WHITE PAPER

Radiation Characterization and Performance Evaluation of the LX2160 Space Processor.

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TELEDYNE | e2v Semiconductors

INTRODUCTION

A Comprehensive Analysis of Total Ionizing Dose, Single Event Effects, and System-Level Robustness.

Spaceborne electronic systems are evolving rapidly, driven by increasing demands for onboard processing, autonomy, and real-time data exploitation. Modern missions—including Earth observation, telecommunications, navigation, and deep-space exploration—require processors capable of handling large volumes of data directly in orbit. This shift reduces dependence on ground infrastructure while enabling faster decision-making and more flexible mission architectures.

At the same time, these systems must operate reliably in harsh radiation environments. High-energy particles can induce both cumulative degradation and transient disturbances in semiconductor devices, potentially affecting system functionality and long-term reliability. As a result, comprehensive radiation characterization is essential to ensure predictable behavior and mission assurance.

The LX2160-Space processor, based on NXP's QorIQ® Layerscape architecture and enhanced through Teledyne e2v's space-grade manufacturing and qualification flow, has been developed to address these dual challenges. Integrating up to sixteen Arm® Cortex-A72 cores alongside high-speed memory and communication interfaces, the device targets next-generation space systems requiring both computational performance and robustness.

To validate its suitability for space environments, an extensive radiation test campaign has been conducted. This campaign includes Total Ionizing Dose (TID), Single Event Latch-up (SEL), and Single Event Effects (SEE) evaluations across cores, memory subsystems, and peripheral interfaces. The present paper consolidates these results and provides a system-level interpretation of the processor's behavior under radiation exposure.

2. LX2160-SPACE PROCESSOR ARCHITECTURE OVERVIEW

The LX2160-Space processor is a highly integrated System-on-Chip designed to balance performance, flexibility, and resilience. Its architecture includes multiple processing cores, an advanced cache hierarchy, and a wide range of high-speed interfaces, enabling it to support complex and data-intensive applications.

A key aspect of this architecture lies in its use of Error Correction Code (ECC) across critical memory elements, which allows the detection and correction of transient errors. In addition, the processor is structured around multiple independent power and clock domains, enabling localized fault isolation and improved robustness. The integration of interfaces such as DDR4, PCIe, Ethernet, SATA, SPI, I2C, and eMMC further supports a broad range of mission profiles.

Equally important is the processor's reliance on software-driven mitigation strategies. Built-in reset mechanisms and system-level recovery capabilities enable rapid restoration of functionality following transient disturbances. This combination of hardware protection and software flexibility provides an effective approach to managing radiation-induced effects without requiring fully hardened design techniques.

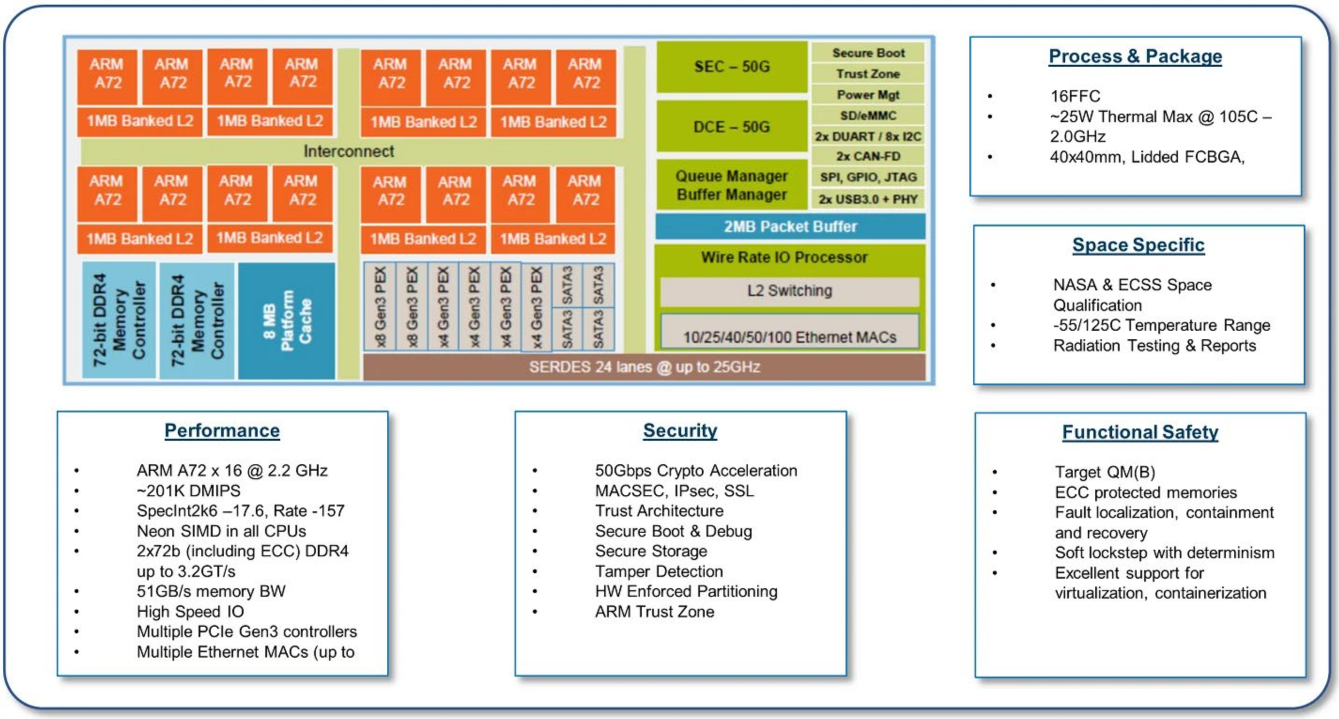

Figure 1 – LX2160 Space Processor Functional Block Diagram

3. RADIATION EFFECTS IN SPACE ENVIRONMENTS

Radiation effects in semiconductor devices can be broadly categorized into cumulative and single-event phenomena. Each type has distinct physical mechanisms and implications for system design.

Total Ionizing Dose represents the long-term accumulation of ionizing radiation in device materials. This leads to progressive changes in transistor characteristics, including threshold voltage shifts and increased leakage currents. Over time, these effects can alter circuit behavior and degrade performance, particularly in analog and mixed-signal blocks.

Single Event Latch-up is a more severe phenomenon, involving the activation of parasitic structures within CMOS devices. When triggered, it can result in a high-current state that may lead to permanent damage if not quickly mitigated. Ensuring immunity to this effect is therefore critical for any space-qualified component.
Single Event Effects encompass a range of transient disturbances caused by individual particle strikes. These include bit flips in memory elements, temporary functional interruptions, and more complex multi-bit errors. Although non-destructive, such events can disrupt system operation and must be carefully characterized to define appropriate mitigation strategies.

Table 1 summarizes the radiation test conditions and measurements performed on the LX2160 as part of the overall characterization campaign. The device was evaluated under representative operating conditions during both cumulative and single-event irradiation tests, including TID and heavy-ion exposures. Key electrical and functional parameters were continuously monitored to capture the processor’s response across cores, memory subsystems, and interfaces, ensuring a comprehensive assessment of its behavior and robustness in realistic space radiation environments.

Test Group	Description
Open/Short	Open/Short circuits
CRES	Contact resistivity
Trip	Leakage between supply and ground
Fuse	Internal register fused during final test at NXP
Leakage	Leakage on I/Os
Sidd	Static power Consumption
DC Scan	Stuck-at fault detection
DC Spec	VOL and VOH test
DDR4	Memory controller test
EMI	Peripheral interface test
1588	Peripheral interface test
HSSI	High speed serial interface test
Slowbus (GPIO, I2C...)	Low speed serial interface test
USB	Peripheral interface test
SNVS	Security Engine
Lynx test guide (LTG)	High speed serial interface test
AC Scan	Transition fault detection
RGMII	Ethernet interface test
SPI	Serial peripheral interface test
CRES	Contact resistivity

Table 1: Parameters measured during electrical testing

4. TOTAL IONIZING DOSE CHARACTERIZATION

The TID performance of the LX2160-Space processor was evaluated through irradiation up to 100 krad(Si), using a Cobalt-60 gamma source under representative operating conditions. Throughout the exposure, key electrical parameters such as power consumption, leakage currents, frequency margins, and operating voltages were continuously monitored, both during irradiation and during post-irradiation annealing phases.

The results demonstrate that the processor maintains stable functional behavior across the entire dose range. No significant degradation or drift in critical parameters was observed, and all variations remained within expected limits for advanced semiconductor technologies, including 16 nm FinFET processes.

From a system perspective, this level of robustness ensures that the device can operate reliably over long mission durations without requiring derating or complex compensation mechanisms. The demonstrated tolerance is compatible with a wide range of orbital environments, from Low Earth Orbit to more demanding Geostationary missions where cumulative radiation effects are more pronounced.

5. SINGLE EVENT LATCH-UP IMMUNITY

The susceptibility of the LX2160-Space processor to Single Event Latch-up was evaluated through heavy-ion irradiation testing under conservative worst-case conditions. These conditions included high Linear Energy Transfer (LET) levels exceeding 93 MeV·cm^2/mg, elevated temperatures, and maximum operating voltages, ensuring a rigorous assessment of device robustness.

Throughout the test campaign, all power domains were closely monitored for abnormal current behavior. No destructive latch-up events were observed. While some high-current events were detected, these were found to correspond to gradual and reversible current increases rather than true latch-up phenomena.

These events were fully recoverable through standard power cycling and did not result in any permanent degradation. Their behavior is consistent with transient charge effects rather than the activation of parasitic thyristor structures. The absence of destructive latch-up under such stringent conditions confirms the processor's strong intrinsic immunity. This greatly simplifies system design by eliminating the need for complex protection circuitry and significantly reduces the risk of catastrophic failure in orbit.

6. SINGLE EVENT EFFECTS CHARACTERIZATION

A comprehensive SEE evaluation was performed across the processor cores, memory subsystems, and peripheral interfaces to assess the impact of transient radiation-induced events on system operation.

At the processor core level, Single Event Functional Interrupts were observed, indicating sensitivity to particle-induced disturbances. However, the recovery mechanisms proved highly effective. The vast majority of events were resolved through simple reset procedures, while only a very small fraction required more extensive reinitialization. Importantly, no events necessitated a complete power cycle, demonstrating the efficiency of built-in mitigation strategies.

Memory subsystem testing revealed the occurrence of transient errors in cache structures at moderate LET levels. These errors exhibited complex behavior influenced by both LET and particle fluence. Despite this, integrated ECC mechanisms and architectural design features ensured effective error management. System-level analysis further indicated that the probability of such events occurring in orbit remains extremely low, even under pessimistic conditions.

The evaluation of peripheral interfaces highlighted varying levels of sensitivity depending on controller architecture. Transient disturbances were observed in communication interfaces such as DDR4, Ethernet, and SATA, as well as in storage and control interfaces including eMMC and I2C. These disturbances manifested as temporary communication errors or data corruption events, often occurring in clusters associated with particle interactions.

Crucially, all observed SEE events were non-destructive and could be resolved using standard reset mechanisms. The associated cross-sections remained low, confirming limited susceptibility to radiation-induced disruptions. Furthermore, the ability to recover both core and peripheral functionality using uniform mitigation strategies greatly simplifies system-level fault management.

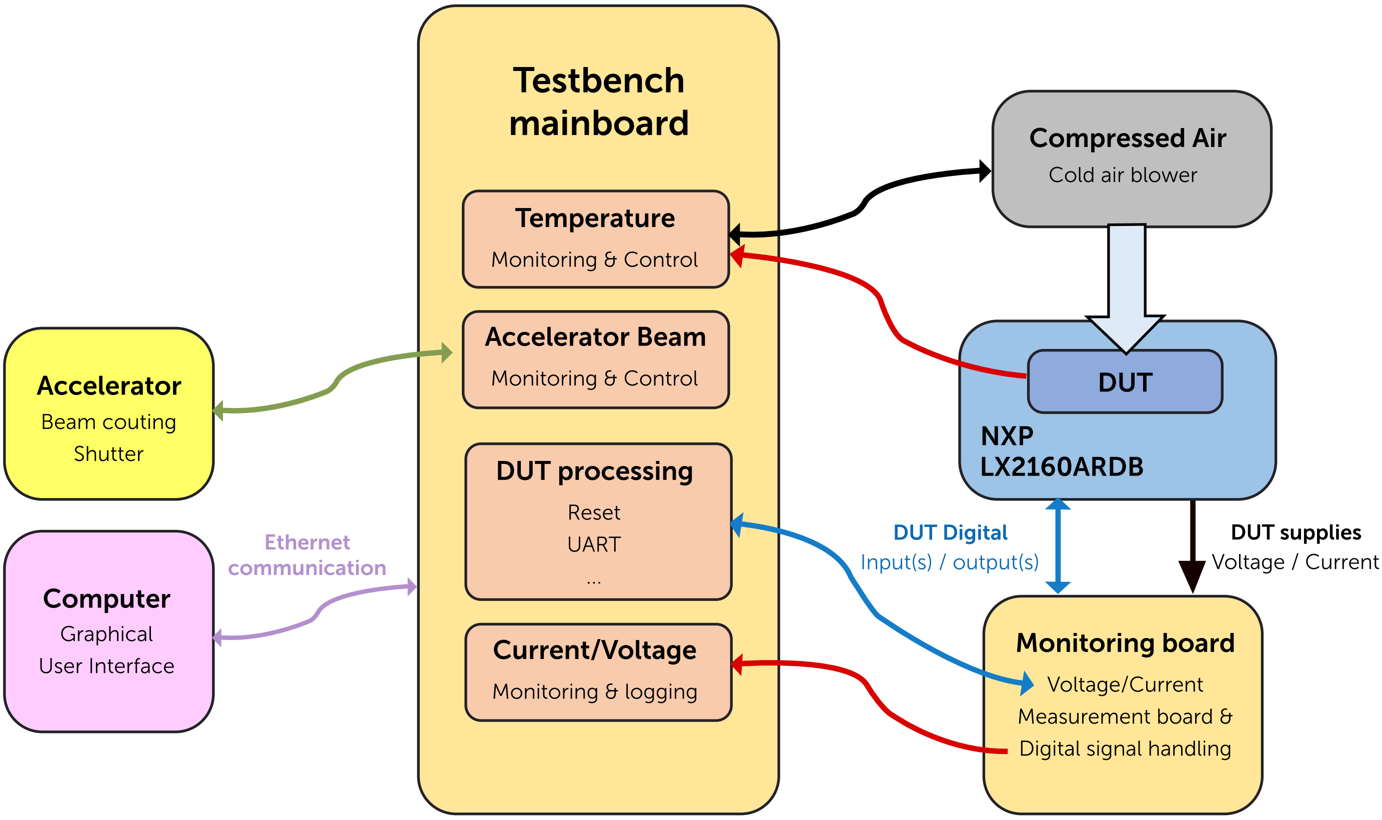

Figure 2 – SEE Test setup

7. SYSTEM-LEVEL IMPLICATIONS

The combined results of the radiation characterization program demonstrate that the LX2160-Space processor exhibits a high degree of robustness across all examined domains. It maintains stable operation under cumulative radiation exposure, shows complete immunity to destructive latch-up, and demonstrates predictable and recoverable behavior in response to single-event effects.

These characteristics enable the implementation of modern mitigation strategies based on software supervision and system-level resilience. Rather than relying exclusively on radiation-hardened hardware, designers can take advantage of reset-based recovery techniques and redundancy schemes to ensure reliable operation.

Orbit-level modeling further confirms that the expected rate of radiation-induced events remains compatible with mission reliability requirements across a wide range of environments. Even in worst-case scenarios, the impact of transient effects on system availability is minimal.

8. CONCLUSION

The radiation characterization of the LX2160-Space processor provides a comprehensive understanding of its behavior in space environments. The device demonstrates strong tolerance to cumulative radiation effects, complete immunity to destructive latch-up, and robust resilience to transient disturbances.

Although single-event effects may occasionally disrupt operation, they remain non-destructive and can be efficiently mitigated using well-established recovery mechanisms. This combination of performance, robustness, and recoverability ensures that the processor meets the stringent requirements of modern space missions.

By integrating advanced semiconductor technology with effective architectural and software-based mitigation approaches, the LX2160-Space processor represents a highly capable solution for next-generation space systems. It enables the deployment of high-performance onboard processing capabilities while maintaining the level of reliability required for operation in harsh radiation environments.

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