Radiation Effects on Integrated Circuits and Systems for Space Applications

Raoul Velazco • Dale McMorrow • Jaime Estela
Editors

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Preface

The launch of Sputnik 1 in 1957 started the space era and initiated the development of electronics designed specifically for use in space. Space applications present significant challenges, requiring new approaches, and even new technologies. Sputnik 1 had a simple, robust, vacuum tube-based design. Sputnik 2, also launched in 1957, carried the first living creature into space. In this case the mission requirements were ambitious, demanding sophisticated technical solutions. Explorer 1, which verified the existence of the Van Allen radiation belts, was launched in early 1958; its limited payload capacity required significant innovation, including the first insertion of solid-state transistors into a space vehicle to reduce size, weight, and power consumption.

During the 1950s, the study of radiation effects on electronic components was in its infancy. Originally, military-grade electronics were used for space missions, but those did not necessarily exhibit the characteristics required for space flight, a shortcoming that motivated the development of electronics specifically designed for use in space, or other high-radiation environments. To this day, evolving applications associated with real missions have continued to drive the development of radiation-hardening approaches for dedicated space components.

Over time, the space environments have become better characterized and better understood, microelectronic technologies have undergone significant evolution, and the various physical phenomena associated radiation-induced degradation have continued to expand. This new knowledge of the threats posed by ionizing radiation led to improvements in space electronics and mission design. Advances in computational capabilities led to simulations able to predict the effects of the space environment on specific missions, an area that continues to develop. Mitigation techniques and recovery mechanisms can protect data; electronic and physical fault injection approaches can be used to probe and validate robust designs.

This volume provides a snapshot in time of different aspects of the rapidly evolving field of radiation effects on electronic components. Much has changed since the initial volume was published in 2007: as technologies have evolved our understanding of radiation-induced degradation and failures has expanded, and radiation mitigation approaches have become more sophisticated. The contents of this volume reflect this evolution.

The recent move towards small satellites and constellations, or “swarms” of smaller satellites, has altered the space electronics landscape. The new generation of small-sats and cube-sats requires electronic components that are compact and high-performance, with low power consumption; such properties, however, often are traded for reliability. Once relegated to the university domain, small satellites are quickly becoming mainstream, with efforts underway at all the major space agencies across the globe. The shorter timelines to launch, together with size, weight, and power constraints, are leading a rapid paradigm shift in the industry. This involves part selection, procurement, and, especially, qualification.

An overview of the current state of the art in space electronics, discussions on the implementation and qualification of commercial parts for space systems, and examples of innovative test and simulation approaches are included in this volume. Mitigation approaches, including board- and system-level fault-tolerant architectures, are presented and discussed, as are microprocessor testing, modeling, and fault mitigation schemes. As the use of commercial components (COTS) in satellites increases, the space community must develop innovative ways to manage the increased risk. Novel qualification methods, flexible qualification standards, and innovative data protection methods are required; several chapters are dedicated to such challenges. The complexity of testing and qualification increases as technology evolves; novel test and fault injection approaches are discussed, including the use of laser-based approaches for injecting single-event effects into microelectronic devices.

The goal of this volume is to collect and distribute the diverse knowledge of radiation effects possessed by the authors, and to make available aspects of their experience in the design and evaluation of space-based electronic systems. This effort aims to broaden the baseline knowledge within the space electronics community and to provide inspiration for the next generation of specialists with expertise in space component design and qualification.

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Raoul Velazco is Director of Research (DR) at the CNRS (National Center for Scientific Research) and the Head of the RIS (Robust Integrated Systems) team at TIMA (Techniques of Informatics and Microelectronics for Integrated Systems Architecture) Laboratory, in Grenoble, France.

Dale McMorrow is Head of the Radiation Effects Section at the US Naval Research Laboratory, in Washington, DC.

Jaime Estela is CEO/CTO, Small Satellite Technology, at Spectrum Aerospace Group, in Munich-Germering, Germany.

Mr. Jaime Estela is an Electronic Engineer born in Lima, Peru. He worked at GSOC, DLR, in Oberpfaffenhofen for more than 11 years. In this period he gathered experience in satellite operations and systems engineering and supported several LEO satellite missions like TerraSAR-X, TanDEM-X, Prisma A and B, GRACE 1 and 2, CHAMP, BIRD, and TET. Mr. Estela was also involved, as Ground Segment Engineer, in the ESA project Columbus, the European Module of the International Space Station (ISS). Furthermore, he has supported nanosatellite missions developed by Universities. He supported the project QB50, an international constellation of 50 CubeSats which will study the higher ionosphere in a low Earth orbit and during its reentry as suborbital research platform. In 2010 he founded Spectrum ARC GmbH and served as CEO/CTO. He is currently managing the companies Spectrum Aerospace Technologies UG (Munich, Germany) and Spectrum Aerospace Research Corporation SAC (Lima, Peru). Both companies belong to the Spectrum Aerospace Group. Mr. Estela has published and co-authored papers and articles in international journals and conference proceedings. The terminology Space-COTS, its concept and philosophy of qualifying commercial electronics for space applications, was invented by Mr. Estela. The research study of Space-COTS is geared towards finding a middle ground between unqualified components and fully qualified EEE parts.