COMMERCIAL COMPONENTS IDENTIFICATION IN NATURALLY RADIATION HARDENED TECHNOLOGIES

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Abstract—**This paper presents the results of the study on commercial components identification and evaluation in naturally radiation hardened technologies.**

I. OBJECTIVE AND INTEREST

Commercial components are of prime interest for reducing the cost and dimensioning of on-board space applications, while increasing their performance.
New emergent markets (telecommunications, automotive, multi media) require more and more speed, performances, very low consumption and high reliability, and so push technology in an innovated way. New technologies appear in the commercial components world and they are produced in very high volume.
Some of these technologies (SOI, XFCB, ...) present an intrinsic immunity to radiation effects : Single Event Latch-up (SEL) free, less Single Event Upset (SEU) expected and, may be, less drifts in Total Ionising Dose (TID). This relative immunity will allow to avoid radiation evaluation tests, which are very expensive.
The purpose of this study was to determine all these "immune" technologies, in order to identify the components to be selected and used into spacecraft programs.
This study has been carried out with ASTRIUM in the framework of CNES R&D component activities

II. SILICON–ON–INSULATOR TECHNOLOGY

A. SOI PROCESS

Silicon-On-Insulator (SOI) technologies have existed for more than 30 years, and have been used in analog bipolar and BiCMOS (bipolar and CMOS combined) processes, as well as in radiation-tolerant and high temperature digital CMOS electronics [1]. Recently, demand for low power portable devices has opened a much larger market for SOI technologies in mainstream commercial CMOS applications. Indeed, operating voltage are reduced, dictated by reliability and power consumption. However, low supply voltages limit the performance of bulk CMOS circuits. System speed requirements, as well as device physics and circuit considerations place lower limits on the operating voltage of bulk CMOS circuits. SOI extends the operating region of CMOS circuits to lower voltages without sacrificing performance.
The SOI technology consists in placing a thin layer of silicon on top of an insulator such as silicon oxide or glass. Then the transistors are built on top of this thin layer of silicon. The figure below shows the difference between Bulk CMOS and SOI CMOS technologies [2]:

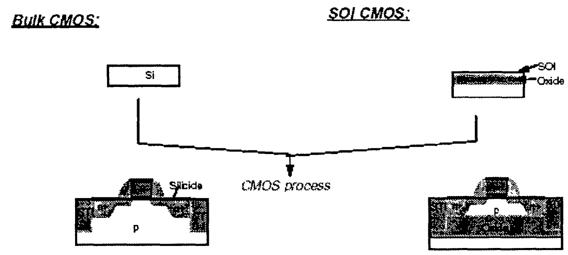

Fig.1 Bulk CMOS and SOI CMOS

B. EXTRA FAST COMPLEMENTARY BIPOLAR PROCESS

The XFCB process is Analog Devices proprietary [3]. XFCB is a dielectrically isolated 12-Volt high-speed complementary bipolar process with double level metal and thin film resistors. Full dielectric isolation is achieved by using a combination of a buried oxide layer and trenches surrounding each active circuit area.

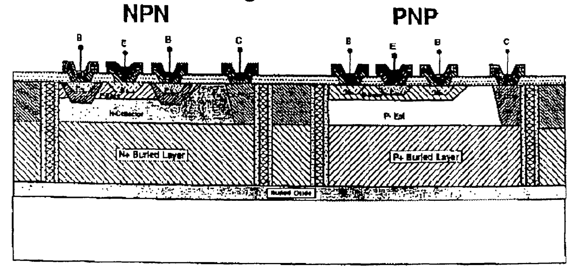

Fig. 2 XFCB technology

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III. RADIATION TRENDS ON SOI TECHNOLOGY

Of great interest to the space community is the development of Silicon-On-Insulator CMOS and BiCMOS technology and devices. The advantages of SOI include resistance to soft errors, i.e. alpha and neutron-induced ground-based SEU. Thus, SOI has become attractive for applications that require radiation hardness as well as low-power logic, high-performance analog, mixed signal, and smart power/high voltage ICs. In the October 1997 "1st Symposium on Soft Errors, Radiation Effects, and Reliability in VLSI", much interest was expressed by commercial IC manufacturers in the future of SOI ; in particular, this is true as power supply voltages begin approaching the alpha limit for soft errors.

- *Single Event Upset :*

Silicon-on-insulator technology has advantages for radiation-hardened electronics and also for small-feature-size devices. The buried insulator limits the region from which charge can be collected for a given ion strike compared to bulk devices. Thus one might expect the sensitivity to SEU to be less for devices on SOI substrates. However, the charge deposited in the silicon region may be sufficient to cause minority carrier injection across the source-body junction, which can then activate a parasitic bipolar action between the source and drain. This parasitic bipolar current can enhance the effect of the ion hit, leading to an increased sensitivity over what it would otherwise be. However, there are techniques for suppressing this bipolar current, such as shorting the island body to the transistor source.

- *Single Event Latch -Up :*

Silicon-on-Insulator technologies, are immune from Latch-up, since a contiguous four-layer structure does not exist.

- *Total Ionising Dose :*

The response of SOI devices during total dose irradiation is more complex than for bulk-silicon devices. In addition to gate and parasitic field leakage current, common to SOI and bulk-silicon devices, radiation-induced charge trapping in SOI buried oxides can also affect SOI device performance [4]. The possible use of SOI substrates for high performance or low power applications also raises additional possible leakage paths due to different oxides. The three oxides of interest are : the gate oxide, the sidewall oxide, and the buried (insulation) oxide. The sidewall oxide may be thicker than the gate oxide and thus shows a larger response to radiation. The buried oxide is unique to SOI technology and account for the primary difference in total-dose degradation between SOI and bulk-silicon devices. The buried oxide can trap charge just as does the field oxide in a bulk technology, and can contribute to a "back channel" leakage to the normal device current. Trapped charge in the buried oxide can also cause drifts in threshold voltage for fully depleted devices. So, depending upon the oxide's features, hardness of SOI technology devices against dose is not straightforward.

IV. PRESENTATION OF THE APPROACH

The study was divided in four work packages [5].
The first was dedicated to the offer analysis. The manufacturers of isolated substrate technology were identified. For each identified manufacturer the components list was established by functions and applications.
The second work package consisted in the selection of components for spacecraft applications. We selected five components, for each, the manufacturer data were analysed and the validation plan was defined.
The third work package was the realisation of the validation tests as described below :

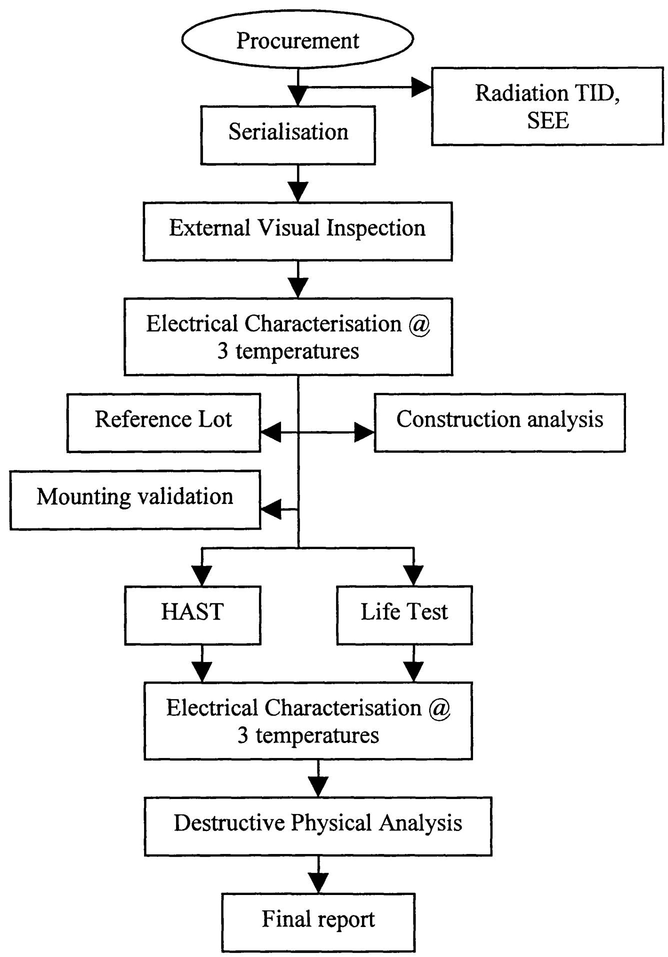

Fig. 3 Validation Plan

The electrical, environmental, reliability and total ionising dose tests and construction analysis were performed in CNES laboratories by CNES and LCIE teams. Heavy ions experiments were conducted at IPN in Orsay, France, by TRAD company. The mounting validation was performed in CNES and ASTRIUM laboratories.

The last work package was the redaction of the Justification Document which contains all data about the component and test results, in order to justify the use (or non use) of the part in a space project.

V. COMPONENTS SELECTION

In order to select commercial components in naturally radiation hardened technologies we have identified the manufacturers of isolated substrate technology. This work has been done in Q4 2000. For each identified manufacturer the components list was established by functions and applications. We analysed in deeper manufacturers such as Analog Devices, Philips, Intersil, IBM, Epson and Matsushita. Analog Devices offered a wide variety of components like analog to digital converters, amplifiers, comparators, switches, multiplexers in XFCB technology, described in section II.B. Philips proposed CAN transceiver and power amplifiers in SOI technology. Most of the product offered by Intersil were dedicated for high frequency application. When we made the selection, we found others manufacturers' announcements about components in SOI technology, but unfortunately no devices were available for procurement.

The devices selected were the AD8009AR, AD8598AR, AD8063ART and AD8184AR from Analog Devices and the TJA1050T from Philips. They are described in their respective manufacturer's datasheets and in the following table :

	AD8009	AD8598	AD8063	AD8184	TJA1050
Device function	Low distorsion amplifier	High speed comparator	Rail to rail amplifier	Video multiplexer	High speed CAN transceiver
Manuf acturer	Analog Devices	Analog Devices	Analog Devices	Analog Devices	Philips
Package	SO8	SO16	SOT23-6	SO14	SO28
Date Code	0023	9924	0039A	0052A	9932
Techno / Process	Bipolar XFCB	Bipolar XFCB	Bipolar XFCB	Bipolar XFCB	SOI

Tab. 1 Component description

VI. TECHNOLOGY ANALYSIS AND RELIABILITY

A. CONSTRUCTION ANALYSIS

We performed a construction analysis of each component types. These analysis covered different plastic packages from Analog Devices : SO8, SO14, SO16 and SOT23-6. All analysed components have shown a well controlled back-end process. The encapsulation process of SO28 from Philips was also well controlled.

The photographs below show the principle of the XFCB technology (Figures 4 and 5) and SOI technology (Figure 6). For XFCB technology, cross sections allow to exhibit the islands of silicon isolated by buried oxide and trenches.

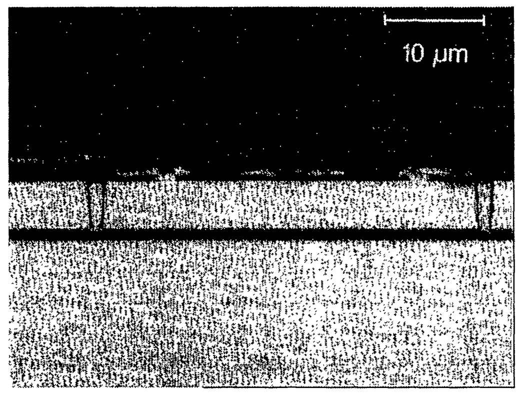

Fig. 4 XFCB technology

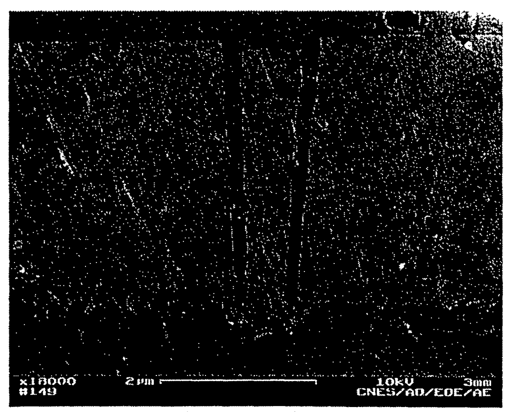

Fig. 5 XFCB : Isolated trench

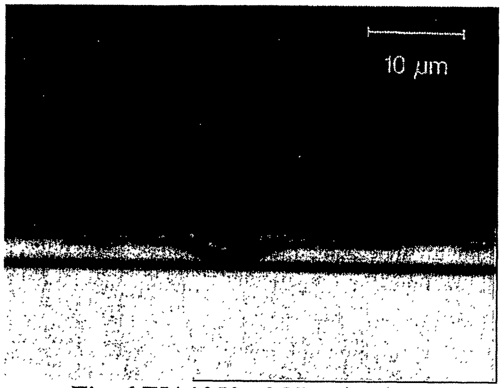

Fig. 6 TJA1050 : SOI technology

B. ENVIRONMENTAL AND RELIABILITY TESTS

The components were put through an accelerated ageing test : HAST, in order to know the packaging performances in moist atmosphere. We applied following conditions on 10 devices : 130°C / 85%RH / 96h . The aim of the dynamic Life-test was to estimate component performances at end of life and to calculate the electrical parameters drifts. The test conditions were : 2000h, 125°C on 10 samples.

HAST and Life-Test were realised on the TJA1050 from Philips in SO24 and AD8184 from Analog Devices in SO14. Others tests are going on.
Before and after these tests, the TJA1050 samples were characterised in extended temperature range (–40°C/+125°C). The parameter Vilmax from TXD input was out of specification at –40°C and +125°C and the delay bus inactive to RXD ($td_{(BUSoff-RXD)}$) was out of specification at +125°C, before and after endurance. It was surprising to find parameters out of specification because this component was guaranteed in –40°C/+125°C temperature range. These results have to be taken in account by designers. After HAST there was no drifts except the parameter high-level input current (Iih) from TXD input of one sample which was abnormally high after the test. 2000 hours of Life test haven't shown parametric drifts on the TJA1050 from Philips.

The electrical characterisation of the AD8184 components has shown that all the parameters were in the specifications in the extended temperature range, even though this component was guaranteed in the industrial temperature range. There was no parametric drifts on the AD8184 after HAST and Life test.
We have also sent a technology request to Analog Devices [6]. The manufacturer provided us with all reliability and qualification reports about components in XFCB technology. The qualification test file includes Life test, High temperature storage, PCT, THB, Temperature cycle, Thermal shock, ESD tests and sometimes HAST. The reliability results provided by Analog Devices show an excellent reliability of their technologies.
All these data (from the manufacturer and our own tests) make us confident in the reliability of these components for space applications.

VII. RADIATIONS

A. TEST DESCRIPTION

Co60 irradiation tests were performed by the CNES. The dose rate was around 220rad/h for each test and annealing was applied after total dose irradiation. For each type, 8 devices were irradiated under bias and 2 were switched-off. Performance tests were carried out prior, during and after irradiation.
Heavy ion experiments were conducted at IPN, France by TRAD and CNES. The received fluence was 1E+6 part./cm². Ions used are listed in Table 2.

Ion	Energy MeV	LET MeV/mg.cm²	Range in Si µm
Fluorine	103	4.2	77.6
Chlorine	156	13	43.8
Nickel	182	29.8	27.7
Bromine	192	40.7	28
Iodine	225	60.4	25

Tab.2 Heavy Ions description

The objectives were to determine heavy ion SEE sensitivities including the Linear Energy Transfer (LET) threshold and saturation cross sections of components for Single Event Transient (SET) and Single Event Latch-up (SEL).

B. TEST RESULTS AND DISCUSSION

Results :

Table 3 summarises the devices tested and the test results , using the following conventions :
SEL : > = No SEL observed
SET : < = LET threshold (MeV/mg.cm²)
σ = saturation cross-section (cm²/device)
TID: ~ = Parametric drifts observed at the indicated dose level (Krad(Si))
> = No parametric drifts observed

Reference	SEL	SET	TID Krad(Si)
TJA1050	LET_{th}>60	LET_{th}<29.8 $\sigma_{sat} \sim 4.1E^{-6}$	~ 5
AD8184	LET_{th}>60	LET_{th}<4.2 $\sigma_{sat} \sim 1E^{-4}$	> 103
AD8598	LET_{th}>60	LET_{th}<4 to 13 $\sigma_{sat} \sim 5.1E^{-5}$	On going
AD8009	LET_{th}>60	LET_{th}<12 $\sigma_{sat} \sim 5.1E^{-5}$	On going
AD8063	LET_{th}>40	Static mode : LET_{th}<10 $\sigma_{sat} \sim 3.2E^{-5}$ Dynamic mode : LET_{th}<5 $\sigma_{sat} \sim 2.2E^{-5}$	> 103

Tab. 3 Radiation results

Discussion :

- *Total Ionising Dose :*

The TJA1050 from Philips was functional up to 30Krad(Si) for biased devices. The unbiased components were functional up to 50Krad(Si). The TJA1050 wasn't fully functional after annealing. The first parameters which overstepped the specification were : the low-level input voltage of transmitter data input (Vilmax of TXD) at 5Krad(Si) on one device and on the others samples at 10Krad(Si) and the low-level input voltage of mode select input (Vilmax of Select) at 15Krad(Si). There was no recovery after annealing. The other parameters were out of specification at 30Krad(Si). So, our results have shown that the "ON" bias configuration is the worst case bias configuration.

The AD8184 and the AD8063 components from Analog Devices were fully functional up to the total dose of 103Krad(Si). No major parametric or functional drift was measured.

- *Single Event Effects :*

The TJA1050 from Philips was immune to SEL up to a LET of 60MeV/mg.cm².
The 2 tested components were not very SET sensitive. The LET threshold was around 29.8MeV/mg.cm² (Figure 7). Their behaviour was not homogeneous : one device was more sensitive than the other. When the TJA1050 was irradiated in receiver mode, SET generated glitches (Figure 8) ; in transmitter mode, SET produced a modification of duty cycle.

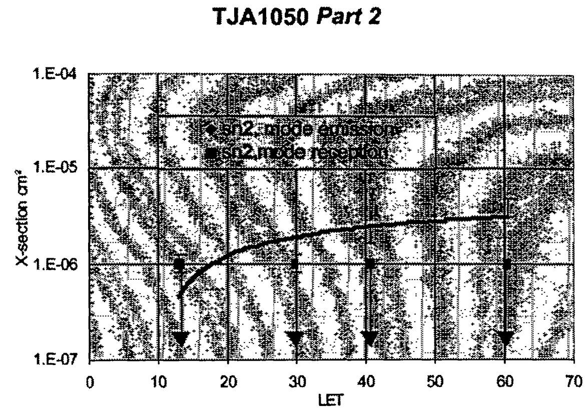

Fig. 7 : TJA1050 : Cross section = f(LET)

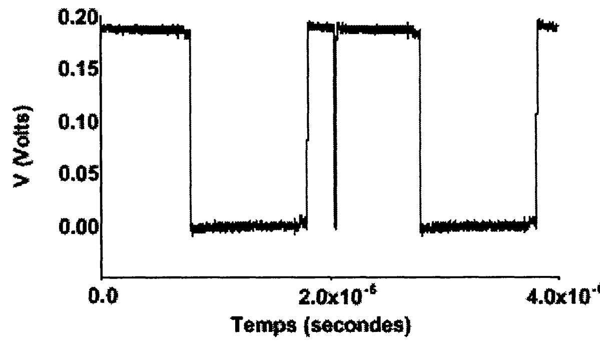

Fig.8 : TJA1050 output in receiver mode

The AD8184 from Analog Devices was immune to SEL up to 60MeV/mg.cm².
The AD8184 multiplexer was very SET sensitive. The LET threshold was around 4MeV/mg.cm². SET produced on the output voltage a transient perturbation with an amplitude of 2.5V and a total duration of 14µs.

The AD8063 from Analog Devices was immune to SEL up to 40.7MeV/mg/cm2.
We studied two types of transients on this amplifier :

- In static mode: a signal with an amplitude of 1V was applied on the input. All perturbations of 0.02V on the output were recorded as a static SET.
- In dynamic mode : a signal with a 300ns period was applied on the amplifier input. A software counted the frequency disturbances as dynamic SET and stored them in a file.

The device was sensitive to both type of SET without a domination of one or other phenomenon. The LET threshold was around 10MeV/mg.cm² in static mode and between 5 and 10MeV/mg.cm² in dynamic mode.

The AD8009 from Analog Devices was immune to SEL up to 60MeV/mg.cm².
The AD8009 was SET sensitive in static and dynamic modes. The LET threshold was around 12MeV/mg.cm² (Figure 9). In static mode SET produced decrease on

output voltage (Figure 10) ; in dynamic mode SET generated glitches (Figure 11).

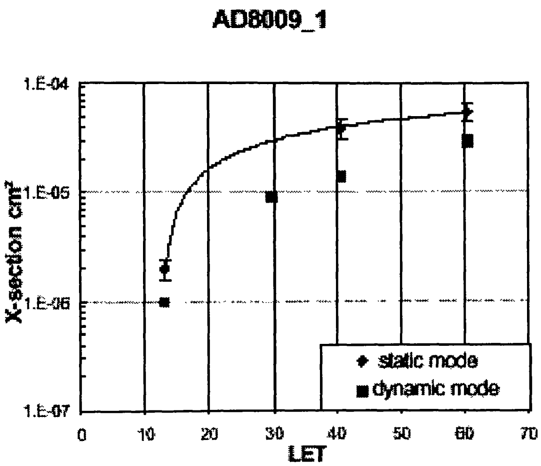

Fig. 9 : AD8009 : Cross section = f(LET)

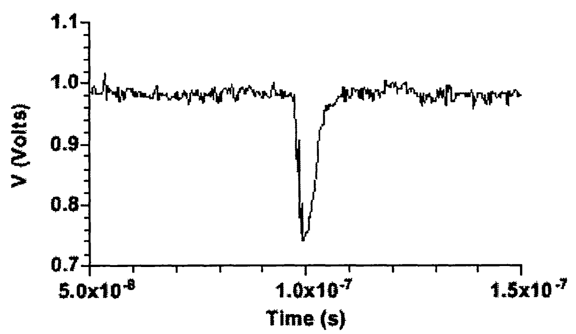

Fig. 10 : AD8009 Output voltage in static mode. Heavy ion used : Iodine

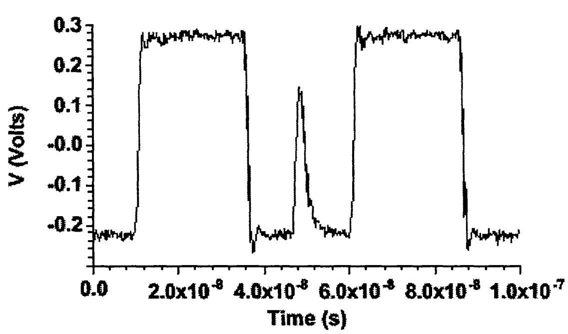

Fig. 11 : AD8009 Output voltage in dynamic mode. Heavy ion used : Iodine

The AD8598 from Analog Devices was immune to SEL up to 60MeV/mg.cm².
The AD8598 comparator was SET sensitive. The LET threshold was between 4 and 13MeV/mg.cm² (Figure 12). SET caused output voltage commutation from 0V to Vout max or from Vout max to 0V (Figures 13 and 14). More the differential input voltage was low, more the SET sensitivity was significant (Figure 15).

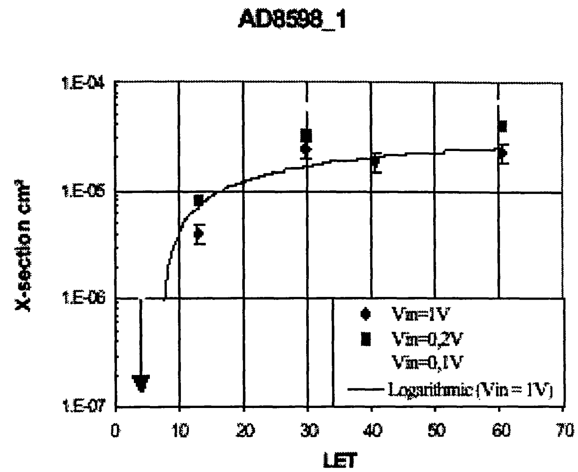

Fig. 12 : AD8598 : cross section = f(LET)

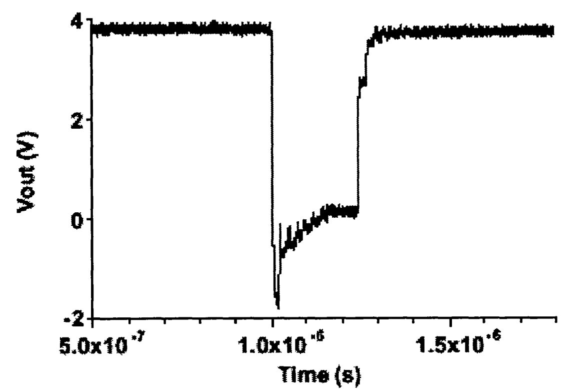

Fig. 13 : AD8598 : SET when input voltage positive Output A. Heavy Ion used : Iodine

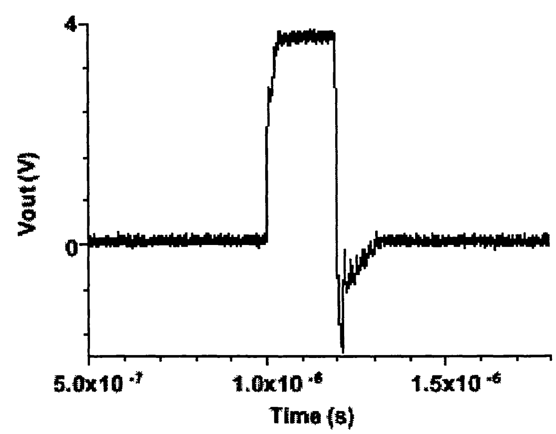

Fig. 14 : AD8598 : SET when input voltage negative Output A. Heavy Ion used : Iodine

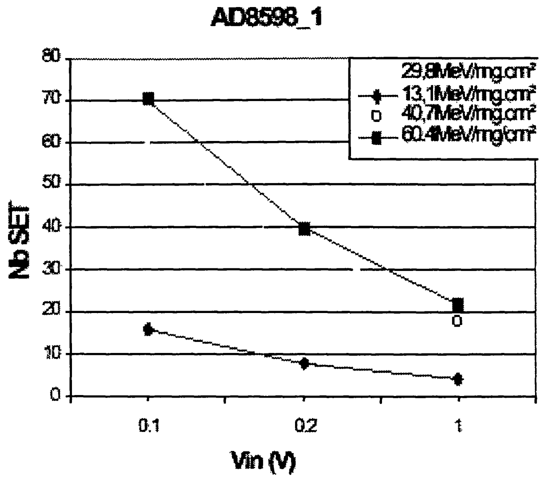

Fig. 15 : AD8598 : Number of SET according to input voltage

To conclude on radiation tests, we can note that the behaviour of the TJA1050 from Philips, during Total Ionising Dose test, has shown that commercial SOI technologies are not fully adapted to hardened applications. The buried oxide isolation and the small volume of silicon present many advantage for speed, density, and hardness to transient irradiation. But unless radiation hardened, the buried oxide introduces an additional path for total ionising dose leakage currents [7]. Nevertheless the bipolar Analog Devices' XFCB process seems to be very resistive to Total Dose.
Heavy ions experiments have shown that the SOI and XFCB technologies are immune to Single Event Latch-up. By reducing the silicon volume in which radiation generates carriers, the SOI structure reduces also the sensitivity to Single Event Transients (compared to bulk devices).

VIII. CONCLUSION

At this time environmental, reliability and radiation (TID) tests and mounting validation are going on. All data will be available for the end of the year in a final report.
The first results presented in this paper show that the components in Analog Devices' XFCB technology can be used in space environments. Furthermore, this study makes us confident to use commercial components in naturally radiation hardened technologies in spacecraft applications. The selected components from Analog Devices which are completely evaluated will be introduced in the "CNES Guide List for the selection of commercial components". The Bus CAN from Philips will be proposed for spacecraft applications which will require a low total dose level.

It is now possible to use commercial components in naturally radiation hardened technologies for space applications. Nevertheless, these technologies and devices are optimised for high speed or low power applications, and so are much more vulnerable than the specific rad-hard SOI technologies.

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