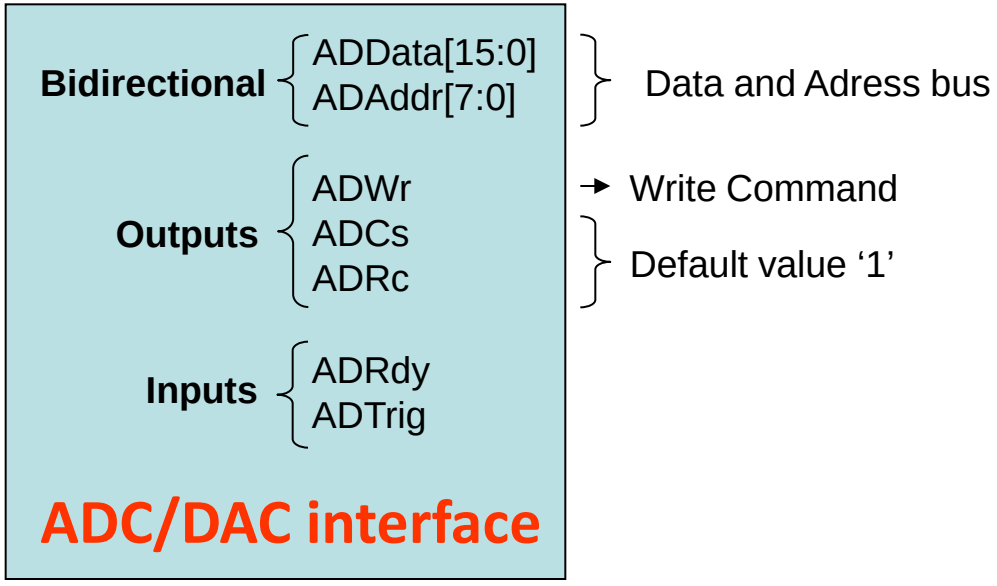
FIFO & ADC/DAC interface



FIFO & ADC/DAC interface: Test method

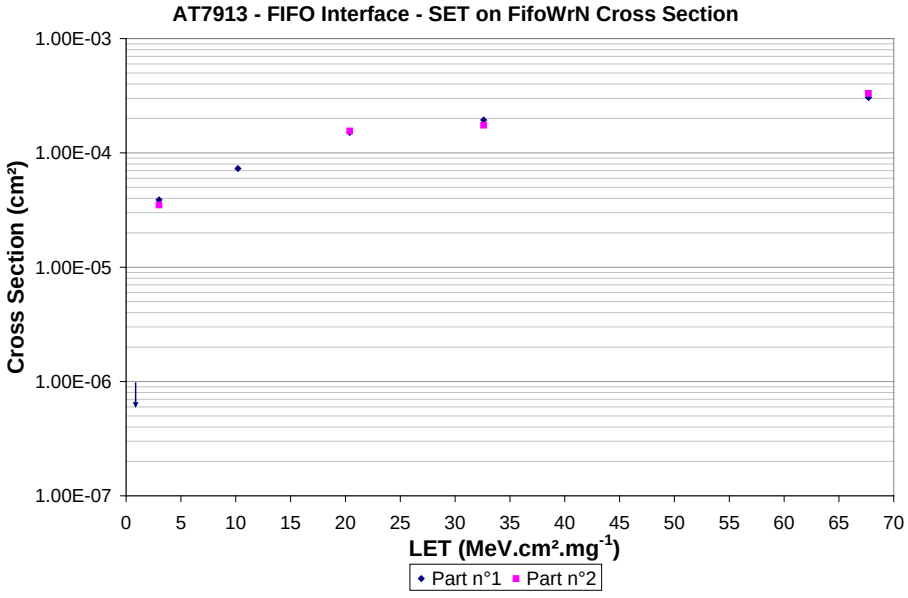
- FIFO and ADC/DAC interface are put in periodic writing operation and these outputs are probed:
  - Data and address bus
  - Write command
  - Static output Default value

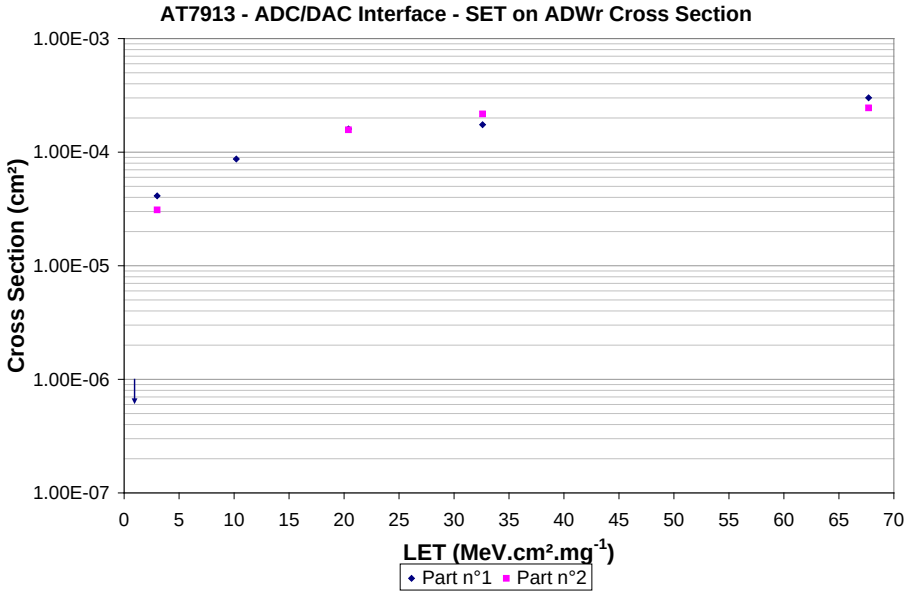




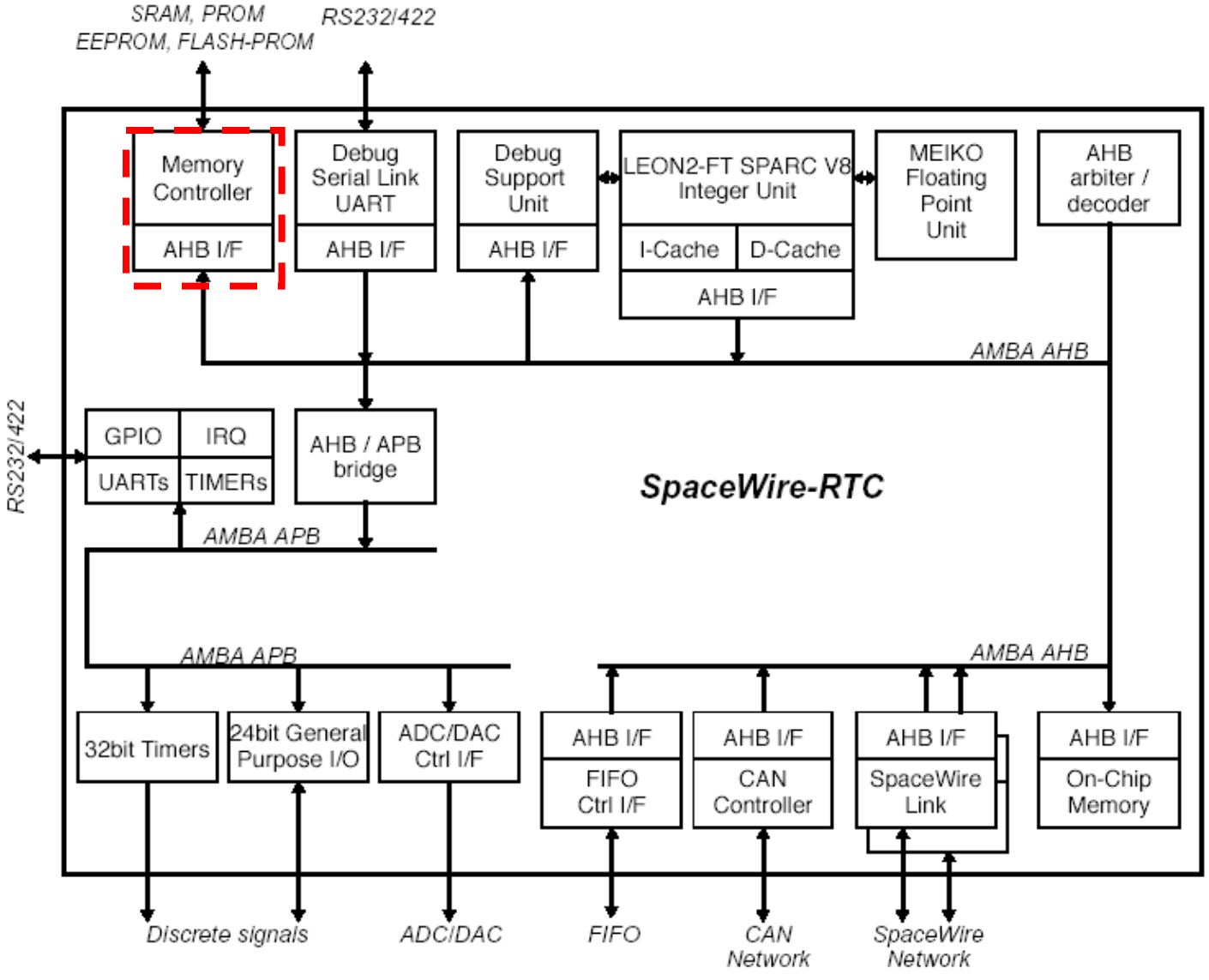
FIFO & ADC/DAC interface: Test results

- SEE detected on both interface:
  - SEU on Write command
  - Few SEFI due to Trap





Memory Controller



Memory Controller: Test method

- Memory controller is put in write operation and its outputs are probed:
  - Data and address bus
  - Write command
  - Static output Default value

RS232

Debug Support Unit

Memory Interface

Outputs
- MemWrN[3:0] → Write Command
- MemA[22:0], MemCsN[3:0] → Address & CheckBits bus
- MemOeN[3:0], RomCsN[1:0], IoCsN, IoOeN → Default value ‘1’
- IoRead, IoWrN → Default value ‘0’

Bidirectional
- MemD[31:0], MemCB[7:0] → Data bus

Inputs
- IoBrdyN
- MemBExcN

Memory Controller: Test results

- SEE detected on both interface:
  - SEFI due to error on register and trap

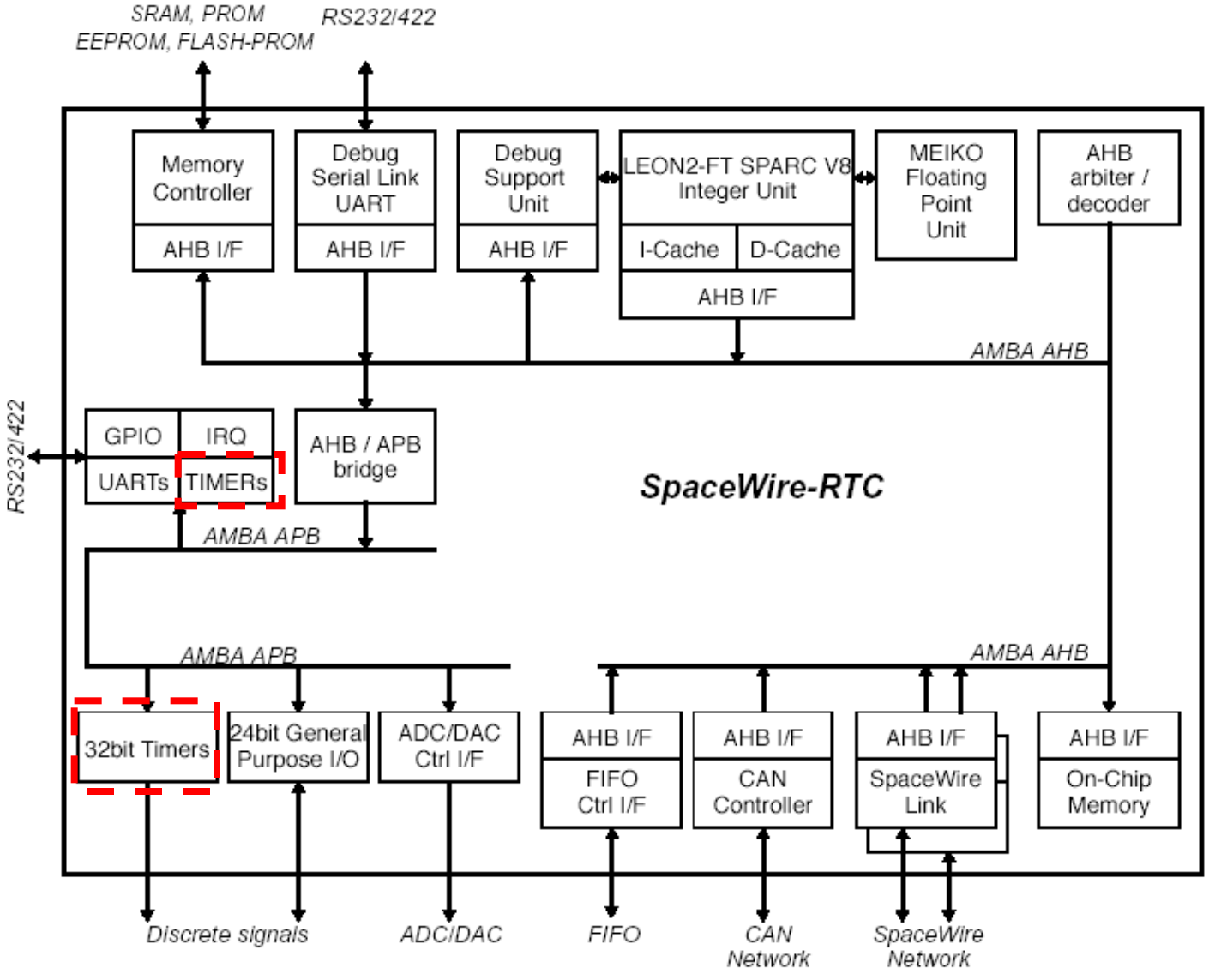
Run	Part	Ion	Energy (MeV)	Range (µm)	LET (MeV.cm²/mg)	Flux (φ) ($cm^{-2}.s^{-1}$)	Time (s)	Run Fluence (Φ) (cm^{-2})	SET WrN	SET Static Signals	SEU	SEFI	Number of Iterration
High Range M/Q=3.3													
13	**1**	**83 Kr 25+**	756	92	32.6	1.09E+03	**555**	**6.03E+05**	**0**	**0**	**0**	**0**	43497
45	**2**	**83 Kr 25+**	756	92	32.6	1.03E+03	**973**	**1.00E+06**	**0**	**0**	**0**	**1**	16383
58	**1**	**58 Ni 18+**	567	100	20.4	1.01E+03	**986**	**1.00E+06**	**0**	**0**	**0**	**0**	12156
75	**2**	**58 Ni 18+**	567	100	20.4	1.18E+03	**849**	**1.00E+06**	**0**	**0**	**0**	**0**	65505
93	**1**	**22 Ne 7+**	235	216	3	1.63E+03	**37**	**6.03E+04**	**0**	**0**	**0**	**0**	7491
High Range M/Q=5													
132	**1**	**124Xe 26+**	420	37	67.7	1.06E+03	**946**	**1.00E+06**	**0**	**0**	**0**	**0**	10160
167	**2**	**124Xe 26+**	420	37	67.7	1.44E+03	**696**	**1.00E+06**	**0**	**1**	**0**	**2**	25246

Test results

Mem CB error				Data expected			
MemCsN ($)	MemCB ($)	Address ($)	Data ($)	MemCsN ($)	MemCB ($)	Address ($)	Data ($)
E	0	555554	55555555	E	C	555554	55555555
D	0	2AAAA8	AAAAAAAA	D	C	2AAAA8	AAAAAAAA

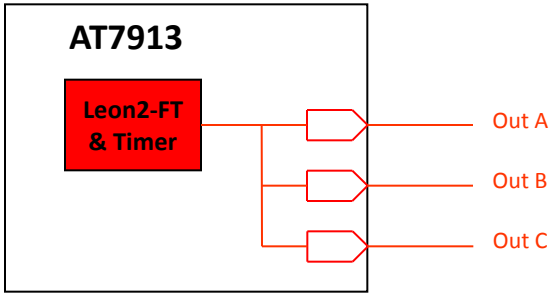
Memory controller SEFI case

32-bit Timers



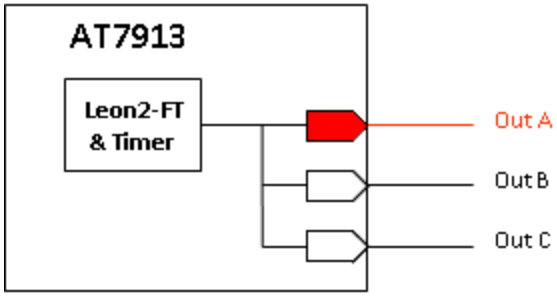
32-bit Timers: Test method

- On each timer interrupt, the Leon2-FT toggle Out A, Out B and Out C. Two kinds of event can be observed:
  - If the error is observed on the 3 output ➔ SEU on Timer or Leon2.



Leon2-FT or Timer error

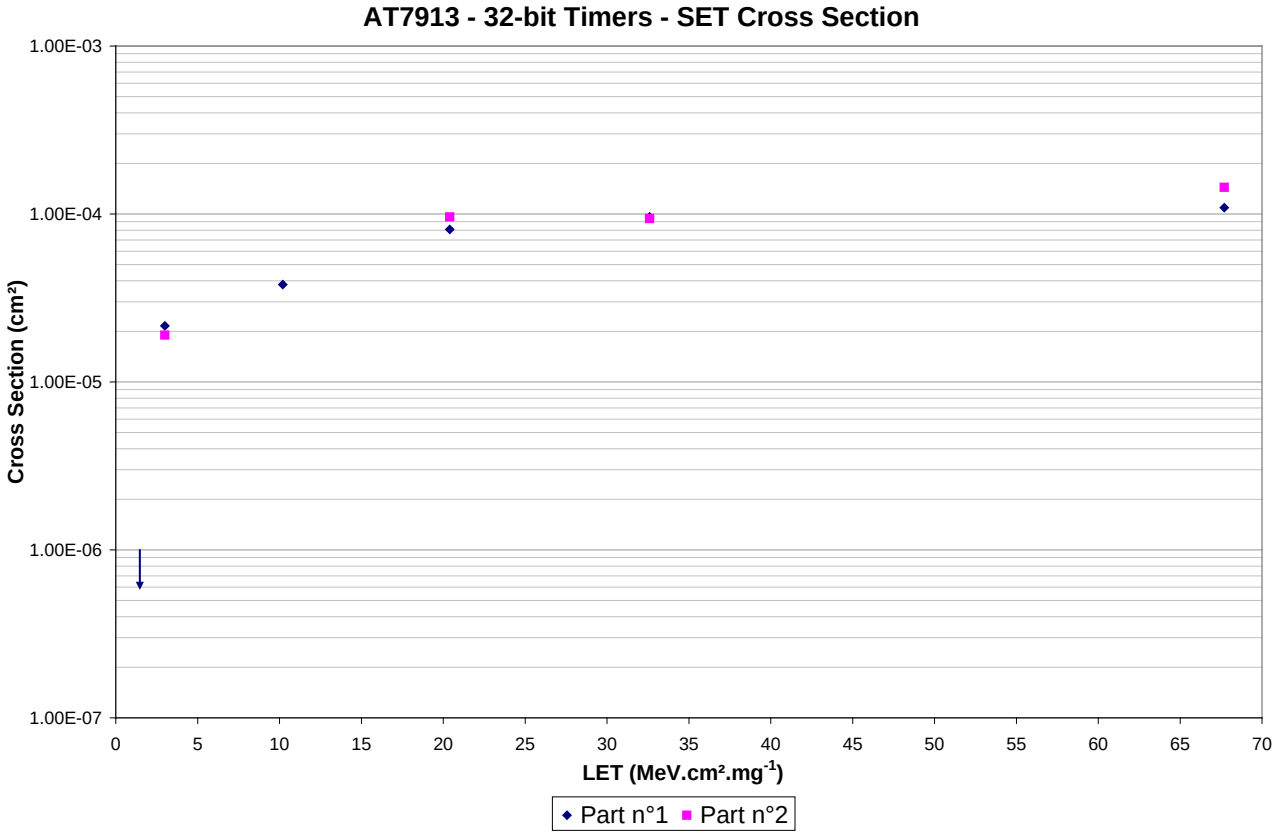
  - If only one output is impacted ➔ SEU on the output stage



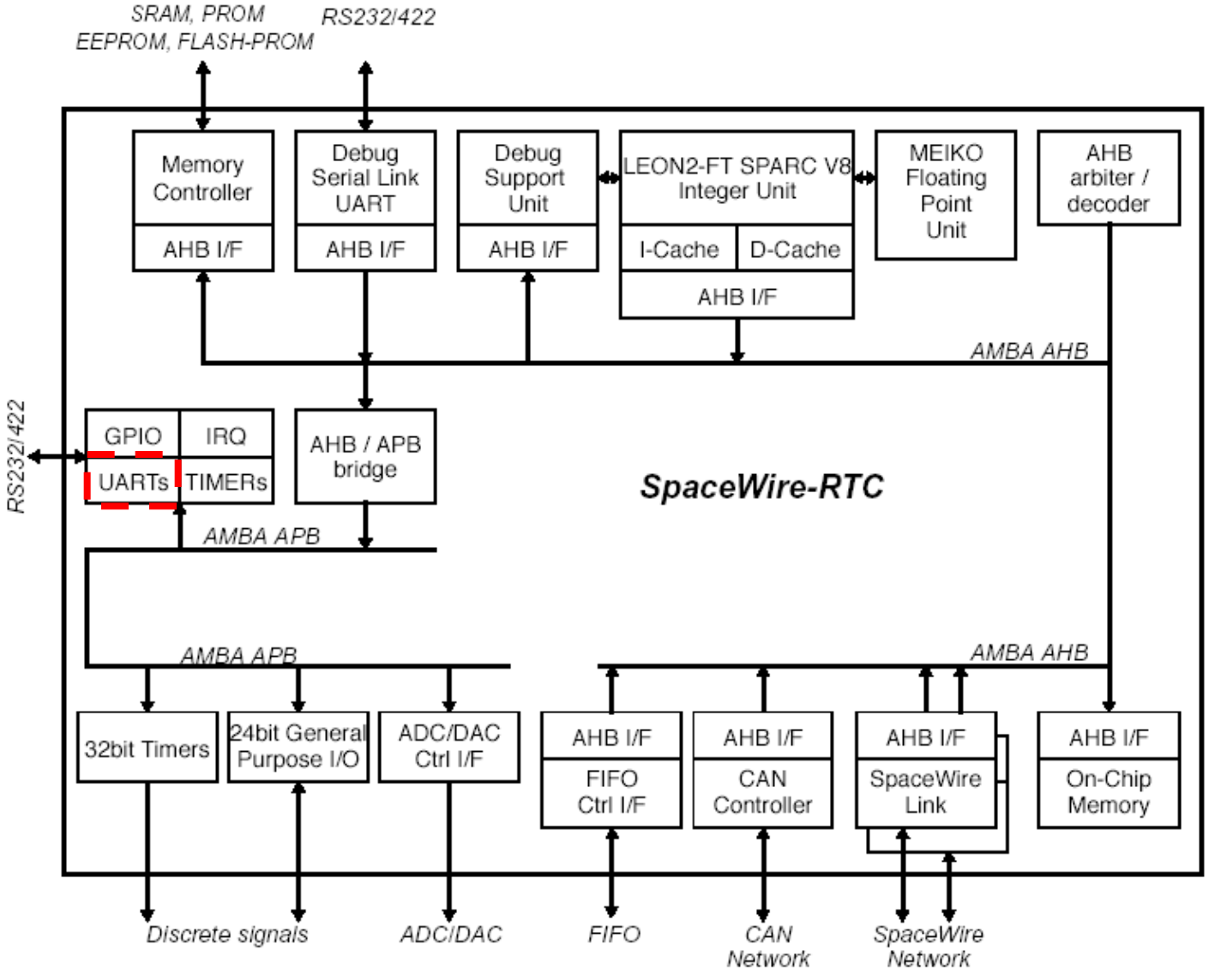
Output stage error

32-bit Timers: Test Results

- SEE detected on:
  - Mainly on Leon and Timer
  - No SEU on Output stage

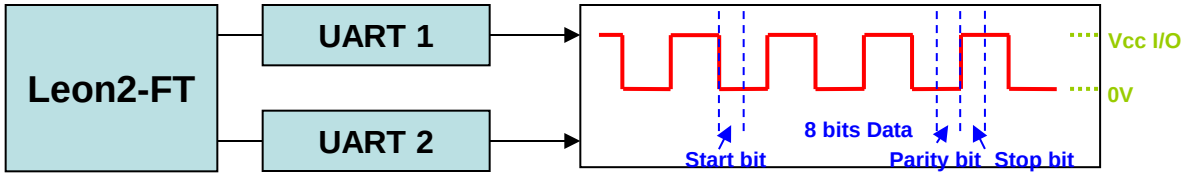


UARTs


SRAM, PROM
EEPROM, FLASH-PROM
RS232/422
Memory Controller
AHB I/F
Debug Serial Link UART
AHB I/F
Debug Support Unit
AHB I/F
LEON2-FT SPARC V8 Integer Unit
I-Cache
D-Cache
AHB I/F
MEIKO Floating Point Unit
AHB arbiter / decoder
AMBA AHB
RS232/422
GPIO
IRQ
UARTs
TIMERs
AHB / APB bridge
SpaceWire-RTC
AMBA APB
AMBA APB
AMBA AHB
32bit Timers
24bit General Purpose I/O
ADC/DAC Ctrl I/F
AHB I/F
FIFO Ctrl I/F
AHB I/F
CAN Controller
AHB I/F
SpaceWire Link
AHB I/F
On-Chip Memory
Discrete signals
ADC/DAC
FIFO
CAN Network
SpaceWire Network

UARTs: Test Method & Results

- The Leon2-FT sends continuously through the UARTs port a same data:
  - An error is detected when the pulse widths change on TX1 or TX2 outputs

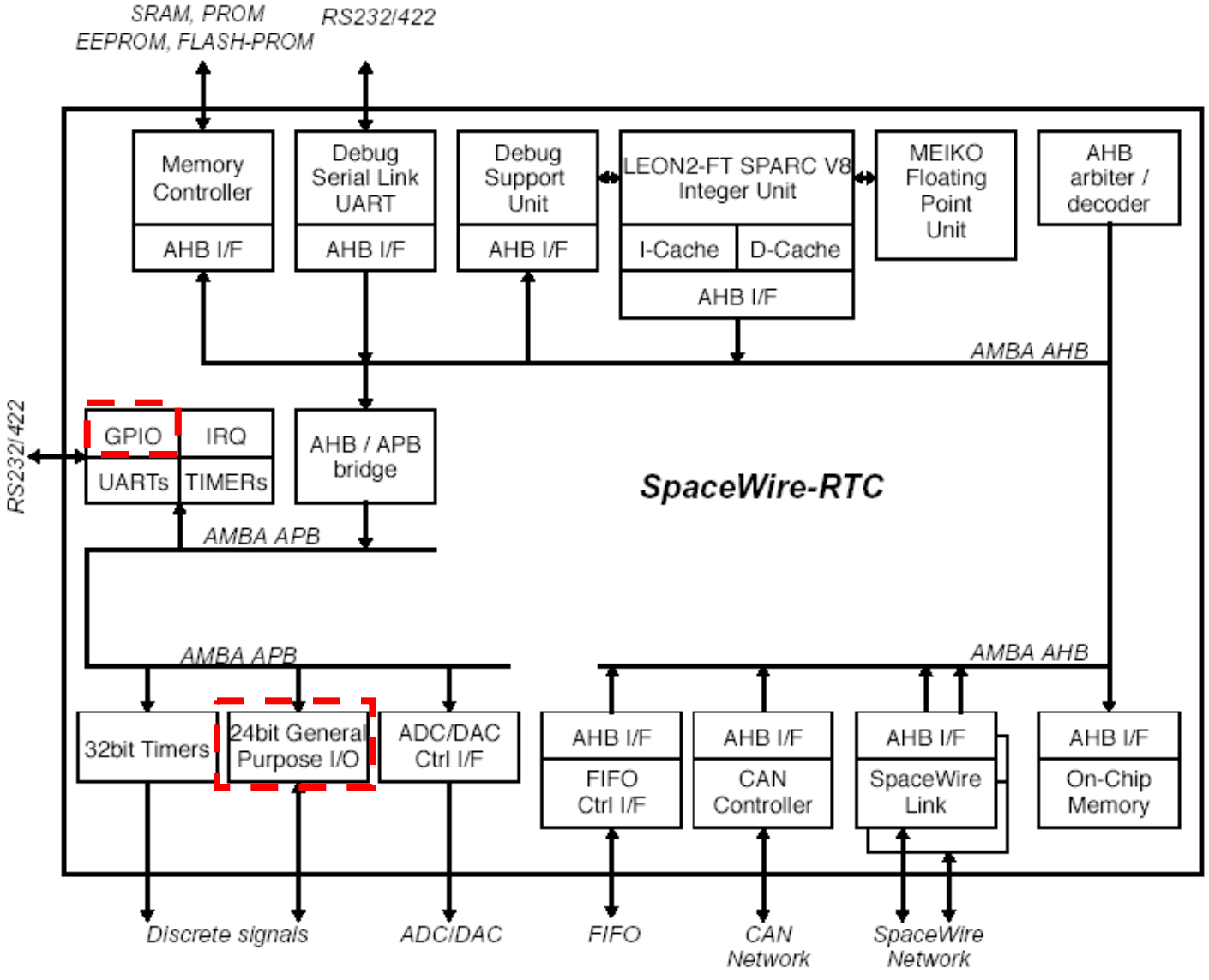


- SEE detected on:
  - Few SET observed
  - Few SEFI observed

LET Eff (MeV.cm².mg-1)	UART 1				UART 2			
	SET		SEFI		SET		SEFI	
	N° 1	N° 2	N° 1	N° 2	N° 1	N° 2	N° 1	N° 2
67.7	0	0	4	2	0	1	0	1
32.6	0	1	0	0	0	0	0	1
20.4	0	1	0	0	0	0	0	1
10.2	0	-	0	-	0	-	0	-
3	0	0	0	0	0	0	0	0

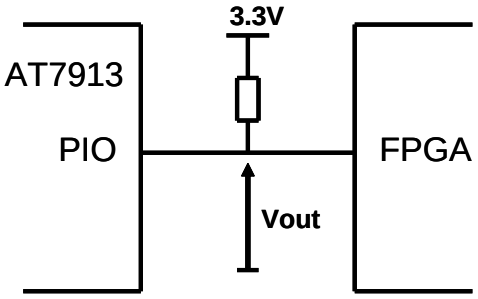
UARTs results

GPIO


SRAM, PROM
EEPROM, FLASH-PROM
RS232/422
Memory Controller
AHB I/F
Debug Serial Link UART
AHB I/F
Debug Support Unit
AHB I/F
LEON2-FT SPARC V8 Integer Unit
I-Cache
D-Cache
AHB I/F
MEIKO Floating Point Unit
AHB arbiter / decoder
AMBA AHB
RS232/422
GPIO
IRQ
UARTs
TIMERs
AHB / APB bridge
SpaceWire-RTC
AMBA APB
AMBA APB
AMBA AHB
32bit Timers
24bit General Purpose I/O
ADC/DAC Ctrl I/F
AHB I/F
FIFO Ctrl I/F
AHB I/F
CAN Controller
AHB I/F
SpaceWire Link
AHB I/F
On-Chip Memory
Discrete signals
ADC/DAC
FIFO
CAN Network
SpaceWire Network

GPIO: Test Methods & Results

- The 32-bits GPIO are set to ‘0’:
  - When a GPIO switches from ‘0’ to ‘1’ due to direction changing, a SEFI is detected.
  - When they is a disruption on GPIO, a SEU is detected



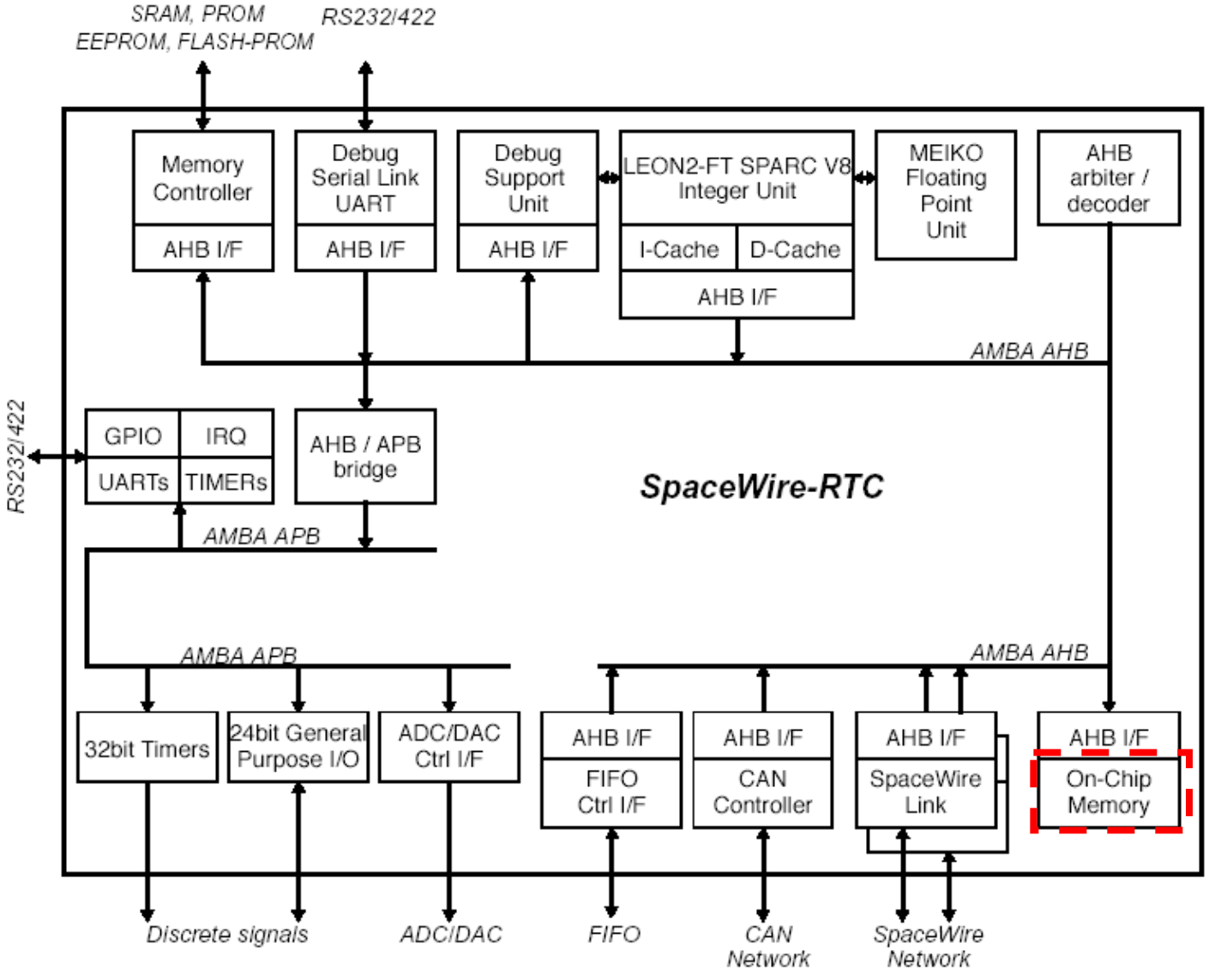
Link between GPIO and the system of error detection

- SEE detected on:
  - No SEU observed
  - Few SEFI observed due to direction switching

LET Eff (MeV.cm².mg-1)	SEU		SEFI	
	N° 1	N° 2	N° 1	N° 2
67.7	0	0	2	3
32.6	0	0	0	0

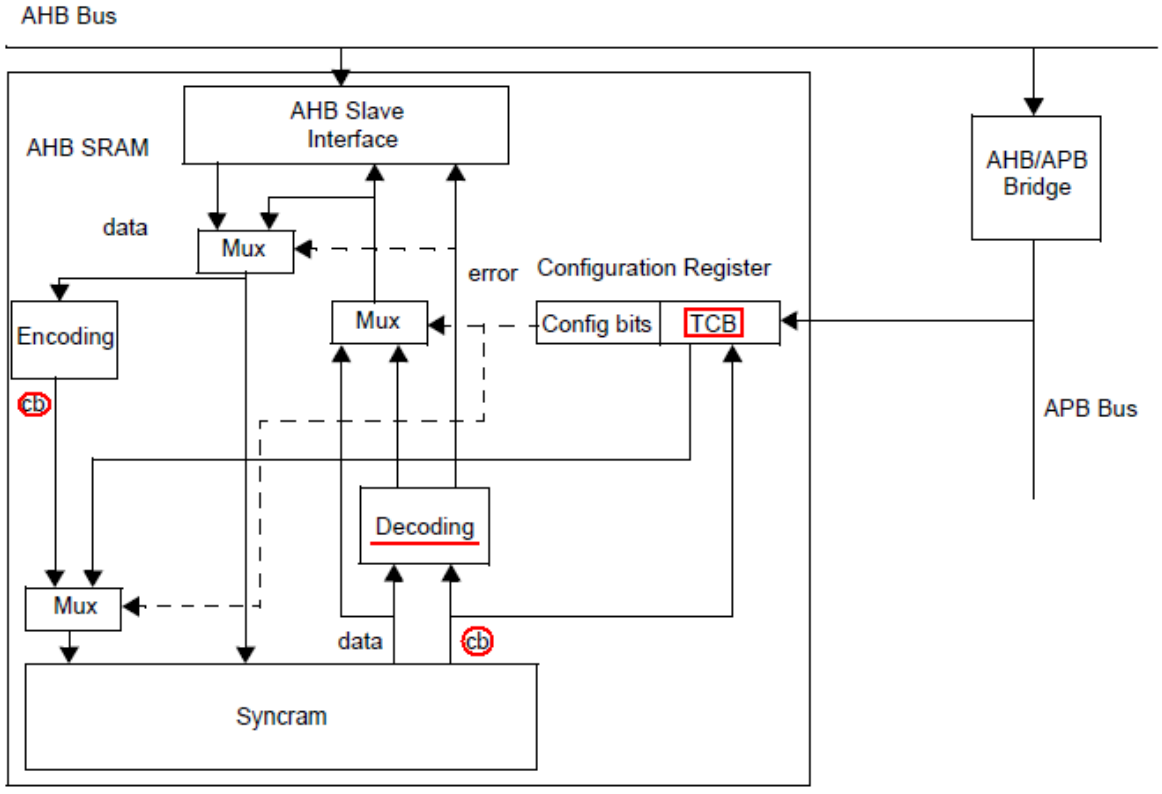
GPIO results

On-chip Memory



On-chip Memory: Test method

- The Debug Support Unit is used to access the on-chip memory
- The on chip memory include an EDAC protection. This protection allow to correct one error and detect two errors.
- The memory is tested with and without EDAC in order to evaluate its effect.

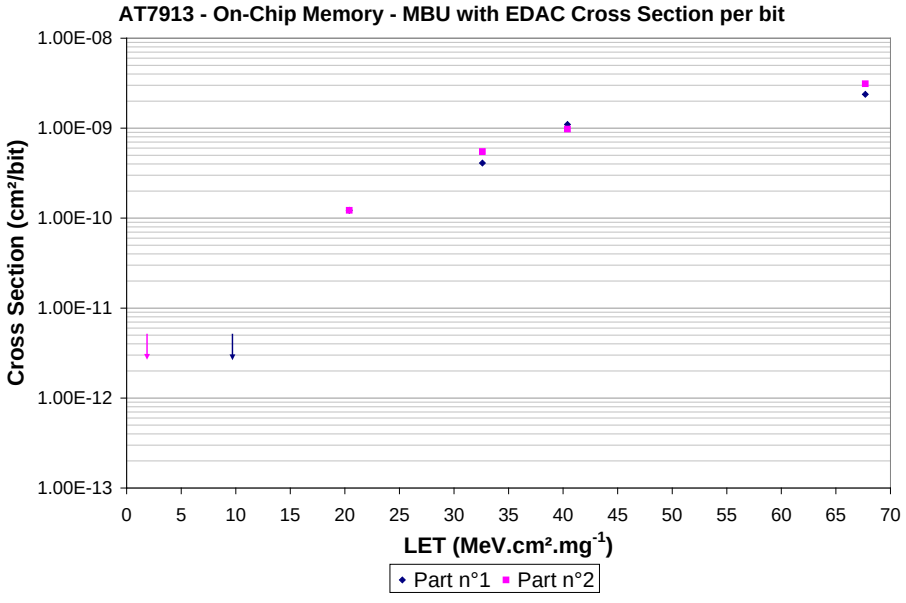


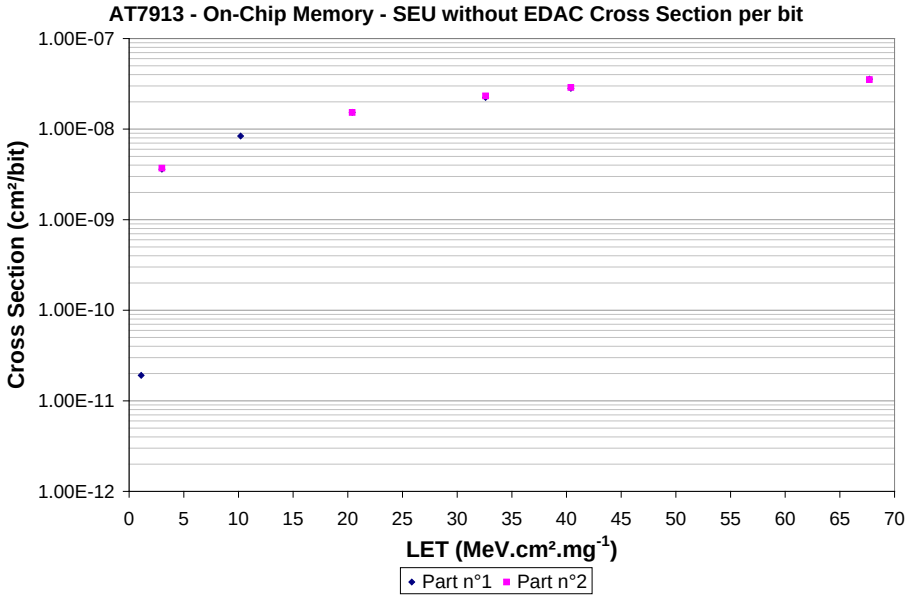
The FT AHB RAM block diagram

On-chip Memory: Test Results

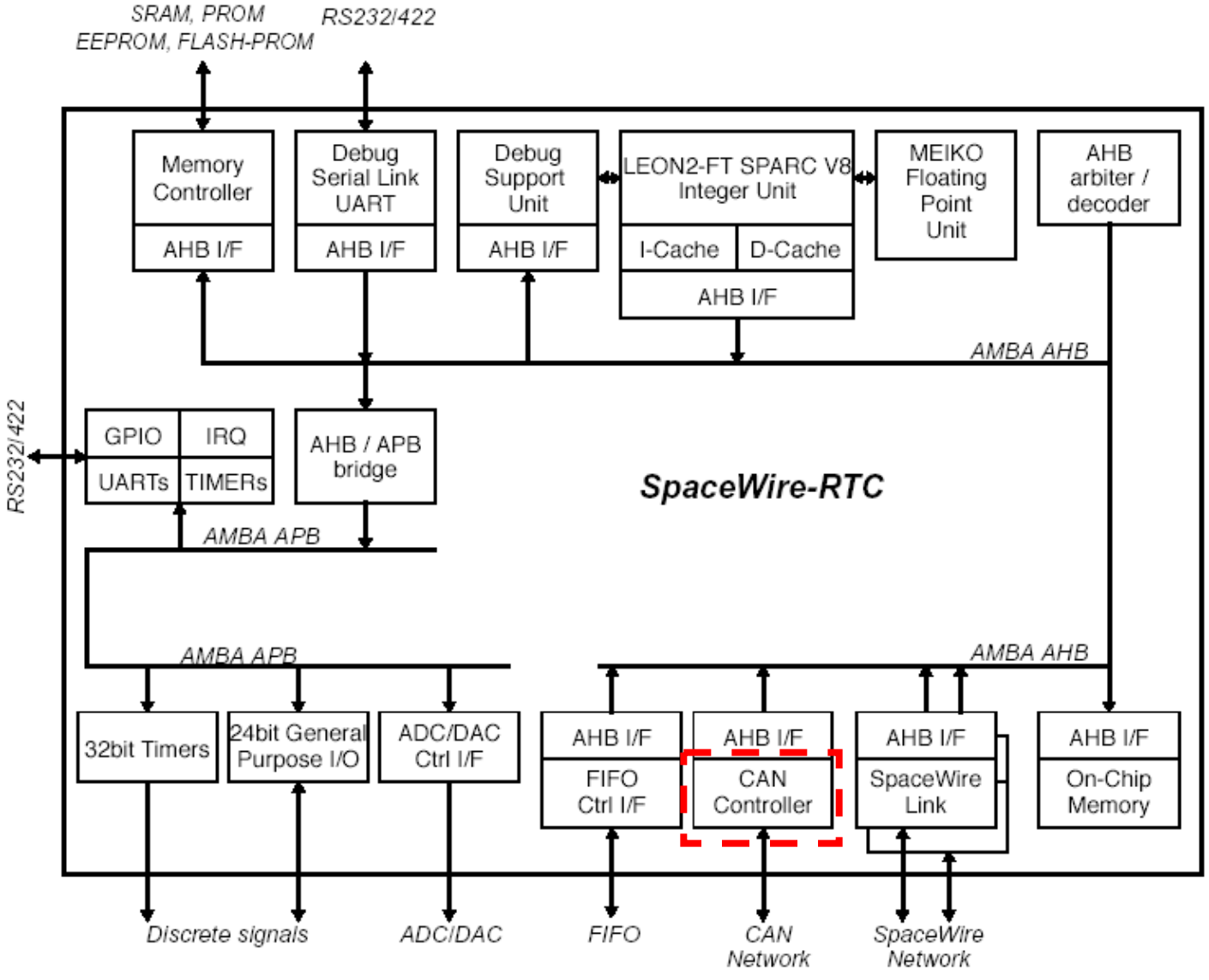
- SEE detected with EDAC:
  - Mainly MBU are detected but that can be due to high flux
  - Few SEU are detected on data due to SEU on 7-bit of EDAC protection

- SEE detected without EDAC:
  - Mainly SEU are detected
  - The sensitivity of MBU is the same with and without EDAC protection



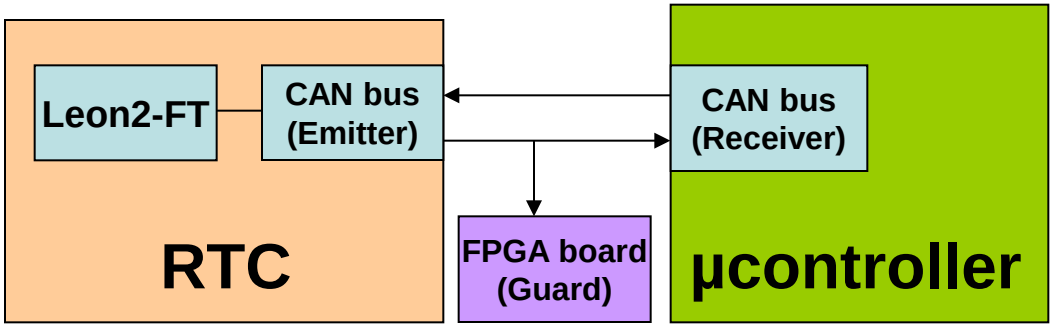


CAN bus


SRAM, PROM
EEPROM, FLASH-PROM
RS232/422
Memory Controller
AHB I/F
Debug Serial Link UART
AHB I/F
Debug Support Unit
AHB I/F
LEON2-FT SPARC V8 Integer Unit
I-Cache
D-Cache
AHB I/F
MEIKO Floating Point Unit
AHB arbiter / decoder
AMBA AHB
RS232/422
GPIO
IRQ
UARTs
TIMERs
AHB / APB bridge
SpaceWire-RTC
AMBA APB
AMBA APB
AMBA AHB
32bit Timers
24bit General Purpose I/O
ADC/DAC Ctrl I/F
AHB I/F
FIFO Ctrl I/F
AHB I/F
CAN Controller
AHB I/F
SpaceWire Link
AHB I/F
On-Chip Memory
Discrete signals
ADC/DAC
FIFO
CAN Network
SpaceWire Network

CAN bus: Test Method & Results

- The Leon2-FT sends continuously through the CAN bus a same data:
  - When a disruption occurs on the TX of CAN bus, a SEE is detected

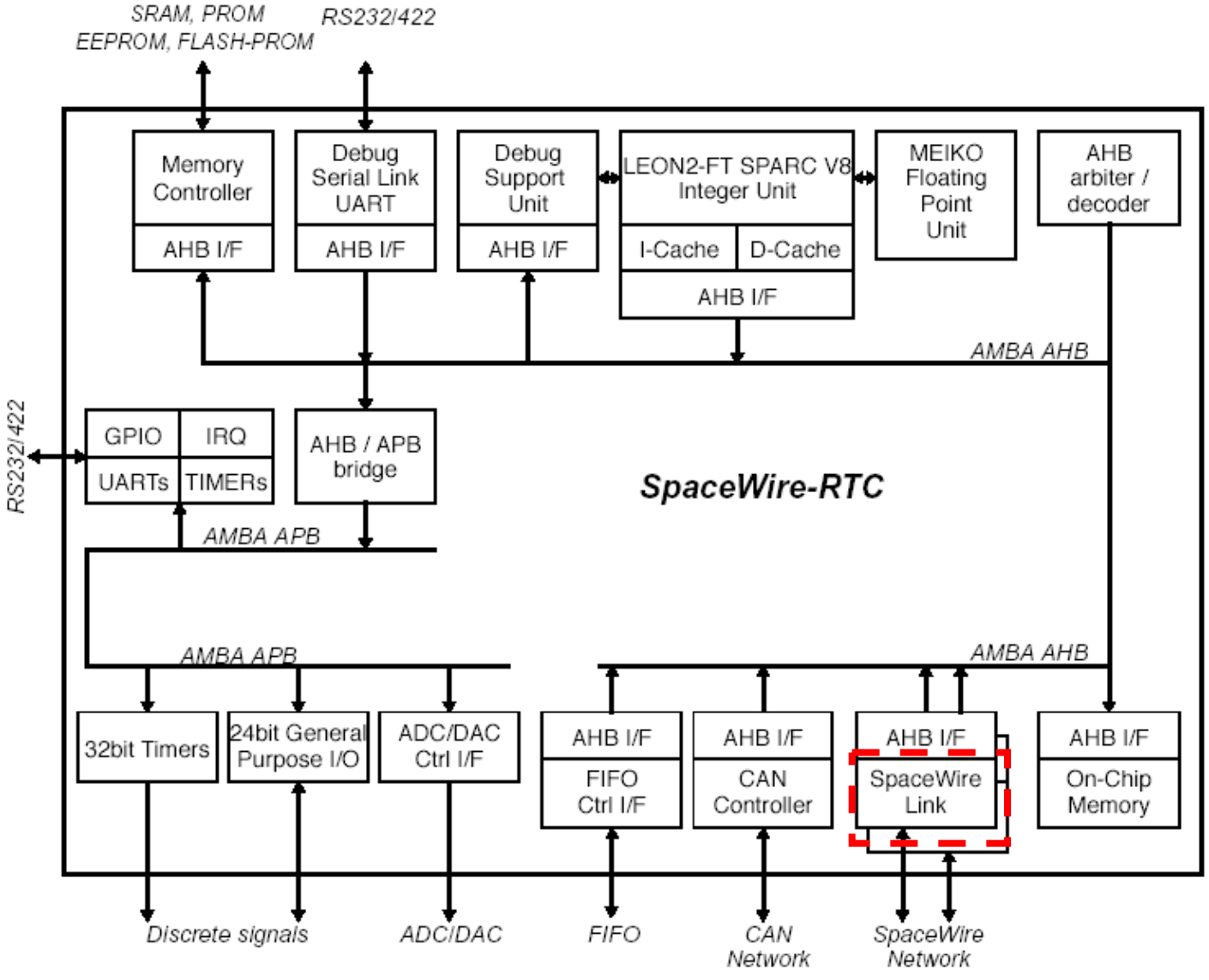


- SEE detected on:
  - Few SEU observed
  - Few SEFI observed

LET Eff (MeV.cm².mg-1)	SEU		SEFI	
	N° 1	N° 2	N° 1	N° 2
67.7	2	3	3	0
32.6	0	0	0	0

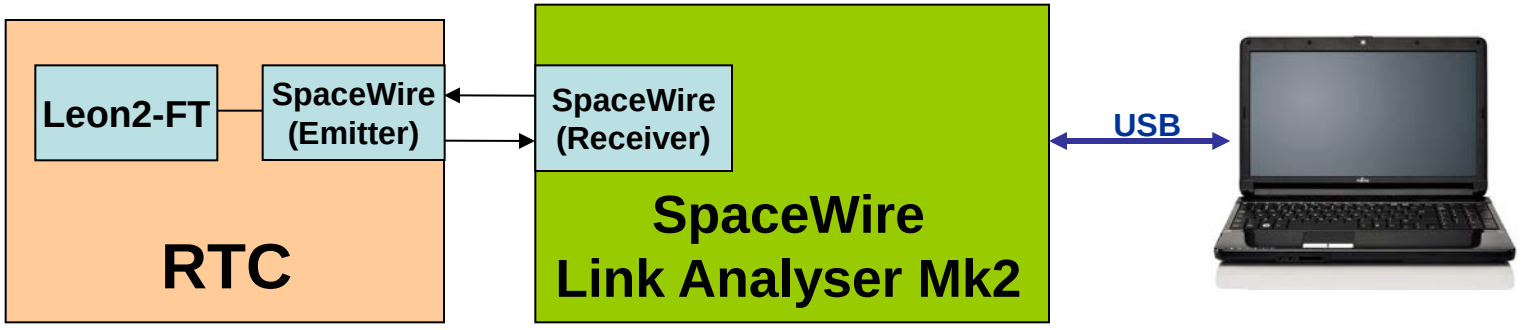
CAN bus results

SpaceWire


SRAM, PROM
EEPROM, FLASH-PROM
RS232/422
Memory Controller
AHB I/F
Debug Serial Link UART
AHB I/F
Debug Support Unit
AHB I/F
LEON2-FT SPARC V8 Integer Unit
I-Cache
D-Cache
AHB I/F
MEIKO Floating Point Unit
AHB arbiter / decoder
AMBA AHB
RS232/422
GPIO
IRQ
UARTs
TIMERs
AHB / APB bridge
SpaceWire-RTC
AMBA APB
AMBA APB
AMBA AHB
32bit Timers
24bit General Purpose I/O
ADC/DAC Ctrl I/F
AHB I/F
FIFO Ctrl I/F
AHB I/F
CAN Controller
AHB I/F
SpaceWire Link
AHB I/F
On-Chip Memory
Discrete signals
ADC/DAC
FIFO
CAN Network
SpaceWire Network

SpaceWire: Test Method

- The SpaceWire link two signals Data and Strobe. The clock signal is encoded into a Strobe signal in such a way that XORing the Data.
- The Leon2-FT sends continuously through the SpaceWire a same data.
- Four frequencies are used : 10, 50, 100, 200 MHz
- The SpaceWire Link Anylser Mk2 of StarDundee is set to trigger and to acquisition of signals for all errors.



SpaceWire: Test Results

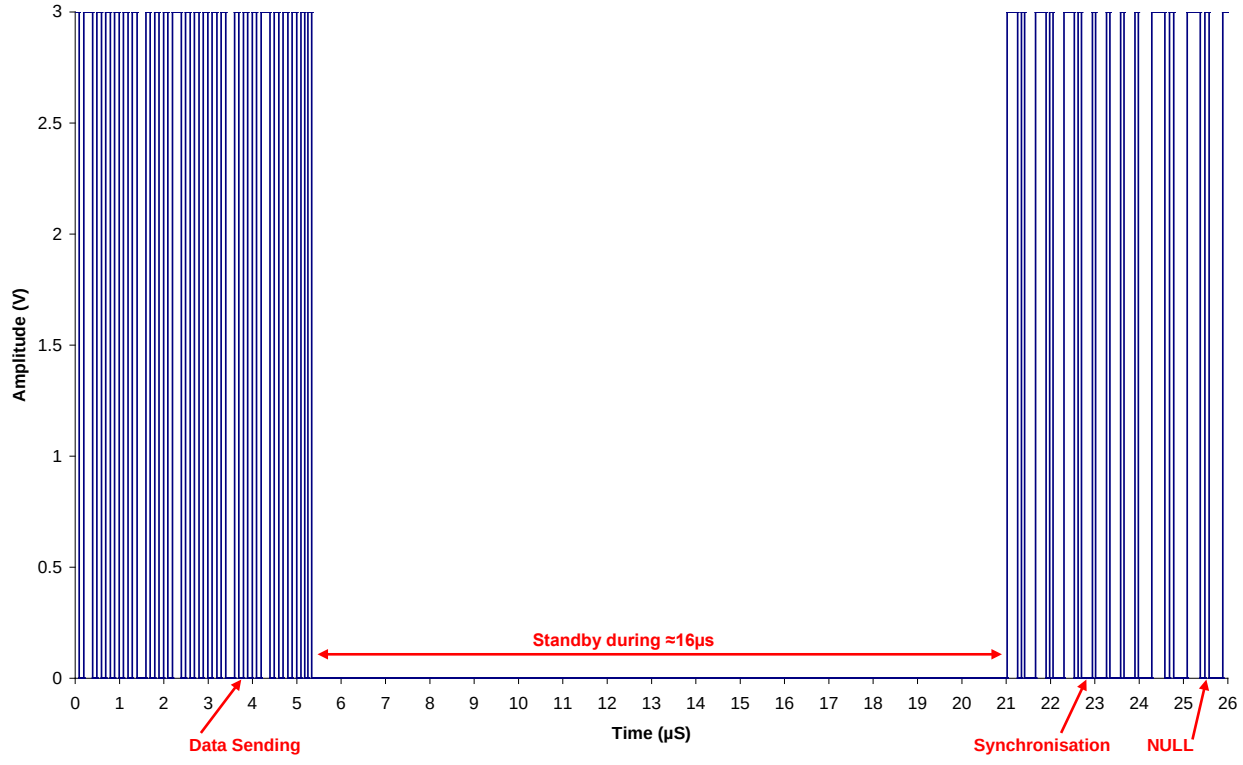
- SEE detected on:
  - Few SEU observed
    - **They is the same sensitivity for four frequencies**
    - **Three error types were observed: Disconnect, Escape-EOP and Parity Error**
    - **After an error the link restart automatically**
  - No SEFI observed

LET Eff (MeV.cm².mg-1)	Cross Section (cm²)							
	10MHz		50MHz		100MHz		200MHz	
	N° 1	N° 2	N° 1	N° 2	N° 1	N° 2	N° 1	N° 2
67.7	7.00E-06	2.25E-06	3.00E-06	2.83E-06	3.30E-06	7.99E-06	1.62E-06	4.40E-06
40.4	1.45E-06	2.00E-06	2.35E-06	2.64E-06	1.00E-06	8.82E-07	<1.00E-06	2.33E-06
32.6	1.00E-06	1.00E-06	2.00E-06	1.00E-06	2.00E-06	<1.00E-06	<1.00E-06	1.00E-06
20.4	3.00E-06	1.00E-06	<1.00E-06	<1.00E-06	<1.00E-06	<1.00E-06	<1.00E-06	<1.00E-06
10.2	<1.00E-06	-	-	-	-	-	-	-
3	<1.00E-06	<1.00E-06	-	-	-	-	-	-

SpaceWire cross-section

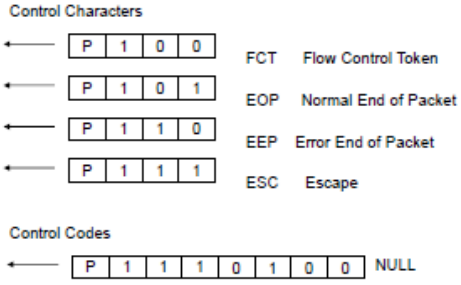
SpaceWire: Disconnect Case

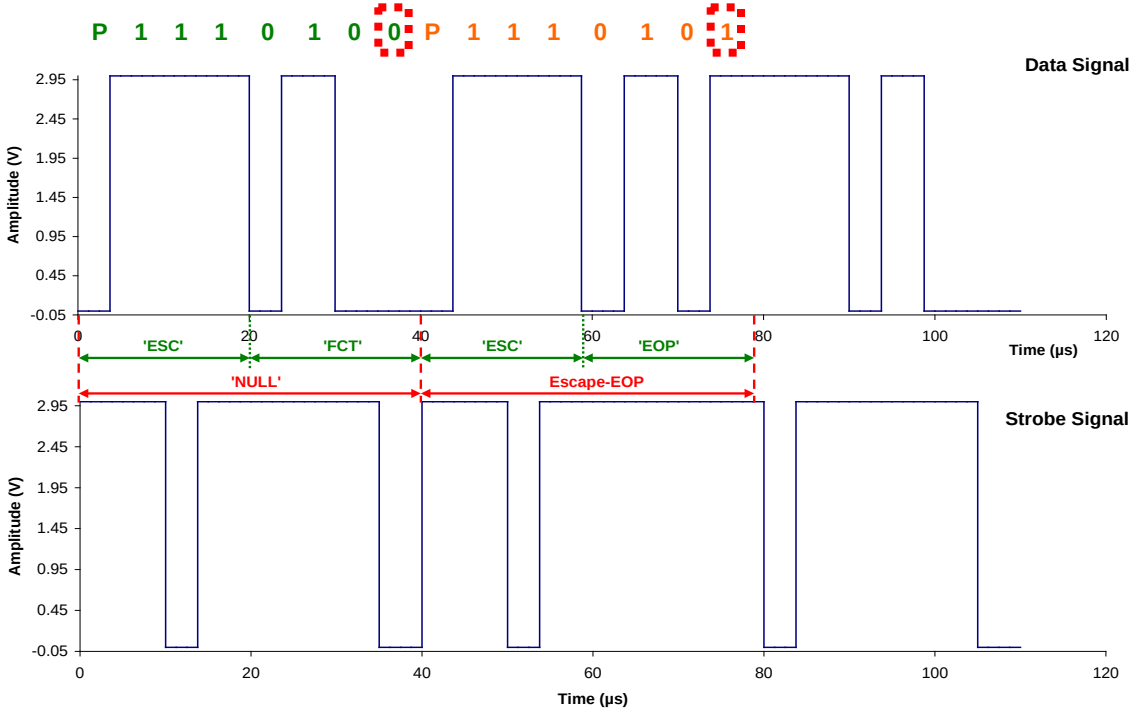
- When a disconnect occurs, the signal is interrupt during 16µs next the link is initialized.



SpaceWire: Escape-EOP case

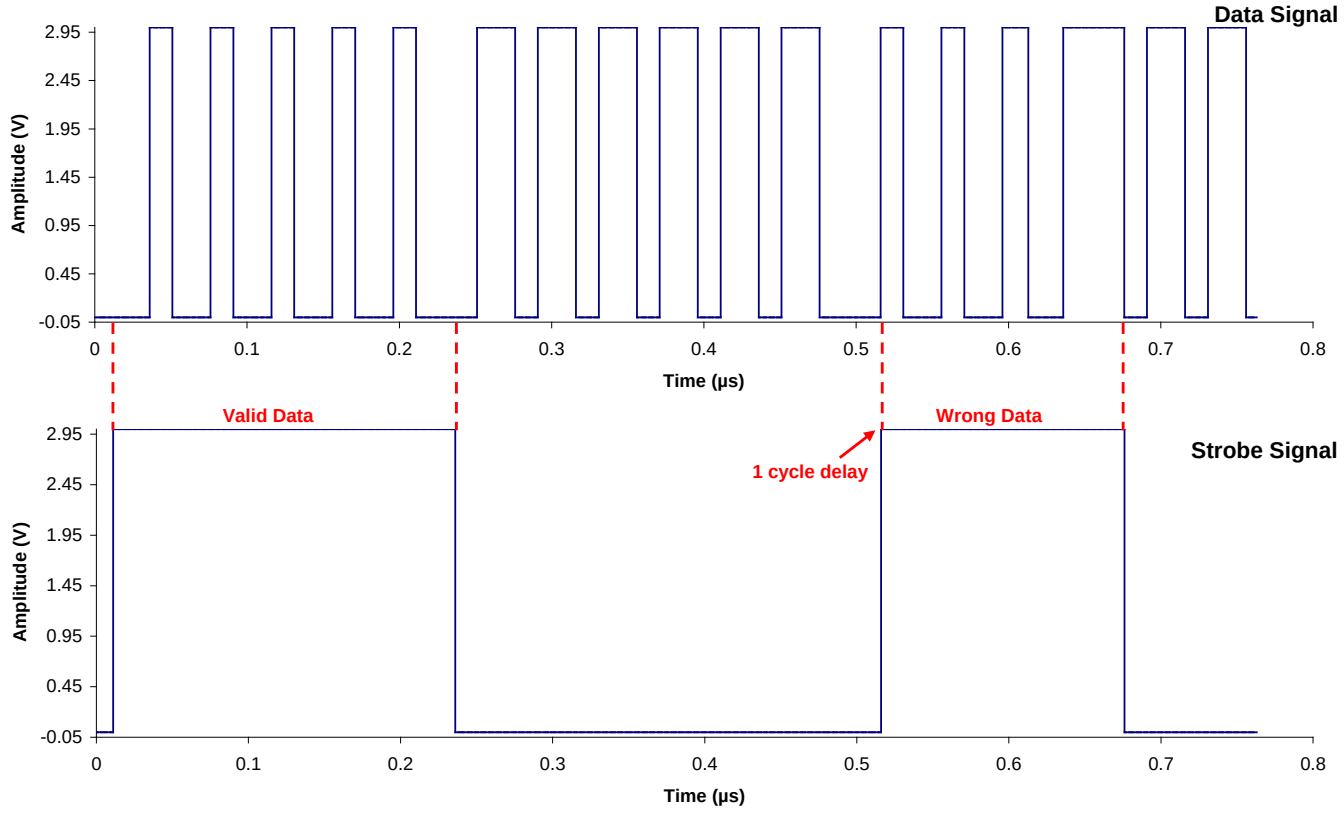
- When no data sending, the link stay enable and continuously sends a “NULL” character.
- A Escape-EOP occurs during the “NULL” character sending.
- A “NULL” consists of “Escape” (ESC) and “Flow Control Token” (FCT) characters
- A “Escape-EOP” consists of “Escape” (ESC) and “End of Packet” (EOP) characters





SpaceWire: Parity Error case

- For each character they is a parity bit
- If they is a delay on the Data and Strobe signals, the system detect a parity error.



Conclusions

- **SEE characterisation**
  - **Parts no sensitive to SEL**
  - **The Leon2-FT and the on-chip memory are more sensitive than peripheral to SEU and SEFI. But the protection decreases this sensitivity.**
    - an embedded microprocessor
      - Dynamic tests ➔ SEU corrected errors for two target applications
      - Statics tests ➔ SEU on cache memories and few SEU on registers
    - a FIFO interfeace ➔ SEU on write command observed
    - a ADC/DAC interface ➔ SEU on write command observed
    - a Memory Controller ➔ One SET and few SEFI observed
    - a 32-bit timers ➔ SEU observed
    - a UARTs port ➔ few SEU and few SEFI observed
    - a General Purpose Input Output ➔ few SEFI observed
    - a On-Chip Memory ➔ sensitive to SEU without EDAC protection and few MBU observed with and without EDAC protection certainly due to high flux
    - a CAN bus controller ➔ few SEU and few SEFI observed
    - a SpaceWire controller ➔ few SEU observed