The NASA Electronics Radiation Characterization Project

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Abstract

The mission of the NASA Electronics Radiation Characterization (ERC) Project is to (1) investigate and characterize the radiation response of microelectronic and photonic devices to support their use for fielded and planned NASA space missions and (2) analyze electronics related problems with fielded missions. In this paper, issues concerning device selection and some current problems with fielded and planned systems will be discussed.

Introduction

Among the most unique aspects of developing systems for space is the performance of electronic systems in the natural space radiation environment [1]. Long and short term radiation effects such as total ionizing dose (TID), displacement damage dose (DDD), and single event effects (SEE) provide aerospace designers' a myriad of challenges for system design. The radiation hazard that a designer faces is not generic: each mission orbit, timeframe, duration, and spacecraft design (mechanical and electrical) provides differing requirements and challenges to deal with. This hazard varies:

- from missions with severe requirements that fly in the heart of the Van Allen belts (such as a medium earth orbit or MEO)
- to avionics systems in the upper atmosphere that are protected from many energetic particle concerns, but still must deal with secondary particles such as neutrons.

With this in mind, the NASA Electronic Parts and Packaging (NEPP Program's ERC Project is responsible for supporting NASA's current and future needs in providing reliable electronic systems in the natural space and terrestrial radiation environments. These systems range from deep space probes with long lifetimes to earth and space science missions to the Space Shuttle short duration missions to avionics in aircraft. In this regard, the ERC project's roles revolve around:

- providing radiation evaluations and assessments of new and emerging microelectronic and photonic technologies to enhance infusion into NASA missions,
- developing guidelines for technology usage in radiation environments, and
- investigating radiation hardness assurance (RHA) issues in order to increase system reliability and reduce cost and schedule.

We work collaboratively with technology developers and users to understand radiation needs, issues, sensitivities, and hardening solutions both within NASA and within other government agencies, industry, and university. The underlying goal of the ERC Project is to aid designers to meet *their challenges* in areas such as performance, reliability, and resources. If the ERC Project is sufficiently funded and we do our job correctly, much of what is accomplished by this project is transparent to the mission management structure: we are able to discover and solve technology challenges *before* NASA missions choose to implement the technology in flight. They, the missions, simply qualify the technology that has been assessed including any hardening schemes that are required and integrate this technology into their system.

In this paper, we will focus our discussion on select recent activities relating to both current and planned NASA missions.

Radiation response of new and emerging technologies

The ERC Project has tasks that encompass ground radiation testing of a wide variety of electronic and photonic devices. This ranges from simple capacitors to complex microprocessors to emerging ultra-high speed technology. In this section, we will briefly discuss two focus areas of technology evaluation that the ERC Project has long-term objectives with to provide insight and reliability prior to in-line insertion into space systems.

SiGe Microlectronics

SiGe is one of a variety of ultra-high speed technologies that shows great promise for future NASA space systems [2]. Technology features beyond simple high-speed (tens of GHz or greater) include compatibility with existing CMOS logic, ability to provide a solution to mixed signal or system-on-a-chip (SOAC) applications, low noise, availability through the MOSIS foundry service, and more.

The ERC Project has a focused planned to evaluate and model this ultra high-speed technology while simultaneously developing a novel RHA testing method to allow testing of this ultra-high speed technology at a greatly reduced cost compared to existing multi-million dollar test equipment. An additional prime objective is to Like many of the ERC Project's tasks, this one is supported by the Defense Threat Reduction Agency's Radiation Hardened Microelectronics Program (DTRA's RHM).

Over the past few years, this ERC Project effort has focused on evaluating the long-term TID and DDD issues associated with SiGe microlectronics technology [3, for example]. To the first order, we have found IBM technology to be suitable for a wide-range of NASA missions. The SiGe itself is quite resistant, however the underlying Si substrate may often be the limiting factor for usage in more extreme radiation damage environments. Evaluation of multiple processes from IBM's line of SiGe (5HP, 6HP, and 7HP) has been or will shortly be completed.

Starting in FY01, the ERC Project began formulating plans to evaluate and model the SEE sensitivity of SiGe technology as well as to determine a viable technology hardening approach. As with all ultra-high speed technology, an expectation to be quite single event upset (SEU) or transient (SET) sensitive was expected due to the signature pulse response of energetic particles versus the short response time and small critical charge required of these technologies. This was borne out with preliminary results released in FY01. More detailed testing is planned over the next several years.

With preliminary technology modeling and radiation SEE tests underway, a roadblock of sorts appeared: the never-ending challenge for performing at-speed tests. With the cost of high-speed test equipment being prohibitive (>>$1M for standard bit error rate testers (BERTs), this task began a multi-year plan with the objective for developing standalone self-test circuitry that was not only capable of testing the high-speed SiGe logic, but also modular enough to provide a potential path to evaluate competing ultra-high speed technologies as well as accommodate a migration path to even higher speed technologies in the future. As a figure of merit, the baselined IBM 5HP technology is on the order of 5-8 GHz in operational, while the current state-of-the-art exceeds 12 GHz. Technologies with digital speeds of >20 GHz are expected within a few years. Thus, a path to provide a test solution at a nominal cost when compared to new test equipment is attractive.

Fiber optic link (FOL) performance in space radiation environments

Since the early 1990's, NASA and its partners have championed the use of fiber optic systems in space [4]. NASA and DoD have worked collaboratively since that time to understand the failure modes and mechanisms induced by radiation exposure as well as to develop predictive models for performance in the space radiation environment.

Since its inception as an ERC Project task, evaluation has been performed on a wide variety of FOLs with speed performance from the 1 MHz to multi-GHz regimes. This has included evaluations of different optical receiver technologies, wavelengths, and designs, various system parameters such as data rate and optical power budget, as well as particle inter-arrival angle (i.e., directional path of the energetic particle as it transverses the photodiode used in the system). All of these factors and more play a significant role in predicting a FOL's bit error rate (BER) performance in space. It should be noted that ruggedized (those designed for harsh applications) and commercial-off-the-shelf (COTS) systems have been evaluated.

One major discovery was uncovered along the way: the impact of direct ionization on the receiver's photodiode from protons. This was not consistent with standard CMOS-based electronics and required a unique approach to collection of data (energy and angular variation) as well as to BER prediction techniques.

One of they key products of these efforts is a guideline for predicting the BER performance of FOLs for proton-induced errors. This guideline compares and contrasts existing tools for standard electronic as well as empirical techniques for rate prediction. Recommendations are made as to how to approach a FOL's performance in a proton environment as well as the associated limitations of the methods.

Analysis of fielded system performance

Acting like a detective and investigating fielded system performance is among the most challenging tasks of the ERC Project. When a flight anomaly occurs, tracing the root cause is often difficult at best. On the positive side, the ERC Project often collaborates with flight projects to gather telemetry for commercial and emerging technologies. A relevant example would be the performance of solid-state memories in earth-orbiting and deep-space missions.

Sometimes when these anomalies occur in space, we can trace the cause to a specific component or technical issue. If we are "lucky", this issue may be one that we have an active research program in. One RHA issue will be described below that has been associated with several in-flight anomalies.

Single event transients (SETs) in linear bipolar devices

SETs are not a new phenomena [5, for example], however they are only recently being associated with in-flight anomalies. This may well be due to newer applications of linear technologies that encompass lower voltage/current or higher speed applications. It is expected that this trend will increase as power supply voltages drop further and finer resolution analog systems are being required.

An SET is a simple concept: a particle deposits energy that is converted to a pulse that may or may not propagate outside of the circuit an impact performance. In a reset circuit application, it may cause a system reset. In a data collection application, it may simple cause a bad data sample.

In the past year, several un-named NASA missions have experienced anomalies that could be traced to analog comparators (LM or PM139 devices). These devices have been used for many years in space applications, but it is only in the days of finer resolution and reduced power supply voltages that we have attributed anomalies to SETs. When one uses these devices as 500 mV comparators, one should expect some particle-induced transients to occur. And this has been the case in several NASA systems.

ERC Project Data Dissemination

The ERC Project disseminates the information it gathers in multiple media and forums. These include, but are not limited to:

- IEEE Transactions on Nuclear Science,
- NEPP information websites (http://nepp.nasa.gov),
- NASA radiation websites (http://radhome.gsfc.nasa.gov and http://radnet.jpl.nasa.gov), and
- Numerous conferences.

Conclusions

NASA's ERC Project is a multi-faceted research project that encompasses the wide and varied radiation support needs of NASA flight projects. Research areas vary from the mundane to the exotic in terms of technology. In this paper, we have presented several relevant examples of tasks for the ERC and their application to fielded and planned space systems.

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References

1. Janet L. Barth, "Modeling Space Radiation Environments", IEEE Nuclear and Space Radiation Effects Conference Short Course Notes, Snowmass CO, July 21, 1997.
2. Kenneth A. LaBel and Lewis M. Cohn, "Applying State of the Art (SOTA) Commercial and Emerging Technologies to Space Systems," IEEE Nuclear and Space Radiation Effects Conference Short Course Notes, Newport Beach CA, July 20, 1998.
3. John D. Cressler, et al "The Effects of Proton Irradiation on the Lateral and Vertical Scaling of UHV/CVD SiGe HBT BiCMOS Technology", IEEE Trans. On Nuc. Sci, Vol. 47, No. 6, pp 2515-2520, Dec 2000
4. K.A. LaBel et al., "On the Suitability of Fiber Optic Data Links in the Space Radiation Environment: Historical and Scaling Perspective," Proc. IEEE Aerospace, Snowmass, CO, March 1998.
5. K.A. LaBel, et al, "Emerging Radiation Hardness Assurance (RHA) Issues: A NASA Approach for Spaceflight Programs", IEEE Trans. On Nuc. Sci, Vol. 45, No. 6, pp 2727-2736, Dec 1998