ASTEP (2005-2015): Ten Years of Soft Error and Atmospheric Radiation Characterizations on the Plateau de Bure

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Abstract

This paper surveys ten years of experimentation conducted on the Altitude SEE (Single Event Effects) Test European Platform (ASTEP), a permanent mountain laboratory opened in 2005 on the Plateau de Bure (Devoluy, France) at the altitude of 2,552 m and primarily dedicated to the characterization of soft errors in electronic circuits subjected to terrestrial cosmic rays. The paper retraces the foundations of the project and gives an extensive overview of the different past, current and future experiments conducted on ASTEP in the fields of SER (Soft Error Rate) real-time testing and natural radiation monitoring and metrology.

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1. Introduction

Since soft errors induced by terrestrial natural radiation have been considered as one of the most important primary limits for modern electronics reliability at ground level, determining the soft error rate (SER) of a given circuit is a major issue for IC manufacturers and users [1]. In complement to the popular accelerated SER tests using intense particle sources or beams, real-time (RT) measurements represent a very accurate experimental solution to determine the SER from the monitoring of a population of devices subjected to the true natural radiation environment and operating under nominal conditions [2]. Conducting real-time tests is therefore not trivial because such experiments cannot be launched without a solid logistic, a dedicated test location and a long-term technical support. In order to benefit from a permanent facility precisely dedicated to RT testing, we have developed since 2005 a test platform at mountain altitude, the Altitude Test Single-event European Platform (ASTEP). Located in south French Alps at 2552 m of elevation, ASTEP has been continuously used from this date to investigate the impact of atmospheric radiation (terrestrial cosmic rays primarily composed of atmospheric neutrons) on the SER of circuits manufactured in different technological nodes and various CMOS bulk technologies.

This paper retraces the foundations of the project (Section 2) and gives an extensive overview of the different experiments conducted on ASTEP in the fields of SER (Soft Error Rate) real-time testing (Section 3) and natural radiation monitoring and metrology (Section 4). New additional data concerning real-time experiments on advanced SRAM technologies will be presented at the conference and included in the final paper, as well as details about the forthcoming experiments on CMOS SOI technologies and scientific perspectives for the future of ASTEP.

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2. A brief history of ASTEP

The project to create an altitude laboratory dedicated to long-term experiments in the domain of soft error characterization in devices, circuits and systems was launched in 2001 by STMicroelectronics and JB R&D. The initial idea was to build a permanent facility with a dual academic and industrial research vocation, opened to the radiation effect community and to conduct, in the same location, both soft error rate (SER) measurements and terrestrial cosmic ray metrology. The project was formally named “Altitude SEE (Single Event Effects) Test European Platform” (ASTEP) in 2003; it has been supported by L2MP-CNRS laboratory (now IM2NP) in Marseille since this date. The same year, the site of the Plateau de Bure (Devoluy, France) and the host support of the institute for millimeter radio astronomy (IRAM) were definitively chosen. A host convention was signed in 2004 between CNRS and IRAM to formalize the installation of the ASTEP platform on the Plateau de Bure. In 2005, the ancient building “POM2” of the IRAM Observatory was fully rehabilitated by the City of Saint-Etienne en Dévoluy in order to host the scientific instruments of the platform (Fig. 1). The first equipments were installed on site in September 2005. The permanent network connection (wireless between the Plateau de Bure and the Devoluy valley) between ASTEP and IM2NP in Marseille was also successfully tested. In parallel, the first real-time experimental bench dedicated to the characterization of STMicroelectronics 130 nm SRAM memories was designed and integrated. The complete setup was presented during a public conference on December 2005 at the General Council of Hautes Alpes in Gap and he platform was officially inaugurated on July 5, 2005. In February 2006, Xilinx installed two boards of 130 nm FPGAs Virtex II on ASTEP in the framework

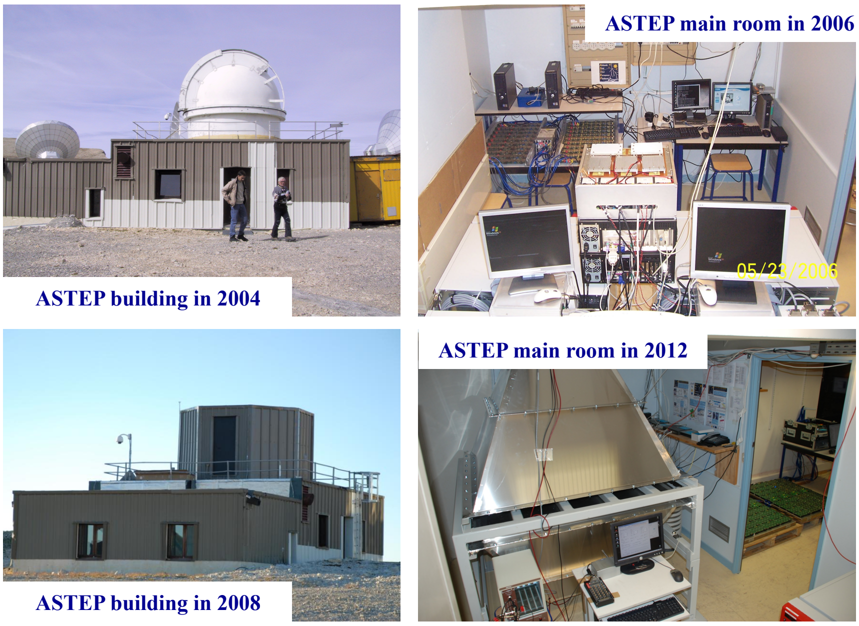

Figure 1. Evolution of the ASTEP building since 2004. The new cupola constructed in 2008 hosts, since this date, the Plateau de Bure Neutron Monitor (PdBNM). The configuration of the ASTEP main experimental room changed several times since 2005, as a function of hosted experiments. Since 2012, the Plateau de Bure Muon Monitor (PdBM2) is definitively installed in this room.

of the Xilinx's Rosetta experiment [3] (see Fig. 2). One month later, the ST 130 nm SRAM setup was installed on ASTEP and RT measurements started on April 29, 2005. The first experimental measurements were presented at the European Conference on Radiation and its Effects on Components and Systems (RADECS 2006) in September 2006 in Athens [4]. In 2007, the rehabilitation works of the first floor of the ASTEP building (ancient cupola of the POM2 building) were launched during the summer period. Works were therefore interrupted by the snow and bad weather conditions in October. The construction of a second real-time test setup dedicated to ST 65 nm SRAM memories was launched. In January 2008, the 65 nm setup was installed on ASTEP. Rehabilitation works resumed at the end of May 2008. The Plateau de Bure Neutron Monitor (PdBNM) was installed on the first floor of the ASTEP building on July 23, 2008 (see Figs. 1 and 2). The instrument has been fully operational since this date. The first results concerning 65 nm SRAMs were presented at RADECS 2008 in Jyväskylä (Finland), in September 2008 [5]. In 2009, high temperature tests (85°C) were conducted on the 65 nm SRAMs to investigate Single Event Latchup (SEL) and micro-latchup mechanisms. In 2010, the ASTEP platform and collaboration program were presented during an invited talk at ESREF 2010 [6]. In 2011, a third real-time setup embedding more than 7 Gbits of ST 40 nm SRAMs was designed and integrated. The setup was installed on ASTEP in March (see Fig. 2). The Plateau de Bure Neutron Monitor joined the Neutron Monitor Database international network [7]. The Plateau de Bure Muon Monitor (PdBM2), developed at IM2NP-CNRS laboratory in Marseille, was installed on the ASTEP platform during July/August 2011. A new type of wafer-level characterization based on more than 50 Gbit of 90 nm NOR flash memories subjected to natural radiation was also launched. The first results concerning the 40 nm SRAM experiment were presented at the International Reliability Physics Symposium (IRPS 2012) in Anaheim (USA) [8]. Additional results concerning thermal neutron sensitivity of these 40 nm SRAMs were presented at the 2012 Nuclear and Space Effects (NSREC) Conference [9]. In 2013, the first results concerning the characterization of flash memories subjected to natural radiation were presented at IRPS in Monterey (USA) [9]. The 40 nm experiment was stopped and transported to Marseille for sea level measurements. Finally, in 2014, a fourth generation of real-time setup embedding more than 4 Gbits of ST 28nm SRAMs manufactured in FD-SOI technology was designed and integrated. This setup will be installed on ASTEP in June 2015.

3. Atmospheric neutron and muon flux monitoring

Since 2008 and 2011, respectively, ASTEP is equipped with a neutron and a muon monitors. The two original instruments, designed and constructed by IM2NP for ASTEP, are shown in Fig. 3. Note that a clone copy of each instrument is available at IM2NP in Marseille on

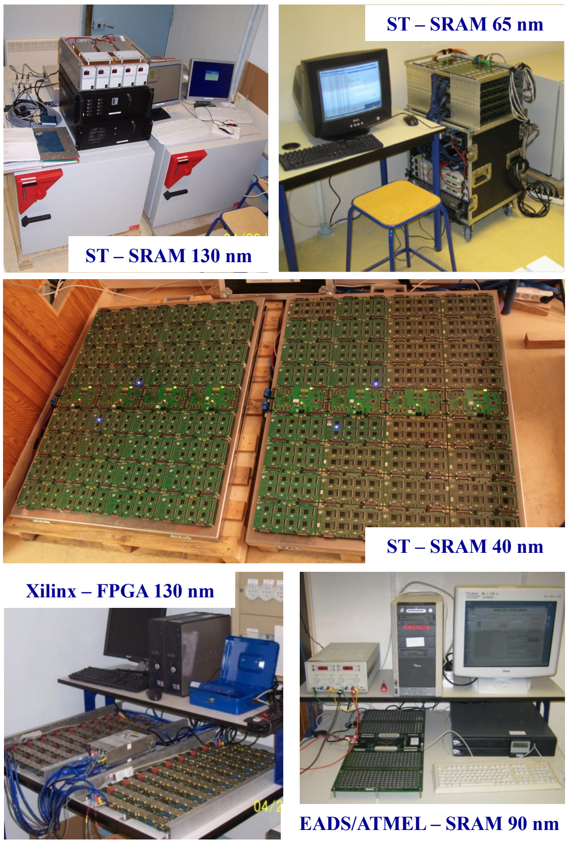

Figure 2. Panel of SER real-time experiments conducted on the ASTEP platform since 2005.

the new established TERRAMU platform [11]. Both monitors have been used to determine the acceleration factor of the real-time experiments with respect to sea-level conditions. Annual, seasonal and daily variations of the particle flux can thus be evidenced, as a function of atmospheric pressure, solar cycle variations and solar event (Forbush decreases). These points will be carefully detailed in the final paper and presentation.

4. Real-time SER experiments

Table 1 gives the current status of the different real-time experiments conducted on ASTEP, at LSM (Underground Laboratory of Modane) and at IM2NP in Marseille during the last decade. Two experiments have been recently moved from ASTEP (40 nm, see Fig. 4) and from LSM (65 nm) to Marseille. The final paper will report for the first time these additional sea-level measurements and will discuss the adequacy of these results with respect to the estimated contribution of the internal chip radioactivity. A status about the test of two flash technologies will be also reported.

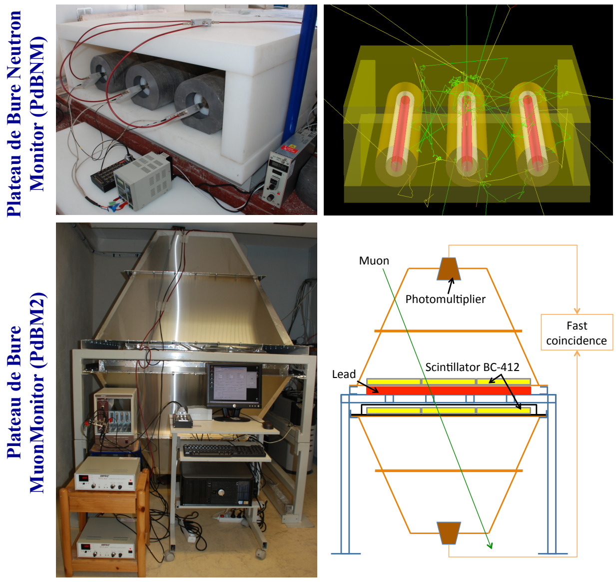

Figure 3. General views (left) and schematics (right) of the Plateau de Bure Neutron monitor (PdBNM) and muon monitor (PdBM2) installed on ASTEP.

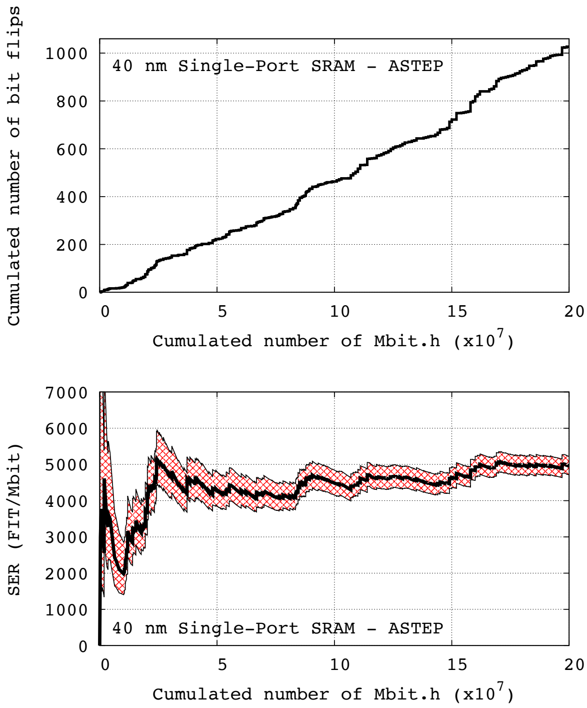

Figure 4. Definitive results for the 40 nm single-port SRAMs characterized in altitude on the ASTEP platform Top: Cumulative number of bit flips versus test duration. Test has been conducted under nominal conditions: $V_{DD} = 1.1$V, room temperature, standard checkerboard test pattern. Bottom: Bit flip SER (FIT/MBit) versus test duration calculated from above data. The 90% confidence interval is also indicated (hatched area).

Table 1
Summary of RTSER experiments conducted on the ASTEP platform and at LSM during the period 2006-2015.

Platform	Circuit & Technology	Test temperature	Initial Mbit under test	Start date	Stop date	Effective Cumulated hours of test	Main Reference
ASTEP	**130 nm SRAM**	RT	3,664	03/31/2006	11/26/2006	5,200	[4]
LSM			3,472	10/16/2007	10/15/2010	24,747	[6]
ASTEP	**65 nm SRAM**	RT	3,216	01/21/2008	05/07/2009	11,278	[5]
		85 °C	2,884	06/26/2009	01/24/2013	28,482	[2]
LSM		RT	3,226	04/11/2008	01/25/2015	57,058	[5]
Marseille		RT		03/03/2015	Ongoing	~ 2,500	This work
ASTEP	**40 nm SRAM**	RT	7,168	11/03/2011	06/03/2014	28,495	[8]
Marseille		RT		10/16/2014	Ongoing	~5,000	This work
ASTEP	**90 nm Flash (wafer-level)**	RT	~50,000	07/2011	Ongoing	> 32,000	[10]
ASTEP	**55 nm Flash (wafer-level)**	RT	~40,000	11/30/2012	Ongoing	> 20,000	This work

Acknowledgments

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