Foreword to Special Issue

IN their 40-year history, satellites have revolutionized how we communicate. In the 21st Century, they will continue to do so in ways we can only imagine. Electronic and photonic devices and integrated circuits (IC's) are the hearts and brains of satellite-based communication and observation systems. However, the space radiation environment is not kind to many types of these devices and IC's. Total dose radiation exposure can reduce the lifetime and degrade the performance of space systems. Moreover, the interaction of a single high-energy heavy ion, proton, or neutron within the sensitive volume of a device or IC can cause a soft or hard error at any time during the lifetime of a space system. The probability of such an event depends on the radiation environment at a particular time for a given orbit and the amount of shielding material that surrounds the device or IC. The impact of any such error depends on the role of the affected device in the system, the device response to the single event, and system mitigation techniques that are employed. Thus, the impact can range from effects that are transparent to system operation in the best case, to catastrophic system failure in the worst case. The challenge to the spacecraft designer is to maximize system performance in this difficult environment at a cost that still allows profitable system operation.

Single-event effects (SEE's) are becoming more important as modern IC technology enables devices to shrink dramatically in size. This issue of the TRANSACTIONS is composed of 30 invited, fully refereed papers on SEE and the space radiation environment written by many of the leading experts in the field. It is our hope that the sampling of topics in this special issue will aid system designers and parts engineers to better understand and define the space, avionics, and terrestrial radiation environments, to select appropriate devices for systems that must operate in these environments, and to reduce the number of radiation-induced errors and mitigate their effects.

The first six papers in the issue (Feynman and Gabriel; Gussenhoven *et al.*; Stassinopoulos *et al.*; Dyer *et al.*; Daly *et al.*; and Boscher *et al.*) review recent progress in understanding the space radiation environment. Of special significance is the wealth of new satellite data, and the improved models of the space radiation environment that have resulted from these data. The two following papers update recent progress in understanding spacecraft charging (Frederickson) and total dose effects (Pease), which are also quite important issues for space systems. Spacecraft anomalies due to SEE are highlighted by Barillot and Calvel, and the increasing concern about SEE in avionics due to cosmic ray by-products (primarily atmospheric neutrons) is discussed by Normand.

McNulty entertains and enlightens us with a first-person account of the light flashes seen by astronauts that are caused by the passage of a high energy particle through a sensitive region of the eye. The same types of particles were later found to disrupt IC's in similar ways. Papers by Pickel and Petersen treat the vexing problem of how to predict cosmic ray- and proton-induced error rates in space from ground test data. These are followed by four papers on SEE-induced hard errors in space. Latchup is treated by Johnston and by Bruguier and Palau; gate rupture and burnout in power devices are covered by Titus and Wheatley and by Johnson *et al.*

A lucid history of the computer simulation of single-event charge collection is presented by Dodd. Massengill then provides an extensive review of efforts to understand and mitigate SEE in dynamic random access memories (DRAM's) in terrestrial and space applications. The difficult topic of SEE in analog and mixed-signal electronics is discussed by Turflinger. The next four papers illustrate SEE and/or high energy proton effects in several modern electronic and photonic device and IC technologies: silicon-on-insulator electronics (Musseau); charge-coupled devices (Hopkinson *et al.*); GaAs devices and IC's (McMorrow *et al.*); and fiber-optic links (Marshall *et al.*). System techniques to reduce the impact of SEE, including error detection and correction methods, are summarized by LaBel and Gates. The final five papers cover the crucial issues of testing and understanding a device's susceptibility to SEE: via high-energy particle accelerators, the present standard technique (Koga, and Duzellier and Ecoffet); via laser and Cf-252 simulation (Buchner *et al.*); and via microbeam methods (Sexton, and Takai *et al.*). That total dose exposure can modify device SEE sensitivity, as illustrated by Sexton, is a point that is often neglected in SEE tests.

Additional information about SEE and the space radiation environment is contained in many books, journal articles, and short courses. The interested reader is especially referred to the December issues of the IEEE TRANSACTIONS ON NUCLEAR SCIENCE through the 1980's and 1990's for information on these and other topics that may not have been covered in detail in this issue (e.g., techniques to harden digital MOS electronics to SEE, a topic of particularly great activity in the 1980's). New information on radiation effects on electronics in the space environment is best obtained by attending the annual IEEE Nuclear and Space Radiation Effects Conference (NSREC) and its European counterpart, the biennial Conference on Radiations and Their Effects on Circuits and Systems (RADECS), as well as by reading the IEEE TRANSACTIONS ON NUCLEAR SCIENCE on a regular basis!

We thank the Radiation Effects Steering Group of the IEEE NSREC for sponsoring this issue, and the TRANSACTIONS *Editor*, Paul V. Dressendorfer, for helping to arrange for the issue. Most of all, though, we thank all of the authors and reviewers for their efforts in crafting this issue. It is their continuing dedication that make the IEEE TRANSACTIONS ON NUCLEAR SCIENCE a well-respected publication, and that have made this a truly "special" issue.

DAN M. FLEETWOOD, Sandia National Laboratories, USA
REMI GAILLARD, Nucletudes SA, France
Guest Editors