Community Oral and Poster Abstracts

Europa Jupiter System Mission
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The appearance of abstracts in this document does not imply EJSM project endorsement.

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Space Qualified Solutions From Aeroflex Microelectronic Solutions
For the Europa Jupiter System Mission

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Introduction

Aeroflex is a diversified manufacturer of microelectronic devices and test equipment. Founded in 1937 and headquartered in Plainview, New York, the Aeroflex Microelectronic Solutions division is comprised of 10 business units; six of which supply space level products.

Aeroflex has 30 years experience in providing radiation hardened, space level standard products, custom designs, build to print and manufacturing services. Our design expertise in Space Qualified Standard Product ICs, Digital & Mixed Signal ASICS, Power Solutions, RF, Motors and Motion Controllers and discrete diodes and transistors coupled with our NASA Certified Circuit Card Assembly and Space Qualified Chip-On-Board services has brought about numerous contract awards for satellites, launch vehicles and science missions.

Customers

Aeroflex boasts a customer base that consists of virtually every major space level prime and subcontractor in the US and abroad. Here is a sampling of our space customers: NASA, ESA, Lockheed Martin, Boeing, Northrop Grumman, Orbital Sciences, Thales Alenia, Astrium, JAXA, ISRO, L-3, Sandia, Loral and Raytheon.

Flight Heritage

Platforms: 601,702, A2100, FS1300, SPACEBUS, LEOSTAR, STARII, etc.
Launchers: Delta, Atlas, Taurus, etc.
Missions: GPSIIA, GPSIIR, GPS IIRM, GPSIIF, MUOS, WGS, ISS, Space Shuttle, Cassini, Dawn, Stereo, Messenger, Hubble, MARS Spirit and Opportunity Rovers, MARS Reconnaissance Orbiter, Phoenix, New Horizons, Themis, SBIRS, AEHF, etc.

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Locations / Capabilities

Aeroflex Colorado Springs, Colorado Springs, CO

- MIL-PRF-38535 Class Q, T and V Space Level Standard Products including LEON Microprocessors, Microcontrollers, Memories, Logic, LVDS, Clock Management, FPGA, 1553 Databus and SpaceWire. Up to 1 Mrad TID
- Digital and Mixed Signal ASICs up to 1 Mrad TID
- Mixed Signal Standard Products including Analog Muxes, ADCs and DACs
- Space Level Circuit Card Assembly. NASA 8739, J-STD-001, ISO9001:2000 and AS9100 Certified.

Aeroflex Plainview, Plainview, NY

- Space Level Standard Products, including Power Management, Voltage Regulators, Analog Muxes, PWMs, Resolver to Digital Converters, RS-485 Transceiver and Lithium-Ion Battery Electronics Units. Up to 1 Mrad TID
- RF/Microwave Hybrids, MCMs and Chip-On-Board Modules including LNAs, HPAs, Up/Down Converters, T/R Modules and RF Switches. Custom Build-to-Print manufacturing as well as Build-to-Spec design capabilities.
- MIL-PRF-38534 Class H and K, ISO9001:2000 and AS9100 Certified

Aeroflex Gaisler, Goteborg, Sweden

- LEON3FT 32-bit Fault Tolerant Processing Solutions and Intellectual Property
- SpaceWire, 1553, Ethernet, USB, Telemetry Control, USB and other IP Solutions
- LEON based Hardware and Software Development Tools and Real-Time Operating Systems

Aeroflex Motion Control, Hauppauge, NY

- Motors, Gimbals, Actuators, Electronic Controllers and Slip Rings designed to space level requirements.
- Standard and custom product capability

Aeroflex RF/Microwave Filter Products, Hauppauge, NY

- Cavity types with metal or ceramic resonators
- Lumped component filters such as Band Pass, Low Pass, Band Reject
- Diplexers and Triplexers.

Aeroflex / Metelics, Lawrence, MA

- JANS certified Switching, TC Zener and Zener Diodes
- Qualifications coming for Current Regulators, Schottkys, Transistors and SCRs
- DSCC Certified

Sandia National Laboratories:
Critical Capabilities for the Europa-Jupiter System Mission

Highly reliable radiation-hardened microelectronics required for nuclear weapons are also exceptionally well suited for mitigating the harsh EJSM radiation environment. For more than 50 years, Sandia has been responsible for the development, design and maintenance of several thousand parts found in any given nuclear weapon system, including radiation-hardened microelectronics. In support of this mission, Sandia National Laboratories has a prominent role in advancing the state-of-the-art in microsystems research and development, incorporating radiation-hardened microelectronic devices and components designed to withstand total ionizing doses exceeding 1Mrad(Si). In order to withstand this level of radiation, Sandia applies its expertise in radiation effects, reliability physics, device and process modeling, COTS (commercial off the shelf) parts qualification, failure analysis, packaging, and both rad-hard-by-process and rad-hard-by-design techniques. In addition, Sandia offers a fully qualified silicon-on-insulator (SOI) radiation-hardened complementary-metal-oxide semiconductor (CMOS) integrated circuit technology realizing digital, analog, and mixed-signal circuits designed in our accredited Trusted Design Center and fabricated in our MESA Trusted Foundry. These capabilities can greatly assist and support the radiation risk mitigation necessary for the EJSM to be successful in the harsh planetary environment.

Radiation-Hardened CMOS

Our radiation-hardened CMOS process is the foundation of Sandia's rad-hard microelectronics program. There are two efficient and effective avenues to design in this technology: one uses a structured application-specific integrated circuit (sASIC) called the ViArray, and the other is through Sandia's Multi-Product-Wafer (MPW) program. The ViArray is a metal-via configurable, fabric-like structure requiring only one reticle to fully customize circuit function. Using the ViArray, product delivery cycle times are greatly reduced in comparison to custom ASICs, first pass yield is more likely, and product development is more cost effective (one reticle, fewer wafers, faster cycles of learning). Low-power applications benefit from the isolation of unused transistors in ViArray, which minimizes power consumption, static current, and photocurrent effects. Sandia's MPW services combine a number of different IC designs on a single reticle set. Sharing mask and wafer resources reduces the cost per design and makes it more cost effective to produce custom ICs in low quantities. Sandia's MPW program offers access to its Trusted Design Center and its ISO 9001:2000 certified, high-reliability ASIC production facilities.

Radiation Effects Studies, RadFET Devices

The Radiation Physics, Technology, and Assurance department at Sandia National Laboratories maintains 4 gamma ray radiation sources, including two Co-60 sources and two Cs-137 sources; these are routinely used for radiation qualification of Sandia and commercially fabricated ICs, as well as for basic studies of the physical mechanisms responsible for radiation effects in semiconductor devices. Three Aracor 4100 X-ray irradiators are especially well suited to wafer-level radiation studies. Single-event effects testing is typically performed off-site at large heavy ion or proton accelerator facilities.

This department is also developing an MOS radiation sensor, the RadFET, that is more integrable than typical dual-dielectric dosimeters. RadFET sensitivities and device characteristics (including no requirement to be biased during exposure) can be tailored to meet an array of real-world applications– including the EJSM. Since it does not need to be biased except during readout, the component is excellent for low power applications – another key advantage for the EJSM.

Power and High-Voltage Electronics

Sandia has expertise in the design, development and production of radiation-hardened power electronics and has delivered rad-hard DC-DC converters for space-based systems. We are currently developing novel rad-hard power MOSFETS with very low on-resistance and gate capacitance. These would allow the design of high-efficiency, high-frequency switching converters that provide high-current low-voltage

regulated space power systems with reduced mass and volume. In addition, Sandia is developing radiation-hardened, high voltage (>20V) CMOS silicon-on-insulator (SOI) technology for space-system power electronic controller integrated circuits.

Non-Volatile Memory

We are developing a rad-hard non-volatile memory capability based on SONOS technology, allowing the fabrication of either standalone or embedded non-volatile memory. Preliminary demonstrations show >20-year retention of data, >10,000 write-erase cycles, and high radiation tolerance.

THz

Sandia has the capability to design, grow, fabricate and test THz quantum cascade lasers for use as local oscillators at frequencies from 2 to 5 THz. We have experience in integrating these lasers with rectangular waveguides, making and testing integrated THz circuits, and using the lasers as local oscillators. We reliably produce lasers with greater than 1 mW output, but we have not optimized packaging or heat sinking. The devices are reaching the maturity level required for a research instrument for space missions.

Advanced Packaging

The Advanced Microsystems Packaging Department actively engages in advanced research and development, and packages and assembles a diverse suite of components. These include MEMS, compound semiconductors, optoelectronic and advanced photonic devices, micro-sensors, RF devices, and analog, digital, and mixed signal high-reliability ASICs. The packaging department has a proven record of successfully engaging in Class S/V assembly for past space missions (e.g., Galileo, and various satellite projects), and is currently a recognized leader in tin whisker mitigation strategies.

Reliability Physics

Sandia has a strong foundation in device physics and reliability physics. Several automatic wafer prober systems are used to perform reliability tests such as gate oxide integrity and hot-carrier degradation from -55°C to 300°C. The ability to test large sample populations in parallel reduces the time required to obtain meaningful statistics. This capability can be extended to perform reliability predictions on irradiated parts; this is critical for determining the longer-term viability of the EJSM subsequent to its primary goal. Device characterization and model generation in the mK temperature range are also in progress.

Commercial Off-the-Shelf Component Qualification

Sandia's Component Information and Modeling organization maintains a staff of engineers with extensive experience in the selection and qualification of COTS electronic components for high-reliability applications. This capability would be very beneficial for up-screening COTS for the EJSM when rad-hard components are unavailable. The organization has several decades of experience supporting space and weapon programs.

Failure Analysis

Failure Analysis (FA) provides critical information such as defect localization and identification to microsystems design, process, and technology integration engineers and scientists. Sandia is a leader in the FA field and has developed many advanced FA techniques, in particular laser-based techniques for static and dynamic investigations of silicon integrated circuits (ICs). Sandia-developed techniques, such as LIVA and TIVA, are now used worldwide in the microelectronics industry. Besides using techniques developed in-house, Sandia has a depth of expertise and a breadth of state-of-the-art equipment that rivals any FA lab in industry, academia, or the government. We are able to leverage Sandia's significant, world-class, on-site resources in other scientific disciplines (e.g. surface science, ion beam analysis, and microsystems fabrication, test, and packaging) that allow us to offer a unique and complete solution.

Example capabilities and techniques include light emission, TIVA, LIVA, e-beam based techniques such as PVC and CIVA, atomic force and scanning capacitance microscopy, laser scanning microscopy, SEM including nano-probing and environmental imaging, FIB including dual beam and backside circuit edit capabilities, TEM, SQUID, and a complete de-processing laboratory.

Ability to Deliver

Sandia's Microsystems and Engineering Sciences Applications (MESA) Complex is designed to integrate the numerous disciplines necessary to produce functional, robust, integrated microsystems. MESA represents the center of Sandia's investment in microsystems research, development, and prototyping activities. Our customer base includes Nuclear Weapons NNSA/NA10, Non Proliferation NNSA/NA20, DARPA, Department of Defense, and Homeland Security. MESA specializes in developing and delivering low-volume, high-consequence, high-trust, custom products, and has delivered over 30,000 Trusted microsystem components to Sandia's national-security customers since 2006. Our strengths are

- Trusted designs and final products
- Strategic radiation-hardened custom integrated circuits (ICs)
- Digital/analog/mixed-signal/RF ICs
- Radiation effects expertise
- 5-level MEMS ("micro-machines"), including the first space-qualified MEMS product
- Qualified COTS
- Failure analysis and reliability physics
- Advanced packaging
- Specialized sensors

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Sandia National Laboratories

Exceptional Service in the National Interest

Network on a Chip Radio and Millibeam™ Heavy Ion Testing

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Abstract
A multi-cluster Network on a Chip (NoC) ASIC has been designed during a NASA Phase I program in 2009 to operate in harsh radiation environments and provide scalable throughput from 1 Mbps to 1Gbps. The NoC Radio also provides for scaling of throughput for power saving depending on available power. The NoC Radio is designed based on multiple clusters of NoC in particular a MIMO-OFDM cluster that supports beamforming [1] and a radio front end cluster that supports variable bandwidths, anti jamming and adjacent channel rejection.

The multi-cluster NOC Radio is based on unbundling of signal processing primitive elements such as CORDIC operations, Multipliers and Accumulators, Division operations and memory resources so that at various stages of algorithm implementation these elements are freed up and re-used for various processing requirements. This saves area and power. The primitive elements, referred to as computational agents, are networked together using a pipelined switching fabric. Reconfigurablity is achieved using the switch fabric and multiple RISC agents. Some agents such as agents that store data in EDAC protected Block SRAM are more complex than the primitive agents. In the NoC Radio, developed by Micro-RDC, a variable length fixed point FFT has been implemented by re-using CORDIC and Multiplier primitives. Also a 2x2 fixed point Singular Value Decomposition (SVD) algorithm has been implementedby re-using the same CORDIC and Multiplier primitives. This is to support 4x2 MIMO Beamforming SVD for maximum range and throughput [1] with a limited number of antennas in the remote receiver on Rovers (with more antennas on the orbiting satellite).

A key advantage of the Multi-cluster NOC Radio is that every primitive agent and RISC including the Block SRAM agents are individually accessible externally (through SPI interfaces in addition to 1.25 Gbps SERDES host interface). Thus, all agents can be independently tested.

Figure 1 (a) shows the general architecture of the multi-cluster NoC Radio. A prototype layout of the NoC radio on a 10x10 mm ASIC chip is shown in Figure 1(b). The proposed ASIC chip supports either a 1.25 GHz SERDES LVDS link to the host or a SpaceWire LVDS Codec, both on-chip. The ASIC uses Micro-RDC's proven Radiation Hardened by Design (RHBD) CMOS cells and temporal latch technology for SEU mitigation and also macro elements based on the ViASIC RHBD Structured ASIC Fabric on IBM 9LP 90nm CMOS process. The Hardness Estimate for the NoC ASIC using RHBD is as follows: TID > 1Mrad(Si), SEU > 1e-5 Errors/day, SEL > 100 MeV-cm2/mg (LET).

For testing the NoC Radio for harsh radiation environments, Micro-RDC will use its Millibeam™ technology [2]. Using the Millibeam™, heavy ion beams are used in the Berkeley 88-inch cyclotron to achieve spatial resolutions that are easily varied between ~5 µm and >500 µm on the DUT. Micro-RDC has designed and taped out a 1 GHz charge pump PLL on the IBM 90nm CMOS process. The PLL was tested using the Millibeam™ to determine the dominant response circuit elements to SEE. In the case of a charge pump PLL, the dominant response circuit is the switching current charge pump as shown from the millibeam results shown in Figure 2 (b). In the development and testing of the NoC Radio ASIC, we will heavily exploit Micro-RDC's Millibeam™ technology to prove out the multi-cluster NoC concept and to also identify the dominant response agents to SEE. This includes characterizing the SEE of the switch fabric versus the computational agents.

Micro-RDC has recently taped out two Systems on a Chip (SoC) RHBD Structured ASIC designs based on the IBM 9LP 90nm process. The SoC's are for spaceborne sensor networks and support host interfaces using Spacewire and USB. For the sensor networks, SPI, I2C and RS-422 are used for interfaces. This work is part of the ASIM Plug and Play Satellite program. Micro-RDC has the tools and facilities required for Post Silicon Verification and testing of the parts. In particular Micro-RDC has extensive experience in radiation testing. Micro-RDC has successfully taped out and tested custom designed RISC processors running at 50 MHz and SERDS BIST engines running at 125 MHz on the IBM 9LP 90nm CMOS structured ASIC fabric.

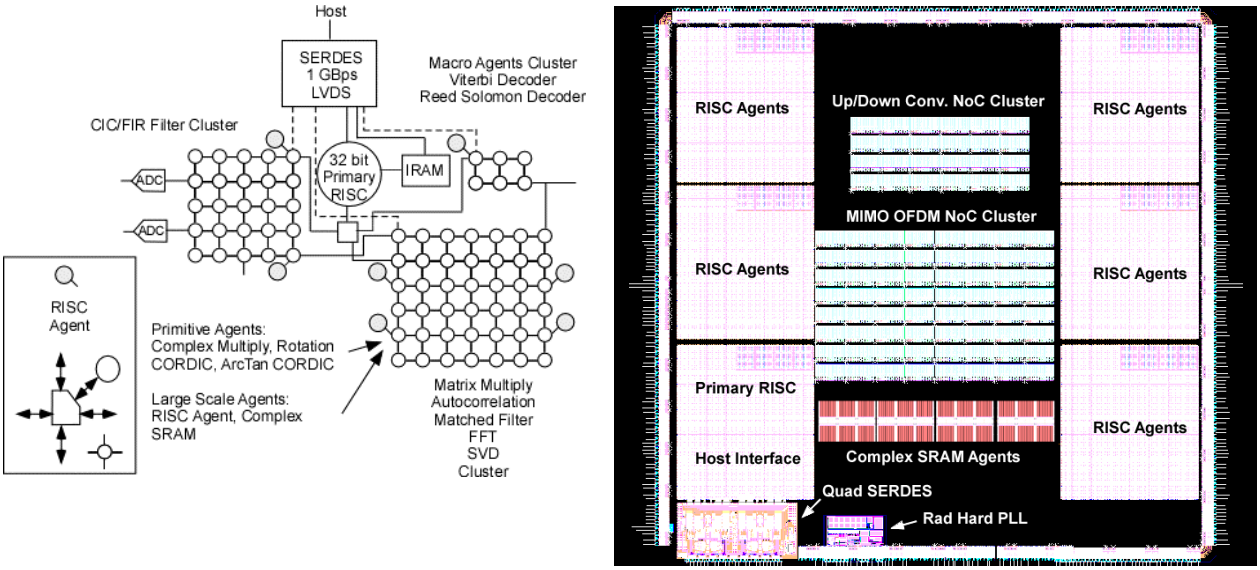

Figure 1. Multi-Cluster NoC Reconfigurable Radio Architecture (a) and ASIC Prototype (b)

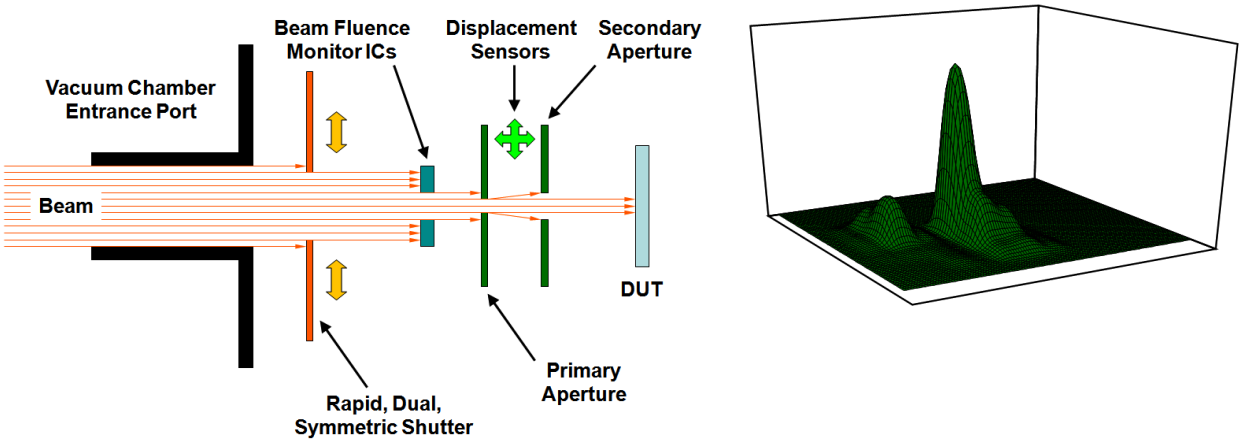

Figure 2 Micro-RDC Millibeam(a) and 90 nm CMOS Charge Pump PLL Response(b)

[1] , J. Gao , Can Ozdural, Sasan Ardalan, Hauping Liu, "Performance Modeling of MIMO OFDM Systems via Channel Analysis," *IEEE Transactions on Wireless*, May 2006

[2] Dave Mavis, et. al. "New Test and Analysis Approaches for SEE Characterization,"*GOMACTech-10*, 24 March 2010

MITIGATING THE EFFECTS OF RELIABILITY DEFECTS INCLUDING RADIATION EFFECTS IN SPACEBORNE INTEGRATED CIRCUITS

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Radiation effects will have a continued impact on ICs scaled to ultra deep submicron dimensions. Process and design scaling produces lower operating and threshold voltages, thinner gate oxides, shallower junction depths, smaller physical dimensions, and modified doping concentrations. Single event effects (SEE) and total ionizing dose (TID), however, result from energy interactions with matter that do not necessarily scale with circuit feature sizes. Hence, ultra deep submicron (UDS) ICs are highly susceptible to radiation effects and this trend will continue in scaled solid-state devices. While radiation hardening by process (RHBP), hardening by design (RHBD), triple modular redundancy (TMR), and error detection and correction (EDAC) have been applied with varying degrees of success, certainly new paradigms are needed at scaled technology nodes, especially in the area of built-in reliability monitoring and space based systems.

Single event transient (SET) and TID effects manifest themselves as transient circuit current and gradual parametric degradation in device and circuit characteristics over time that includes functional failure. Furthermore, conventional reliability defects such as hot carrier injection (HCI), negative bias temperature instability (NBTI), time dependent dielectric breakdown (TDDB), and electromigration can result in excessive current leakage due to a shift in threshold voltage or resistive shorts. Research into mitigating radiation effects has produced a variety of solutions, including shielding, RHBD, RHBP, new materials, and new technologies. Cost, complexity, performance constraints, and power consumption have forced aggressive R&D efforts to be conducted at every level. One benefit of this R&D cross-fertilization has been the diversification of engineering expertise required to fully understand tightly coupled and complex issues in device physics, process technology, circuit design, physical layout, failure modes, fault models, and reliability.

This technology focuses on the use of an innovative built-in current sensor technique since radiation effects manifest themselves as unique leakage current signatures. Current sensors have been used on and off chip to monitor transient and steady state current (I_{DDQ}) levels associated with faulty and fault free complementary metal oxide semiconductor (CMOS) and silicon on insulator (SOI) circuits. Indeed, several decades worth of research and development in this area has produced an abundance of research results from simulation and modeling to circuit layout and partitioning. Furthermore, monitoring circuit current has been shown to be an effective reliability metric for a broad range of circuit types and configurations. However, very little research has been conducted on the effectiveness of current sensing techniques for radiation effects using BICS in scaled process technologies. Today, more than ever there is a driving need for hardened radiation tolerant microelectronics with higher reliability, minimal design impact, or performance penalties. The BICS technology provides a significant opportunity to extend the reliability of integrated circuits.

This technology is based on an innovative built-in current sensor (BICS) (US Patent #6,144,214). The BICS measures low-level leakage currents in on-chip partitioned circuits and propagates amplified current-represented faults on the power supply (i.e. VDD) line. This makes it possible to easily observer faults off chip at the VDD line using a low power low-resolution in-line current

monitor. The novel BICS approach is suitable for scaled and future technologies and processes including CMOS, SiGe and SOI.

This technology is currently under development under an SBIR contract from the Air Force Research Labs (AFRL), Albuquerque, New Mexico. DEC possesses design, simulation, layout,and test capabilities and resources allowing us to lead the development of intellectual property (IP) for full- or semi-custom application specific or commercial off the shelf (COTS) integrated circuit. DEC has designed, simulated, layed out, and is preparing to test and characterized analog and digital prototype circuits in silicon from a 180nm CMOS process (see Figure 1).

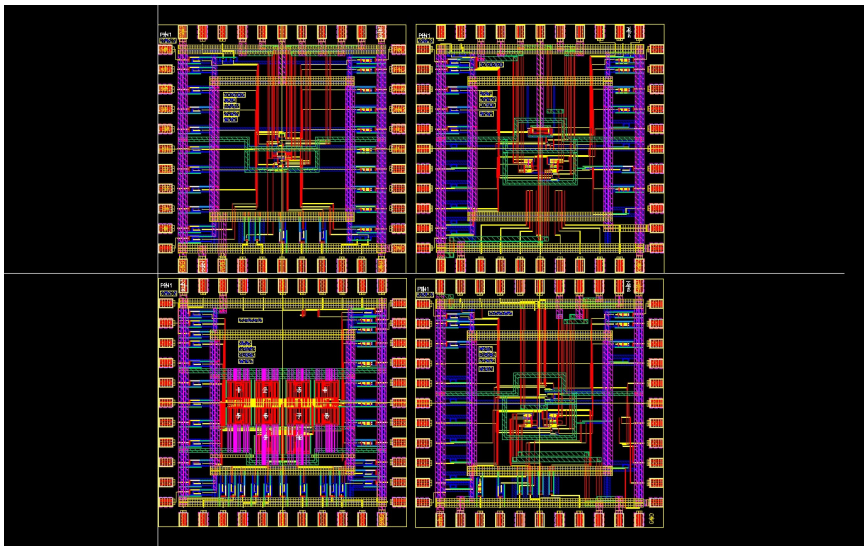

FIGURE 1: Prototype test circuits with BICS

Dr. Stephan Athan is the Chief Engineer at DEC. He tracks emerging technologies and oversees DEC's technology roadmap, providing innovative solutions to new and legacy technologies and programs. Dr. Athan has specialized in developing solutions for mitigating radiation effects and brings over 30 years of combined industrial, academic R&D, and technical consulting experience to DEC. His background includes analog/digital design and test at the chip, subsystem, and system levels in applications, including process control, biomedical engineering, VLSI design/reliability/testing, and fiber optic telecommunications. Dr. Athan has authored numerous technical publications and holds six U.S. patents including US Patent #6,144,214 "Method and Apparatus for use in IDDQ Integrated Circuit Testing" issued in November 2000. He was a member of the faculty at the University of South Florida (USF) for 12 years, where he pioneered research in VLSI design, testing, and reliability. He has been involved with the International On-Line Test Workshop, International IDDQ Test Symposium, North Atlantic Test Workshop, International Test Conference, VLSI Test Symposium, International Conference on Computer Aided Design, IEEE Engineering in Medicine and Biology Society, IEEE Reliability Society, IEEE 1149.1 Technical Review Committee, NSF and DARPA proposal review committees, Single Event Effects Symposium, and NSREC. Dr. Athan received a BSEE from USF in 1980, an MSEE from USF in 1992, and a Ph.D. in electrical engineering from USF in 1995. His Ph.D. dissertation is enitled "I_{DDQ} Testability of Deep Submicron CMOS Integrated Circuits".

Seamless Hardware Module Swapping for Partially Reconfigurable Stream Processing Systems

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Abstract
Adaptation is a key requirement for space-based systems due to harsh and rapidly changing conditions outside of the Earth's ecosystem. These systems must be able to adapt data rates to counter changes in available bandwidth (e.g., inter-satellite and satellite-earth communications) and bit-error rates [2] (e.g., radiation, single event upsets (SEUs)) and adapt functionality to account for human error [1]. Additionally, in some situations a designer may need to repurpose a space-based system for an entirely different mission. To provide these adaptabilities while limiting system overhead (e.g., system down-time, area), the partial reconfiguration (PR) capability of modern FPGA devices is advantageous for such missions. PR devices provide the flexibility to dynamically load and unload internal hardware components/modules on demand without forcing a system reset or shutdown, which could result in catastrophic system failure due to the unavailability of vital system functionality.

PR-enabled system fabrics typically consist of a static region and a set of partitions connected to the static region. The static region is configured during startup, and contains all hardware functionality that remains fixed during system execution. One or more partitions can be independently reconfigured while the rest of the system, including other partitions, remains operational. This architectural structure enables efficient dynamic runtime placement of hardware modules inside available partitions, a technique known as dynamic hardware module switching. Hardware module switching is an enabling technology in novel operating system frameworks [3] and artificial intelligence systems, and is comparable to the dynamic swapping of components in an FPGA-based system-on-a-chip (SoC).

Hardware module switching capabilities are particularly advantageous for reconfigurable stream processing systems (RSPSs), such as those which process sensor data in space-based missions. RSPSs are composed of a set of hardware modules and software modules connected together to transform a data input stream into a processed data output stream. On FPGA SoC architectures, software modules execute on an embedded microprocessor (hard or soft core) implemented inside the FPGA. Software modules communicate with the hardware modules through either industry standard interfaces, like Fast Simplex Links (FSLs), CoreConnect, the Advanced Microcontroller Bus Architecture (AMBA), or custom-designed interfaces. An RSPS may also use an inter-module communication network to pass a data stream between peripheral components without interrupting software execution. An example of an overall system architecture is an audio/video processing RSPS. The RSPS may include hardware functionality such as MPEG decoding, rasterizing of the video fields, and audio and video digital-to-analog conversion while the software module functionality may include digital audio filtering, subtitle insertion, and audio data parsing to skip silent periods. Since input data particulars (e.g., illumination, image resolution, contrast, etc.) dictate the type of decoding hardware modules or desired filtering effects, the RSPS can dynamically exchange/replace specialized hardware modules. In addition, since application bandwidth requirements dictate processing throughput, different hardware modules specialized for different compression formats can be included to alter processing throughput.

For space-based missions, hardware availability is a critical requirement, and any hardware module switching should be fast and incur minimum stream processing interruption, a goal we define as seamless

module switching. Unfortunately, a serious drawback of PR is lengthy reconfiguration time, as reconfiguration of a reasonably sized partition (around 800 slices on Xilinx Virtex-4 FPGAs) can take on the order of tens to hundreds of milliseconds [4]. A possible solution to lengthy reconfiguration times is to overlap system processing with PR. A new module aimed to replace an older module can be placed in a separate partition while the RSPS continues operation uninterrupted. After reconfiguration, streaming data flows entering the older hardware module must be redirected to the new hardware module, and the new hardware module's output must be redirected to the appropriate downstream hardware module. The inter-module communication architecture can facilitate hardware module swapping by enabling dynamic redirection of the streaming data flows between the hardware modules [6]. In general, the inter-module communication architecture enables RSPS runtime assembly, which is the process of dynamically constructing an RSPS at runtime from a subset of hardware modules ready to execute. A system's ability to perform RSPS runtime assembly significantly enhances reconfigurability, and thus presents a mechanism to effectively hide reconfiguration time.

In this work, we design and demonstrate a scheme for seamless module switching using the VAPRES (Virtual Architecture for Partially Reconfigurable Embedded Systems) architecture introduced in [5]. Our system performs real-time target tracking of a sample object (a bouncing ball for this demo, but the target could be any object such as a moon, planet, asteroid, etc.) followed by a camera. Target tracking is a path/trajectory prediction method used to follow environmental targets such as vehicles, missiles, animals, hostiles, or even unidentified objects. Since Kalman filters are a popular target tracking kernel (FPGA implementations of Kalman filters demonstrate excellent performance in comparison to software implementations) [7], we chose Kalman filters as processing modules to implement the target tracking functionality in our system. Previous reported FPGA implementations of target tracking systems based on Kalman filters [7] do not consider targets with different characteristics, such as widely varying speeds and tracking criticality, resulting in increased processing time and energy consumption. Our implemented system leverages contributions over previous work by performing a seamless module switching scheme over two different versions of Kalman filters: a basic Kalman filter (suitable for targets with non-constant velocity) and a constant-gain Kalman filter (suitable for targets with constant velocity).

Acknowledgments
This work was supported in part by the I/UCRC Program of the National Science Foundation (NSF) under Grant No. EEC-0642422 and by the NSF under Grant No. ECCS-0901706. We gratefully acknowledge tools provided by Xilinx and Vasudha Chaudhary and Srikanth S. for the design and implementation of the camera interface.

References

[1] Anderson Y. and Scarffe V. and Heventhall W. and Doody, D. A. Solving Cassini's Data Glitch Problem during Coherency Mode Transition for Titan Radar Observation, Pasadena, CA: Jet Propulsion Laboratory, National Aeronautics and Space Administration, 2006
[2] Arnon S and Kopeika N. Adaptive bandwidth for satellite optical communication. IEE Proc. on Optoelectron,. April 1998 Volume 145, Issue 2, p.109-115
[3] Handa M. and Vemuri R. An efficient algorithm for finding empty space for online fpga placement. Proceedings of the 41st annual Design Automation Conference (DAC'07). ACM, New York, USA, 960–965.
[4] Hymel R. and George A. and Lam H. Evaluating partial reconfiguration for embedded FPGA applications. In Proceedings of International Symposyum on High Performance Computing (HPC'07)
[5] Jara-Berrocal A. and Gordon-Ross, A. VAPRES: Virtual Architecture for Partially Reconfigurable Embedded Systems. In Proceedings of the Design, Automation Test in Europe Conference Exhibition. (DATE '10).
[6] Jara-Berrocal A. and Gordon-Ross, A Runtime temporal partitioning assembly to reduce FPGA reconfiguration time. In Proceedings of International Conference on Reconfigurable Computing and FPGAs (Reconfig '09)
[7] Meltzer A. and S. Soatto. Fast visual feature selection and tracking in a hybrid reconfigurable architecture. Proceedings of the Workshop on Applications of Computer Vision (ACV'06)

WIRELESS DATA COMMUNICATIONS 8X FASTER FOR SPACE INSTRUMENTATION

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Abstract

Wireless data communications is a critical part of any space instrumentation system. Whether the data collected by the sensors is being transmitted to the lander, orbiter or Earth, the communications must be reliable, fast and energy efficient. Falcon Nano is developing a technology which will enable wireless data communications to be 8X faster than existing technology. For space instrumentation applications, this technology will enable instrumentation system designers to:

- increase data transmission rates,
- reduce transmission power,
- increase immunity to noise including Jovian radiation, and
- increase battery life.

The technology called "Sideband Mitigation" is a transceiver technology which achieves its benefits through substantial increase in spectrum efficiency. It is <u>not</u> a compression technology but will work with standard compression and communications protocols.

Falcon Nano has recently completed a "bench top proof of concept engineering transmitter prototype" which demonstrates the fundamental benefits of Falcon Nano's "Sideband Mitigation." The prototype will available for demonstrations at the end of the day after the Workshops scheduled events have concluded. The prototype will be transmitting thermocouple data.

Falcon Nano plans to have the transceiver technology implemented in rad hard ASICs in 2014. Those ASICs will meet the requirements for the EJSM mission. Prior to 2014, instrumentation system development work can be performed with non-rad hard components. Falcon Nano will provide transceiver modules, ASICs and applications support to instrumentation designers.

Abstracts regarding items of interest to the general instrument community, such as relevant EEE parts resources, radiation testing capabilities, modeling services, etc. are being solicited for the 4th EJSM Instrument Workshop. Abstracts should convey the key points to be made in your poster presentation and should give enough information for the committee to determine its appropriateness for the Europa Jupiter System Mission Instrument Workshop.

About the Authors

W.A. Hastings is the CEO and founder of Falcon Nano, Inc. He is a former Motorola design and project engineer. Additional information is as follows.

- His first startup company created and developed an innovative ASIC and computer display technologies. After running the company for four years, he sold out to a Kodak spin-off. In 2006 the company was trading on the NASDAQ with a market capitalization of over $150 million.

- Former CEO of a company that makes servo controllers and motors. Under his leadership, the company was listed on the Inc. 500 (Fastest Growing Private Companies in the USA) and the Silicon Valley 100 (Fastest Growing Private Companies in the Silicon Valley).
- Taught engineering at UNLV.
- Serves on the NASA Space Grant Board for Nevada.
- Owns and operates Hastings' Chariots which does aerospace research and development with NASA as a primary customer. www.HastingsChariots.com.

D.W. Pepper, PhD, is a co-founder and Board Member of Falcon Nano, Inc. He is also:

- Former Dean of the College of Engineering at UNLV (interim),
- Former technology and science advisor for US Senator Dianne Feinstein (2004),
- Founder of the National Supercomputing Center for Energy and the Environment, and
- Associate Editor, AIAA Journal of Thermophysics and Heat Transfer.

Integral Multi-functional Radiation Hardened Composite Structures

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Abstract

Various Missile Defense Agency interceptor programs over the last decade have required performance in potential combined space and man-made radiation environments involving X-ray and electron bombardment. Typically considered as an afterthought, sufficient shielding requires both a high Z component and an alternating high/low Z gradient material to efficiently shield electronic components and circuits housed within the structure. Often, the necessary shielding at a component level would prevent generating sufficient delta V in the interceptor to achieve the required cross-range to complete the mission successfully. The external application of shielding creates too much parasitic weight and provides no other system benefit. The shielding provided by composite structure alone is insufficient [1].

Vanguard Composites Group engineers have designed several primary structure, electronics housing, sensor sunshade, and optical platform components utilizing various multi-functional aspects of high stiffness, thermally and electrically conductive composite components, resulting in highly efficient interceptor structures that perform more than just structurally. As displayed in **Figure 1**, detailed, thermally and optically stable structures that are both capable of hermetic sealing for long term storage and electrically conductive to avoid charge buildup have great utility in interceptor design, providing structurally efficient, multi-functional materials approaches that save mass and meet stringent performance requirements.

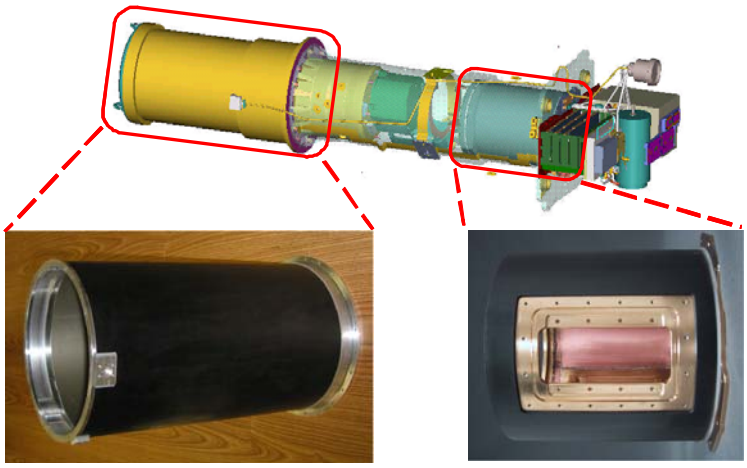

Figure 1: Sunshade and Electronics Housing Components

The introduction of radiation hardening to the mix would appear at first blush to be a simple linear calculation to determine the minimum amount of mass required to achieve sufficient X-ray or electron shielding to protect critical electronic components and circuits from both total dose ionizing radiation over long term and short term exposure to terrestrial space environments, as well as man-made nuclear environments, such as a strategic High Altitude Exo-Atmospheric Nuclear detonation, resulting in both prompt dose hot and cold X-ray exposure, as well as longer term electron bombardment associated with pumped belt areas within the exo-atmospheric regime where ballistic mid-course phase interceptors operate. Choice materials work to attenuate both types of radiation, but no one externally applied material proved to be optimized for both environments.

Working together, VCG and SMI developed a dispersed particulate film that acted both as a structural component of a thin composite sandwich structure, as well as a mass optimized radiation hardening film that provided both the necessary high Z material to provide the required hot X-ray attenuation, but also a gradient low Z/high Z/low Z structure that precluded the typical electron cascade resulting from dislocation of valence electrons by hot X-rays, such as the phenomenon utilized by the JEM-X sensor to detect gamma radiation. The proprietary formulation of the dispersed particulate cyanate ester resin film resulted in a homogeneous distribution of tungsten and gadolinium particles that provide good attenuation of X-rays while being able to a) withstand the resultant local heating without spallation or structural

failure, and b) provide a low mass "core" material to offer significant structural advantage by creating a sandwich structure consisting of low Z graphite composite facesheets and the high Z inner dispersed particulate film. Irrespective of approach angle, incoming electrons were met with a gradient structure that precluded further cascade phenomenon.

Analyses were conducted to correlate terrestrial test environment response to analytical predictions of man-made nuclear environments using formulated resin film samples enclosed in composite skins (see **Figure 2**). Results showed that a predicted optimized mixture of W and Gd particulate yielded a better than rule of mixtures by weight attenuation of X-ray and electron transmission [2], meeting theoretical performance requirements under man-made nuclear environments.

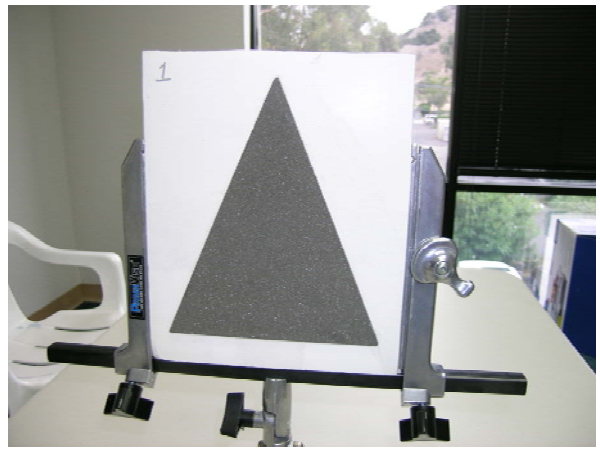

Figure 2: Dispersed Particulate Shielding Film

With education from NASA/ESA personnel on the anticipated radiation environments to be encountered during planned EJSM flights, VCG and SMI possess both the materials development knowledge and the radiation analytical skills to develop variants of the proven radiation attenuating multi-functional structural materials to provide sensor and circuit protection for EJSM systems. Both component level and chip level solutions are available to be applied to mission critical systems while minimizing mass and cost.

Figure 3: **GMD-EKV**

With the reference radiation hardened material currently at a TRL 6 level, the VCG/SMI team has the expertise and experience at space environment test facilities such as the Proton Irradiation Facility, National Ignition Facility, and UC Davis Proton Test Facility to provide the analytical and practical test results for validation of material performance, not to mention in house structural testing capabilities to determine material allowables pre- and post-irradiation. Results provided in reference 2 demonstrate the first application of multi-functional structural and radiation hardening materials.

VCG has significant experience in the space hardware industry, providing dual shell reflector and thermally stable optical metering structures for both DoD and commercial satellite and terrestrial sensor customers, as well as producing in excess of 60 multi-functional primary structures for the Ground Based Midcourse Defense Exo-Atmospheric Kill Vehicle program for Raytheon Missile Systems (see **Figure 3**). SMI has several chip cap technology materials flying on terrestrial based space platforms.

References

[1] Long, E. R., Jr. (1979) Electron and Proton Absorption Calculations for a Graphite/Epoxy Composite Model.

[2] Thompson, M. W, Edwards, C. S, (2007) Low Cost Composite Structure with Integral Radiation Shield for Hardening of EKV Electro-Optics Subsystems

BOEING ABSTRACT

The Boeing Company has submitted a response to the JPL request for Information (RFI) “Circuit to System Reliability Model”, Solicitation Number PB-10-02. This response summarizes Boeing capabilities and tools for analysis of performance and survivability in harsh environments and long-duration operations, from component level to integrated systems.

The Jupiter Europa Orbiter (JEO) mission will be a long-duration flight into environments of harsh ambient radiation up to 3.0 Mega-rads behind 100 mils of aluminum. These environments are described through models developed from data collected in missions during the past 4 decades, which give statistical descriptions of the radiation spectrum expected the interplanetary and circumplanetary path, including fluctuations and uncertainties. The radiation effects on the electronic circuits in the orbiter will be affected by properties of materials in the spacecraft (including shielding and semiconductors), as well as geometries and circuit design - with their associated tolerances and local distributions. A trade-off analysis aiming to minimize shielding mass while preserving the mission probability of success, would require iterative analysis and modeling of: (a) the propagation of ambient radiation through the spacecraft, to define the statistical spectrum of primary and secondary particles incident on the electronics, after shielding; (b) the effects of the incident radiation particles on the electronics, in Total Incident Dose (TID) effects, and Single-Event Transient (SET) effects, to define the degradation and the probability of various malfunction modes of the circuit; (c) the multi-physics effects of radiation and cold temperatures below 100K, typical of the Europa system; (d) the combined system-level ripple effect of the degradations and the spurious malfunctions of the electronics, to define the modes and probability of system failures, and quantify mission risks.

Boeing has technical expertise in radiation effects, and modeling tools for radiation transport and statistical interaction with materials. This is complemented by simulation tools for modeling radiation effects at device and circuit level, calculating statistical distributions of main failure modalities caused by radiation, and Rad-Hard-By-Design (RHBD) libraries. Our models for space environments and our simulation tools are supported by the specialized expertise of Technical Fellows at Boeing. The models are upgraded as new data and new models become available from research activities at NASA, DoD, and Boeing.

For system-level analysis of our military and commercial aircraft, Boeing has developed (and is currently enhancing) an in-house optimization tool for performance analysis, which incorporates statistical reliability and root cause tracing algorithms, to provide diagnostic and prognostic analysis. This is a model-driven or data-driven software tool, which can be applied to perform statistical system analysis of radiation effects at Europa. This suite of simulation tools can be driven by empirical test results, or by physics-based models.

Radiation Effects Modeling for EJSM

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Capabilities and Qualifications

The capabilities and qualifications offered by PR&T, Inc (PRT) to EJSM include:

- Radiation effects modeling and analysis
- Radiation transport analysis
- Design consultation related to radiation effects mitigation
- Radiation effects test planning and execution

These are embodied in the proposed Principal Investigator, Mr. James C. Pickel. Mr. Pickel currently serves as President and Chief Scientist of PR&T, Inc (Physics Research and Technology). PRT is a privately-held small business that was founded in 1995 by James Pickel as a research and technology consulting company specializing in radiation effects on microelectronics and photonics. Mr. Pickel has been actively involved in the study of nuclear and space radiation mechanisms and effects for over 40 years.

Applicable Expertise

The principal areas of expertise applicable to the design of EJSM for survival in the radiation environments include:

- Modeling radiation effects in microelectronics and photonics
- Current state of art research in radiation transport, particularly secondary particle interactions with highly scaled microelectronics and photonics
- Expert knowledge on single event effects (SEE) and mitigation
- Expert knowledge on radiation effects in IR detectors and arrays
- Expert knowledge of state of art IR detector technology and their vendors
- Radiation test planning and execution, both microelectronics and photonics

Experience and Maturity Level of Technologies

The technology being offered by PRT is a comprehensive mature understanding and experience base in radiation effects modeling and testing for both microelectronics and photonics. The maturity level of this technology is based on the 40+ years of experience and record of meaningful accomplishments, as listed below:

- 40+ years experience in radiation effects analysis, modeling and mitigation.
- Developed original SEU rate prediction model based on convolution of RPP sensitive volume with LET distribution. This model is still the baseline approach for rate prediction as used in CREME96 and SPENVIS.
- Developed original SEU testing approach based on measurement of cross-section and effective LET using accelerator ions and angle of incidence variation. This test method is still the dominant approach and almost all SEU test data is based on this technique.
- Analysis, modeling and testing for radiation-induced transients in prototype JWST IR detector arrays.

- ***Developed REACT model and code used to analyze radiation-induced noise transients in JWST IR detector array designs. This model allows radiation-induced charge transport within large arrays to be analyzed and impact of radiation transients on IR sensor performance to be calculated.***
- ***Modeling for JWST won a NASA Certificate of Recognition stating "For the creative development of technically significant software which has been accepted and approved by NASA entitled Modeling Charge Collection in Detectors Arrays," dated May 22, 2003.***
- ***Formulated test requirements for initial characterization of prototype JWST focal plane array technology.***
- ***Member of NASA/Goddard radiation test team for characterization of initial prototype JWST focal plane array technology.***
- ***Analyzed prototype JWST focal plane array technology radiation test results and made recommendations to NASA/Goddard for technology down-selections.***
- Performed early characterization and developed original models for radiation effects in cryogenic microelectronics. Developed technology for mitigating total-dose effects in cryogenic MOS devices based on MNOS gate dielectrics. Won best paper award at 1984 HEART Conference based on this hardening technology development.
- Served on Expert Advisory Board to JPL on subject of single event latchup (SEL) in COTS ICs proposed for use in Galileo mission(JPL). This work led to requirement to development of hardened parts (SEL insensitive) by Sandia National Laboratory and to successful use in the Galileo mission.
- Served on Expert Advisory Board to JPL on subject of radiation effects mitigation in use of COTS microprocessors for JPL missions. This work has led to successful use of COTS processors in NASA missions.
- Successfully completed NASA NRA on charge collection in IR detectors; "Modeling Charge Collection in Detector Arrays," period 2001 to 2002.
- Successfully completed NASA SBIR Phase I and II on Mitigating Single Event Latchup (SEL); "Single Event Latchup Mitigation in Commercial Microelectronics, " period 2002 to 2004.
- Successfully completed MDA SBIR Phase I and II on MPTB Shielding anomaly; "MPTB Total-Dose Anomaly Investigation," period 2004 to 2006.
- Successfully completed NASA Phase I SBIR on design of space experiment for shielding and dosimetry; "MISTI Shielding and Dosimetry Experiment," period 2006.

PRT offers an independent small business solution to EJSM and their contractors for microelectronics and photonics radiation effects design, analysis, modeling, and testing.

Radiation Hardened Electronic Design techniques, Analysis and Support

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ABSTRACT

BAENG is a small business located in San Gabriel Valley, Southern California with its primary focus on Space flight electronic instrumentation Design, Analysis, Test and Support. BAENG had played major roles in the development of advanced radiation hardened electronic circuitries for many of the past and present NASA mission. We offer services and expertise necessary to take challenging EJSM mission requirements and develop them into robust precision flight hardware.

INTRODUCTION

BAENG has extensive experience to provide expert capabilities across all areas of radiation hardening design and qualification disciplines required to support the design, development, analysis, test and support of the EJSM spacecraft electronics in order to operate within the ionizing radiation, single even and displacement damage environments expected for the EJSM mission.

This includes the radiation hardening system engineering disciplines to develop radiation hardening electronic design, qualification and hardness assurance requirements flow down, component/circuit hardening worse case reliability analysis, circuit prototyping with flight path roadmap and design support and special hardening assessment and mitigation capabilities unique to Field Programmable Gate Arrays (FPGAs) and Application Specific Integrated Circuits (ASICs).

BAENG has been involved with many of JPL/NASA space missions and instruments including EOS Aura/Microwave Limb Sounder (MLS) instrument, Mars Exploration Rover (MER), Jason-2/Ocean Surface Topography Mission (OSTM) instrument, Mars Science Laboratory (MSL)/Chemistry and Mineralogy (CHEMIN) instrument, Juno Polar Lander/Micro Wave Radiometer (MWR) instrument and number of Research and Development projects in designing, developing, and delivering similar technologies that are relevant to EJSM.

JUNO Polar Orbiter/Micro Wave Radiometer (MWR) instrument

BAENG provided engineering design services, materials and facilities for the design, development, implementation, analysis and delivery of digital data acquisition module. In this contract BAENG Designed, Developed, Space qualified and Delivered Proto-type, EM and Flight boards.

Performed circuit board and FPGA Reliability, Worse Case Analysis (WCA) and Single Event Effects Analysis (SEEA) necessary to accomplish and meet the mission goals per JUNO project reliability assurance requirements, JPL document D-34005.

Performed study and analysis of electronic circuitry and instrumentation containing SEE sensitive parts to minimize the effect of SEE and to assure that temporary loss of function or loss of data due to SEE does not compromise subsystem/instrument health and full performance can be recovered rapidly and there is no time in the mission that the loss is mission critical.

Performed circuit part modeling, simulation and analysis to predict system performance and degradation caused by radiation, temperature and age and study its effect to subsystem and system levels. Devised alternative design approaches to minimize or eliminate such effects.

In addition to the project reliability and mission assurance documents following general JPL rules and guidelines were followed for the design and analysis:

1- Reliability Analysis for Flight Hardware in Design, JPL D-5703.
2- Spacecraft Electronic Packaging/Cabling Design and Fabrication , JPL D-8208
3- De-rating guidelines, JPL D-8545
4- Design Principles, JPL D-17868
5- Flight project practices, JPL D-58032

As a result of this and other work, BAENG is highly qualified to support future missions to the outer planets, including the most challenging radiation locations.

Extreme Environment Compact Model Development for Ruggedized and Low Temperature Integrated Circuit Designs

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[1]CoolCAD Electronics LLC, 387 Technology Drive, College Park, MD 20742, [2]Dept. of Electrical and Computer Eng., University of Maryland, College Park, MD 20742, akin.akturk@coolcadelectronics.com

We develop compact and distributed design and simulation capabilities for predicting integrated circuit electrical performance under radiation and at cryogenic temperatures. These capabilities are being developed for metal oxide semiconductor field effect transistors (MOSFETs) from standard process lines that are accessible via various fabrication clearing houses such as MOSIS and TAPO. Our observation is that standard MOSFET devices work relatively well at low temperatures in roughly all regions of operation, and radiation induced adverse electrical effects can be mitigated in these standard, easily accessible, lower cost, all silicon-based integrated circuits. However, low temperature and radiation introduce new phenomena such as parasitic transistor edge leakage and enhances existing physics such as impact ionization related current kinks, incomplete ionization and possible hysteresis effects that are usually absent at room temperature. Since compact modeling and simulation tools have been developed for room temperature non-radiation operation, the application specific integrated circuit (ASIC) designers are lacking tools for designing extreme environment circuits including those that are used in read-out integrated circuits (ROICs). To this end, CoolCAD Electronics is developing compact modeling tools to be used along with process design kits (PDKs) for integrated circuit (IC) design, as well as advanced technology-computer-aided-design (TCAD) tools for examining mission-critical devices and nodes for their susceptibility to radiation, transients, and nonlinear effects such as current kinks.

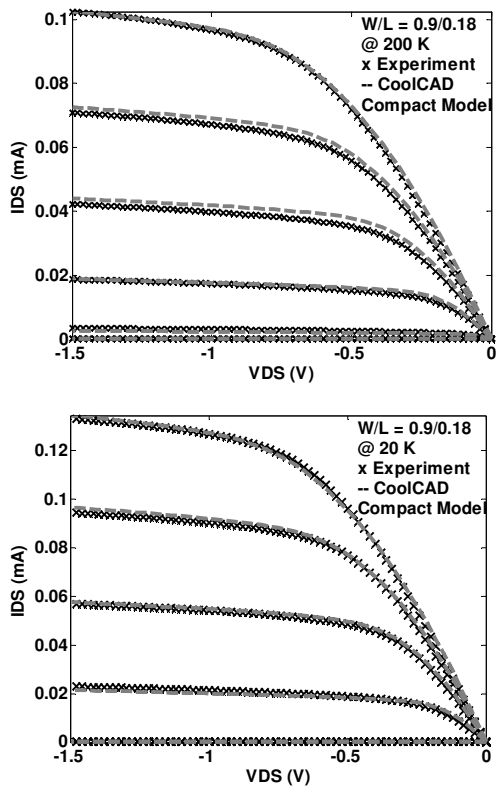

Figure 1: Example p-channel MOSFET 200K and 20K compact model fits for the IBM 8RF process. The same compact model is used to fit data from 4K to 300K.

Cryogenic and Rad-Hard Integrated Circuit Designs: We are focused on developing the capability of using standard MOS based electronics for circuit design at cryogenic temperatures and radiation rich environments like those that will be found during the Europa Jupiter Space Mission. The reasoning behind this focus is that if standard CMOS electronics can operate in these extreme environments, there will be less need for NASA to switch to more exotic materials, saving time and capital.

Modern submicron circuits are very complex and require meeting very stringent criteria for their design. Design is carried out using an array of computer aided design tools, of which the circuit simulator SPICE plays a most fundamental role. To meet NASA's requirements for circuit design, SPICE or SPICE-type computer aided design tools must be used. However, the fundamental problem is that SPICE-type circuit simulators and commercial device simulators are not applicable to the low temperature and radiation rich

environments. Therefore, SPICE and device simulators must be modified, as well as new SPICE-type and device simulators must be developed to meet NASA's circuit design requirements.

To achieve a CAD tool development for cryogenic and radiation effects circuit design that will lead to as-designed FPGA and ASIC operation, we perform cryogenic and radiation effect device measurements in parallel with TCAD modeling for extreme ambient conditions. The semiconductor device TCAD modeling is for understanding the new physical phenomena that may dictate device operation in these conditions, and also for overcoming the limitations imposed by practical concerns where experiments for all operating points and for virtually all temperatures are prohibitive. We then use the measurements and device simulation results to develop cryogenic effect compact models that can be used in SPICE-type compact integrated circuit simulators. Using the data obtained for calibration, we develop new compact circuit models and develop a SPICE-type simulator for the complete cryogenic temperature-radiation environment range. We implement the new models using the analog behavioral programming language Verilog-A which, unlike existing simulators, allows for modification of circuit design equations for cryogenic and radiation-rich conditions. Once comprehensive calibrated SPICE models, and cryogenic and radiation hard circuit simulators are developed, reliable circuits are designed and fabricated [1-4].

Initial Target Processes and BSIM Compact Modeling: We are currently developing all-inclusive cryogenic and radiation-effects compact models for IBM bulk processes that are for the 130nm and 65nm technology nodes. Some of our initial low temperature performance measurements along with the preliminary compact models that fit the experimental data are shown in Figure 1. The use of the standard compact models along with the commercial parameter extraction programs result in simulated current-voltage characteristics significantly different from the measurements, mainly due to the limitations of the industry standard compact BSIM models in incorporating the relevant physics that emerge at cryogenic temperatures. The CoolCAD-developed compact models give rise to performance predictions such as those shown in Figure 1 that can be used for achieving as-designed first pass cryogenic and rad-hard circuits. Furthermore, we also investigate other types of MOSFET designs (that are easily accessible for fabrication) for extreme environment operations. One such process is the silicon-on-sapphire (SOS) technology offered by the Peregrine Semiconductor. We are currently in the process of laying out SOS designs that will be assessed for cryogenic operation as well as radiation immunity.

Experiments and Simulations: To obtain compact models for different MOSFET devices, we first design and lay out our test circuits and devices. This is followed by the fabrication of these chips and the measurement of their current-voltage characteristics under various ambient conditions. Specifically, we measure the performances of devices developed in a given technology at various temperatures ranging from 4K to room temperature and higher. In addition to determining temperature-dependent electrical characteristics, we will also perform total ionizing dose radiation measurements. The measured total dose effects such as the possible parasitic edge transistor formation and the corresponding leakage current increase are then incorporated into the compact model, which can be evoked during circuit design to assess possible changes of performance. The total dose experiments and modeling are performed in conjunction with TCAD single event modeling.

The overall goal is to facilitate IC designs that operate under radiation at cryogenic temperatures.

References: [1] A. Akturk et al. (2010) Compact and distributed modeling of cryogenic bulk MOSFET operation, *IEEE Tran. on Elect Dev.* 57(6), 1334. [2] A. Akturk et al. (2010) Compact modeling of 0.35μm SOI CMOS technology node for 4K dc operation using Verilog-A, *accepted in Microelectronic Engineering*. [3] A. Akturk et al. (2007) Device modeling at cryogenic temperatures: effects of incomplete ionization, *IEEE Tran. on Electron Dev.* 54(11), 2984. [4] A. Akturk et al. (2010) Cryogenic temperature and gamma radiation effects on MOSFET performance, under review *IEEE Tran. on Device and Materials Reliability*.

L-3 Communications JAYCOR Capabilities

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JAYCOR Background

L-3 Communications JAYCOR in San Diego, CA supplies complete services and support processes for radiation/reliability analysis and hardening. Collectively, we have over 300 man years of working on radiation hard, high reliability systems. We can support, or drive, concept development and trade space studies; derivation of requirements and flow down of radiation performance requirements from the system level to the part level; generate, track and audit, via verification and validation test and/or analysis; and control radiation compliance from the foundry to the system, through all levels of integration, including rolling in radiation response back into system reliability. For the military, we handle nuclear weapon effects as well as natural radiation effects. We are also highly regarded as experts in radiation test planning and execution.

Modeling and Simulation Framework Overview

L-3 Communications approach to the analysis of circuit reliability and radiation effects is largely based on a sophisticated suite of commercial software tools offered by SILVACO, Inc., a leading supplier of Technology Computer Aided Design (TCAD) software, and a major supplier of Electronic Design Automation (EDA) software for circuit simulation and design of analog, mixed-signal and RF integrated circuits (www.silvaco.com). Figure 1 shows a high level description of SILVACO's wide range of simulation tools, all of which can play important roles in electronic circuit design and reliability/survivability analysis. L-3 Communications scientists and engineers have a long history of expertise that covers the entire range of software tools represented in Figure 1.

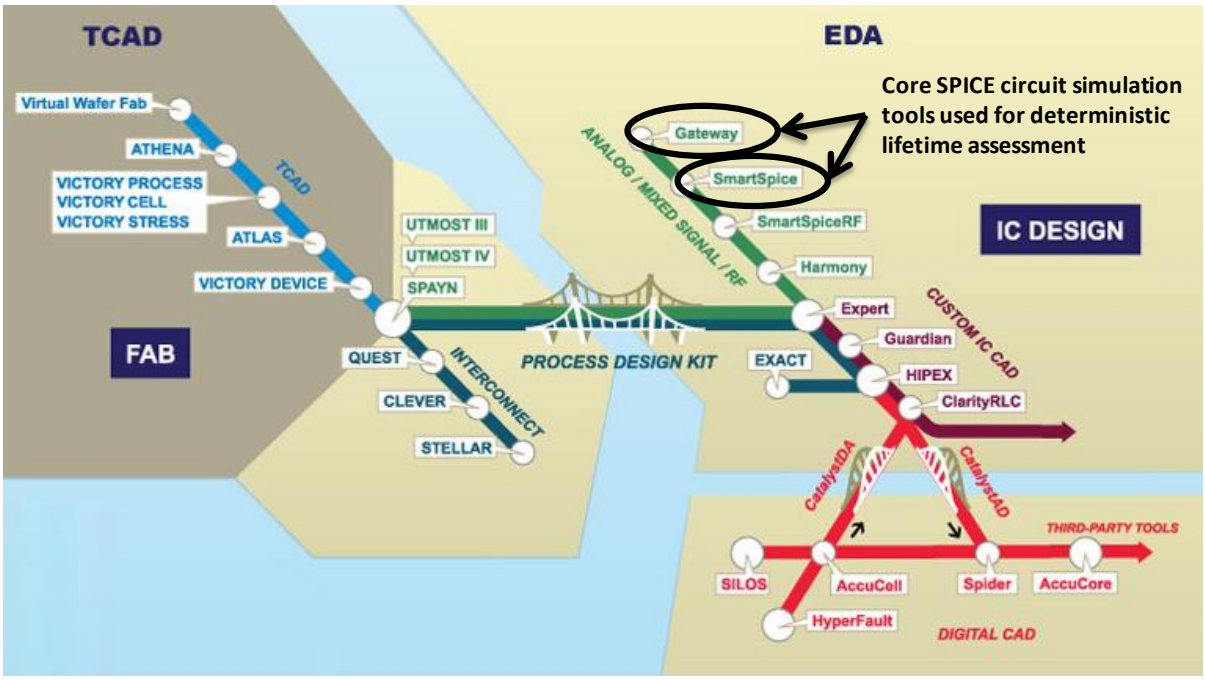

Figure 1. L-3 Communications Electronics Design and Analysis Environment

JAYCOR Modeling for Harsh Environment Survivability

L-3 and Silvaco have been working together for over ten years to expand Silvaco's Tool capability to address the needs of electronic designers designing circuits operating in harsh environments. We have developed interfaces that support ad initio inputs to device level simulation and device to circuits, inclusive of mixed mode (Device and Circuit) simulation. This multilevel modeling approach has been successfully employed to model and simulate complex DoD systems in the areas of reliability, ageing, part grading, and survivability analysis. SMARTSPICE has the capability to capture full transistor/circuit/subsystem/system hierarchies using combinations of transistor-level descriptions along with full support for Verilog-AMS and C++ to define behavioral models. Combining these capabilities with Monte Carlo analysis within the tool, we are able to support the generation of Response Surface plots. The following list highlights key aspects of our simulation capabilities.

- **Complexity**: Support for circuits of up to 12 million active devices in a flat or hierarchical SPICE netlist format.
- **Hierarchy**: Simulations can be at the transistor, cell, block, or full chip level.
- **Physics**: Device simulations (2D and 3D) from the ATLAS and VICTORY toolsets provide detailed transistor level modeling, which can be integrated with circuit level modeling at the SPICE level.
- **Maturity**: The SPICE simulator, SMARTSPICE has been in wide commercial release since 1988 and has consistently been one of the best circuit simulators in the market.
- **High Frequency**: RF circuits can be analyzed using SMARTSPICE-RF - which has both harmonic balance and shooting method RF solution capabilities.
- **Radiation Analysis Capability**: Total Dose, Dose Rate, SEE and combined environments are all addressed within the SMARTSPICE RadHard simulator. This simulation capability has been employed by the US Government and contractors for modeling radiation effects on space, strategic, and survivable electronics.
- **Behavioral**: The Silvaco family of simulators all have the capability to define new models, including mixed electro-mechanical models, using Verilog-A modeling language and also the ability to define models in C++ programming language.

JAYCOR Support Roles for the EJSM

JAYCOR's considerable experience in electronics design, test, and analysis for harsh environment survivability along with sophisticated modeling and simulation capabilities positions us for a variety of support roles for the EJSM. We propose support activities that include:

- **Full system simulation** incorporating the instrument payload, avionics, power bus, communications etc. Such a system model would allow for sophisticated trade space studies, measurement scheduling, power optimization, and performance degradation predictions.
- **Rad-hard ASIC and/or FPGA** requirements definition, design support, process targeting, and foundry engagement. In particular, we advocate the consideration of rad-hard ASICs for "big-analog, small digital" electronics that must reside near sensor front-ends, reducing the ability to apply shielding as a means of hardening. We are experts in rapid and affordable development of low to moderate complexity radiation-hardened mixed signal IC's. Our tool flow is ideally suited for these classes of circuits and we have expertise in numerous suitable onshore foundry manufacturing processes.
- **Radiation and reliability testing** support at system, subsystem, and part levels.

RADIATION ANALYSIS AND SUPPORT CAPABILITIES OF SOUTHWEST RESEARCH INSTITUTE – SPACE SCIENCES AND ENGINEERING DIVISION

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Southwest Research Institute is uniquely qualified, as an independent research entity with broad experience in physics, analysis, and hardware development, to provide expertise, services, hardware and technologies to ensure avionics and instrumentation will survive and operate in the challenging EJSM radiation environment.

Southwest Research Institute (SwRI), headquartered in San Antonio, Texas, is one of the oldest and largest independent, nonprofit, applied research and development (R&D) organizations in the United States. Founded in 1947, SwRI provides contract research and development services to industrial and government clients. SwRI consists of 11 technical divisions that offer multidisciplinary, problem solving services in a variety of areas of the engineering and the physical sciences.

Since 1977, the Space Sciences and Engineering division of SwRI has played a key role in NASA space physics and planetary missions. With world renowned expertise in planetary and space science, instrument design and fabrication, and avionic/data systems development, the Institute contributes significantly to understanding the space radiation environment, the solar system and the study of solar system bodies, in situ and remotely.

Using state-of-the-art computer modeling and data analysis techniques, the Space Science Department investigates the solar wind, the solar system and other astrophysical phenomena from theoretical and observational standpoints. Historically, space research at SwRI has emphasized magnetospheric and auroral physics, centering on the Earth's plasma environment and its response to the solar wind.

SwRI-developed plasma instruments have flown on sounding rockets and satellites, including the Upper Atmosphere Research Satellite, the Polar spacecraft and the Cassini Saturn Orbiter. Other instruments include a novel energy-mass spectrograph for energetic neutral atom imaging of magnetospheric plasmas, a miniature electrostatic dual spherical analyzer for concurrent ion and electron measurements of auroral plasmas, a miniaturized optimized smart sensor (MOSS) for in situ plasma measurements, embody NASA's philosophy for future space missions.

SwRI is a leading developer of processors, command and data handling systems, and related electronics for space flight. The department has full capabilities in system and subsystem design, fabrication, and testing. SwRI processors have flown on more than 30 space missions without an on-orbit failure.

SwRI was the PI institution for IMAGE, the first PI led MIDEX mission. After the very successful IMAGE mission, (ahead of schedule and under budget) SwRI has gone on to be selected as the PI institution for the New Horizons mission to Pluto, IBEX, JUNO, and MMS. As the lead institution, SwRI is responsible for ensuring that all components will survive and operate in each of the missions unique radiation environments.

SwRI has provided instruments or avionics components for over 85 missions. Hardware ranges from an instrument to a single board to the entire spacecraft avionics. Every mission requires the design procedures and analysis capability to guarantee that the hardware will survive and operate in the environment.

Over the decades, SwRI has worked closely with the radiation community including parts engineers at GSFC, JPL, MSFC, and JSC. SwRI's background in space-radiation effects includes the knowledge, expertise, and understanding of the actual physics of the space radiation environment. SwRI is also an

active participant in the space radiation related conferences with papers submitted to NSREC, SEE Symposiums, MAPLD, and RADECS.

Properly radiation hardened design begins at the lowest level. Over the decades, SwRI has compiled a list of tolerant technologies and devices for the designer to choose with staff assigned to maintaining this comprehensive.

SwRI has ready access to a Co60 Hot-Cell that can provide a dose rate of up to 1 Mrad(Si)/hour and we are very close to the facilities at Texas A&M University (TAMU). SwRI personnel have performed radiation testing at TAMU, Berkeley, Harry Diamond, UCDavis, Brookhaven, CERN, and iThemba to name a few.

SwRI has characterized the radiation effects on dozens of devices such as the VIRENA ASIC, the MSA0760 MMIC, the AD648, the HV801, and the AD713. SwRI is an active participant in the current effort to qualify the Xilinx Virtex 5 for a broad spectrum of space application.

SwRI has developed two radiation hardened Application Specific Integrated Circuits (ASIC). The VIRENA is a first pass mixed-signal ASIC built for the Radiation Assessment Detector on the Mars Science Laboratory. SwRI has also developed and produced a radiation hardened Command and Telemetry ASIC that performs CCSDS compliant command decoding and data formatting under IR&D funding. The experience gained through these two ASIC programs is directly applicable to any mixed signal ASIC for space instrumentation.

JUNO and RBSP are two missions with very challenging radiation environments that are directly comparable to the EJSM. These missions required special attention to the usual analog bipolar components for High Dose Rate and ELDRs, and the selection of specifically rad-hard ADCs and DACs, optocouplers, rad-hard memories, special filtering of high speed Low Drop Out (LDO) regulator outputs for SET mitigation. .

SwRI is a unique institution in that it is similar to both a university and commercial industry. With that university/corporate mentality, SwRI interfaces and teams extremely well with universities providing them with the experience and resources they may lack. This is important particularly in the areas of Quality Assurance (QA) and Product Assurance (PA) which includes all aspects of radiation analysis. SwRI's expertise has led to the success of several university led missions such as Swift (Penn State University), Galex (UCBerkeley) and RAD (Christian Albrecht University – Kiel, Germany). SwRI is an excellent teaming partner with the experience necessary to assist a university led payload or mission.

SwRI has produced radiation hardened hardware for many missions including IMAGE, UARS, CASSINI, Deep Space1, Orbital Express, Deep Impact, Kepler, QuikSCAT, ICESat, GPB, AcES, Coriolis, CALIPSO and many, many more (more than 85). SwRI parts engineers, design engineers, systems engineers and program managers are very well known and respected throughout the space community, and are regularly asked to participate in radiation design and document reviews for both civilian and defense missions.

SwRI's has demonstrated over three decades of exemplary radiation hardened experience spanning from flight proven hardware to the physical understanding and study of the space radiation environment. As a strong and experienced team member, Southwest Research Institute will provide services and broad expertise; guaranteeing the success of the EJSMAbstracts regarding items of interest to the general instrument community, such as relevant EEE parts resources, radiation testing capabilities, modeling services, etc. are being solicited for the 4th EJSM Instrument Workshop. Abstracts should convey the key points to be made in your poster presentation and should give enough information for the committee to determine its appropriateness for the Europa Jupiter System Mission Instrument Workshop.

Solutions for Single-Event Effects in Ultra Deep Submicron Semiconductor Technologies Using Simulation and Layout Techniques

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Abstract

Robust Chip Inc. (RCI) provides a tool suite for single event analysis and simulation, and a new layout methodology, Layout Design through Error Aware Positioning (LEAP), along with logic cell IP based on this methodology. The single event analysis capability uses a new simulation method which allows for an accurate prediction of cross-sections and error rates for logic or analog cells. The technique fully accounts for layout, circuit, and substrate effects, and makes it possible to compare different layouts, and to analyze the details of the single event response and the effectiveness of single event mitigation methods.

Introduction

Single event effects in ultra deep submicron technology nodes exhibit a much stronger interaction between the circuit and the generated charge, and between different circuit nodes, than in older semiconductor technologies. These effects render the impact of single events very sensitive to details in the layout, and open the door to effective reduction and optimization of single event behavior through relatively low overhead layout modifications. Due to the complex nature and strong coupling between circuit and charge transport and collection, a comprehensive and accurate analysis and simulation capability is required for circuit and layout designers who want to minimize the single event sensitivity. The tool accuro™ from RCI (developed with support from DTRA) has this capability, and has been successfully applied to, and experimentally verified for, (e.g., [baze08]), 90nm, 65nm, and 45nm CMOS technologies.

Single event analysis tool suite

The simulation technique from RCI fully captures the charge generation, transport, and collection using a full description of the layout and substrate, while still being fast enough to provide complete cross-section (Fig.1) and error-rate predictions. This dedicated single event simulation solution provides an ability to accurately model effects that cannot be measured directly, reducing the very expensive and costly experimental testing (and possible re-designs), and providing a unique design support which will allow for the generation of the best possible radhard circuits and layouts with a minimum of performance penalty. It is an important building block in the design flow for a radhard designer, providing the fundamental information about single event behavior of the basic building blocks in the design.

RHBD layout methodology: Layout Design through Error Aware Positioning, LEAP

The new single event analysis technique supports radhard by design, RHBD, layout methods, as well as the incorporation of RHBD techniques in layout synthesis. RCI has developed an RHBD layout methodology, LEAP, which addresses the increased single event sensitivity and complexity in ultra-deep submicron technologies, by directly using the interaction between different circuit nodes, during a single event, to reduce the single event sensitivity. The technique has proven very effective both for sequential and combinational logic cells, and has been experimentally verified for a hardened (DICE) flip-flop (Fig. 2) [Lee10]

Conclusion

The single event analysis tool suite from RCI would support the EJSM mission by the capability to get accurate error rate predictions at the (logic or analog) cell level, and by providing guidance for the selection of logic cells, design styles, and technology, as well as insight and understanding of the single events effects in different circuit components. A use of LEAP-based logic cells, in the digital design libraries for the most advanced technologies, could dramatically reduce the basic single event rates with a minimal performance penalty.

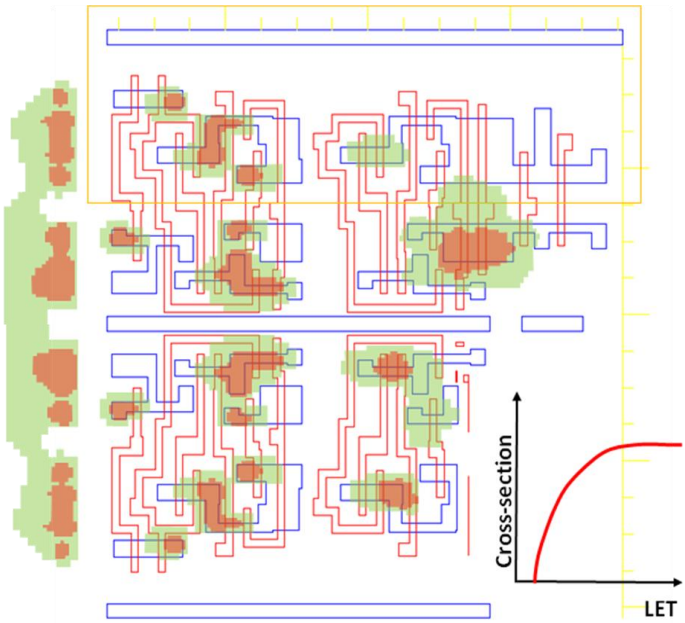

Figure 1. Accuro from RCI has the capability to accurately map out the regions in a layout that generate upsets (or specified transients etc.) for different LET values and for different angles of incidence, illustrated here by the cross-sections regions for two different LET values (red, green), at normal incidence (on top of the layout) and 90˚ tilt (left). The area of these regions is what makes up the measured cross-section curves (lower right).

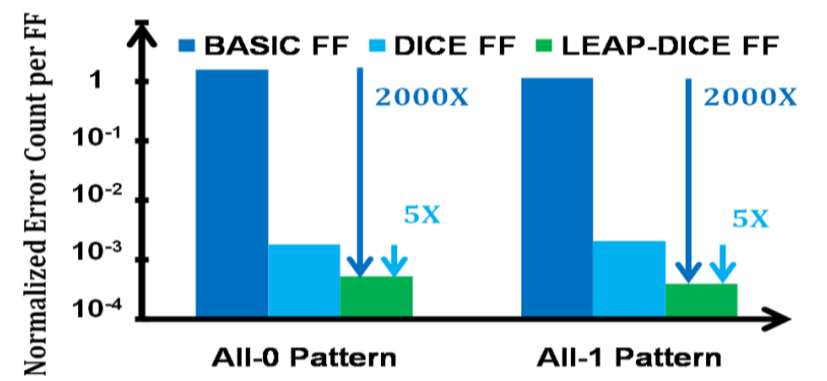

Figure 2. Experimental verification of the LEAP layout methodology [Lee10]. Dynamic single event testing (50kHz). 180nm technology. Using 100% identical circuits the LEAP implementation is 5X better than the non-leap DICE cell.

References

[Baze08] M. P. Baze, et.al., , NSREC 2008, IEEE Trans. Nuclear Sc., Dec. 2008, [Lee10] H.-H Lee, K. Lilja, M. Bounasser, P. Relangi, I. R. Linscott, U. S. Inan, S. Mitra, Int. Reliability Phys. Symp., 2010

Answers to Your Radiation and Performance Questions

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The ASI team presents significant expertise in all aspects of natural and induced environment modeling for space applications. ASI personnel have assisted government programs in flight dynamics calculations, orbital simulations, radiation environments modeling, polarimetric and traditional sensor simulation, requirements development, schedule development, laboratory testing, and validation. The ASI team has the capability to model radiation environments and shielding to determine accurately what spectra will impact your instruments. ASI's team uses virtual hardware to model electronic component performance while running mission software, and has the capability to inject errors representative of SEEs to determine software stability, and calculate performance degradation. ASI also develops knowledge-based software for many customer requirements including: databases, orbital environment simulators, 3-D modeling tools, and radiation transport models.

What is the radiation environment inside my instrument? Is it different in my electronics?

Radiation Hardness Assurance Toolkit (Rad*HAT*™) is a data integrator and software director that interfaces with industry standard software such as Satellite Tool Kit (STK™), AE-8, AP-8, and outputs from CREME96. Rad*HAT*™ also moves 3-D data from computer-aided design (CAD) models through Raytheon's Translation Optimization for Part-wise Adaptive Combinatorial Transport (TopAct™) software. The Rad*HAT*™ and TopAct™ software converts spacecraft models into the inputs required by well-established radiation transport codes such as Shielddose, MCNPx, HZETRAN, and NOVICE. This 3-D approach to modeling may allow the placement of critical components in a low-dose area without the addition of shielding. This software suite allows the use of CAD models for an accurate determination of dose for each part, and the development of requirements with less margin of error resulting in less expensive electronics parts, lower requirements for radiation testing, and less overbuild in the final product.

How does the radiation environment affect my instrument's performance?

Virtual hardware can be modeled using Wind River's Simics® full-system simulator providing a macro-level evaluation of how electronic component selection affects overall system radiation hardness in the mission environment. Simics® enables the customer to develop and run mission software in a simulation that virtually replicates actual mission hardware. The Rad*Cat*® interface with Simics® will add the ability to inject errors due to component radiation faults into the hardware simulation, allowing the mission hardware and software's response to radiation faults to be observed and corrected.

Are optical components susceptible?

The radiation environment can cause substantial degradation of optical parts. Effects such as photo darkening through the formation of color centers and reduced transmission through surface damage on cryogenic crystalline cells have been well documented, but proper choice in materials, fabrication process, and design can improve lifetimes and ensure instrument performance after degradation. RadCat® contains data on hundreds of optical parts and materials which can improve design choices. ASI can assist in developing a test plan, characterizing the effects of component radiation damage on the system level performance, and verifying your qualification documents for both individual optical components and full optical systems.

What testing does my instrument need? How will that affect my budget and schedule?

ASI provides comprehensive test support, including software such as the Radiation Test Environment Simulation Toolkit (Rad*TEST*™). Rad*TEST*™ part tracking software will keep projects on schedule, on budget, and within risk. Entering the Bill of Materials (BOM) into the Rad*TEST*™ system will allow the tracking of the test requirements, aid planning for the required tests, standardize test reporting, and match each test to the validation of the specific component tested and to its criticality in a spacecraft system so that risk can be accurately evaluated and a schedule can be maintained. Rad*TEST*™ will also allow engineers to formulate validation to match requirements specific for each element in the design.

About ASI

ASI is under contract with the Missile Defense Agency to commercialize its Radiation-tested parts Catalog (Rad*Cat*®), and develop a series of codes for the hardening of electronics and materials which may be exposed to the natural and induced radiation environments. Rad*Cat*® is a fully functional database, but further software tool development is underway based on the needs of our clients. These software development projects include Rad*HAT*™ for improved modeling and transport calculations, and the Rad*TEST*™ for test planning and report generation.

Rad*Cat*® currently includes over 5,000 radiation-tested or hardened parts with links to thousands of tests, test providers, and manufacturer's product listings. The database is supported by MDA with no user fee. The database is open to all U.S. persons, and should assist designers in locating radiation tested and hardened electronics parts for the significant natural environment requirements presented for the Jovian mission.

Through the use of ASI's expertise and these knowledge-based systems, the requirements definition can be made with a minimum of margin, radiation hardened parts can be chosen where available, and the validation of multiple systems can be tracked on schedule in a public database across multiple management desktops simultaneously. ASI is uniquely positioned to aid NASA in the development of a next-generation system for radiation-hardened spacecraft design.

For more information about ASI's products and services, contact Richard L. Altstatt at 256-562-2127.

A Deterministic Electrons/Photons, Protons/Trapped Heavy Ions (C-O-S) Transport Suite for the Study of the Jovian System

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A Langley Research Center (LaRC) developed deterministic suite of transport codes which describe the transport of electrons/photons, protons/heavy ions in condensed media is used to simulate the effects and exposures from spectral distributions typical of electrons, protons and carbon-oxygen-sulfur (C-O-S) trapped heavy ions in the Jovian radiation environment. The particle transport suite consists of a coupled electrons/photons deterministic transport algorithm (CEPTRN) and a light/heavy ion deterministic transport algorithm (HZETRN). The primary purpose for the development of the transport suite is to provide a means to the spacecraft design community to rapidly perform numerous repetitive calculations essential for electrons/protons/heavy ions radiation exposure assessments in complex space structures. Several favorable comparisons have been made with statistically oriented Monte Carlo (MC) calculations. ITS V.30 (integrated Tiger series) MC package was used for electrons/photons transport verfication in the Jovian environment [1]. FLUKA and HETC-HEDS were used for protons/heavy ion transport verification at low Earth orbit (LEO) [2] as Jovian heavy ion counter (HIC) spectra were not available to the authors. The proton/heavy ion models have been extensively validated in LEO by comparing to measurements aboard the International Space Station (ISS) and the Space Transportation System (STS) [3]. The transport suite verifications versus MC packages have indicated that for typical space environment spectra at LEO or at Galilean satellites, the particle transport accuracy has not been compromised at the expense of computational speed.

The radiation environment of the Galilean satellite Europa is used as a representative boundary condition to show the capabilities of the transport suite. While the CEPTRN/HZETRN suite can directly access the output electrons/protons spectra of the Jovian environment as generated by the Jet Propulsion Laboratory (JPL) Galileo interim radiation electron (GIRE) model of 2003 [4], for the sake of relevance to the upcoming Europa Jupiter system mission (EJSM4) workshop, the authors have opted to directly use the tabulated 105 days at Europa mission fluence energy spectra [5] to produce the corresponding depth-dose curve in silicon behind an aluminum shield. The transport suite can also accept ray-traced thickness files from a computer-aided design (CAD) package and calculate the total ionizing dose (TID) at a specific target point. The dependency on a CAD generated ray-traced file is inherent in the deterministic nature of the transport formalism. In that regard, using a low-fidelity CAD model of the Galileo probe generated by the authors, the transport suite was verified versus aluminum

equivalent shell simulations for orbit G1–I32 of the Galileo extended mission (1996-2001) [6].

Beyond computing the traditional aluminum-silicon depth-dose curve as a standard shield-target combination, for a limited number of candidate shielding materials such as tantalum (Ta), copper (Cu) and tungsten (W), the transport suite is used to evaluate the particle flux and TID dose due to electrons, protons and C-O-S trapped heavy ions at Europa (Rj=9.4) as a function of latitude, longitude and altitude. Furthermore, the fast execution time of the transport suite allows a design engineer to swap shield materials to perform Z-grade optimization on multi-layered shields.

The Jovian radiation environment will be presented first. An explanation of the particle transport formalism as implemented in the transport suite will follow. Validation results versus Galileo probe measurements will also be shown followed by an explanatory description on how shield designers can go about performing Z-graded studies or final shield optimization.

1. J. E. Nealy, C. K. Chang, R. B. Norman, S. R. Blattnig, F. F. Badavi, A. M. Adamczyk, "A Deterministic Transport Code for Space Environment Electrons," NASA-TP-2010-216168, January 2010.

2. J. H. Heinbockel, T C. Slaba, R. K. Tripathi, S. R. Blattnig, J. W. Norbury, F. F. Badavi, L. W. Townsend, T. Handler, T. A. Gabriel, L. S. Pinsky, B. Reddell, A. Aumann, "A Comparison of the Radiation Transport Codes HZETRN, HETC-HEDS and FLUKA using the 1977 Solar Minimum GCR Spectrum," NASA-TP-2009-215956, December 2009.

3. J. W. Wilson, R. K. Tripathi, C. J. Mertens, S. Blattnig, M. S. Clowdsley, F. A. Cucinotta, J. Tweed, J. H. Heinbockel, S. A. Walker, J. E. Nealy, "Verification and Validation: High Energy and Charge (HZE) Transport Codes and Future Development," NASA-TP-2005-213784, July 2005.

4. H. B. Garrett, I. Jun, J. M. Ratliff, R. W. Evans, G. A. Clough, R. W. McEntire, "Galileo Interim Radiation Electron (GIRE) Model," JPL Pub. 03-006, 2003.

5. http://opfm.jpl.nasa.gov/europajupitersystemmissionejsm/instrumentresources/.

6. P. D. Fieseler, S. M. Ardalan, A. R. Frederickson, "The Radiation Effects on Galileo Spacecraft Systems at Jupiter," IEEE Transactions on Nuclear Science, V. 49, No. 6, December 2002.

OLTARIS – Enhancements Supporting the Europa Mission

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The **O**n-**L**ine **T**ool for the **A**ssessment of **R**adiation in **S**pace (OLTARIS, https://oltaris.nasa.gov) is a web-based set of tools and models that allow engineers and scientists to assess the effects of space radiation on spacecraft, habitats, rovers, and spacesuits. The site is intended to be a design tool for those studying the effects of space radiation for current and future missions as well as a research tool for those developing advanced material and shielding concepts. The tools and models are built around the HZETRN [1-3] radiation transport code and are currently focused on human-related responses. This code and the team behind its continuing development have been identified by NASA to support verification of human radiation design requirements. The current capabilities include:

User Selected Environment(s)

- Free Space Galactic Cosmic Ray (GCR) at 1 AU
- Free Space Solar Particle Event (SPE) at 1 AU
- Earth orbit (Circular)
- Europa design environments (electrons and protons - 105 days at Europa, Jovian Tour, Peak flux at $5R_j$ and $9R_j$)

User Defined Thickness Distributions (complex vehicle geometries)

- Upload thickness distribution(s)
- Supported materials : aluminum, polyethylene (CH_2), and tissue

User Defined Materials for Multi-Material Slab Calculations

- Materials can be defined by chemical formula, elemental mass percentage, or molecular mass percentage
- Arbitrary slabs can be created using the user-defined materials

User Selected Response Function(s)

- Differential flux/fluence
- Dose in tissue or silicon
- Dose equivalent based on ICRP60 standard
- Whole-body effective dose equivalent using the Computerized Anatomical Man (CAM), Computerized Anatomical Female (CAF), Male Adult voXel (MAX), and Female Adult voXel (FAX) body models
- TLD-100 (Thermo-Luminescent Dosimeter)
- TEPC (Tissue Equivalent Proportional Counter)
- LET (Linear Energy Transfer) in tissue or silicon

The focus of this poster is to highlight new capabilities that have been added to support outer planet missions. Specifically, the electron, proton, and heavy ion design environments for the Europa mission have been incorporated along with an efficient coupled electron-photon transport capability to enable the analysis of complicated geometries and slabs exposed to these environments. The poster will describe

how OLTARIS can be used by instrument vendors and mission designers to analyze their specific requirements.

References

[1] Nealy, J.E., Chang, C.K., Norman, R.B., Blattnig, S.R., Badavi, F.F., Adamczyk, A.M., "A Deterministic Computational Procedure for Space Environment Electron Transport," Nuclear Instruments and Methods in Physics Research B, Volume 268 pp. 2415–2425 (2010).

[2] Slaba, T.C., Blattnig, S.R., Aghara, S.K., Townsend, L.W., Handler, T., Gabriel, T.A., Pinsky, L.S., Reddell, B., "Coupled Neutron Transport for HZETRN," Radiation Measurements, Volume 45 pp. 173-182 (2010).

[3] Slaba, T.C., Blattnig, S.R., Badavi, F.F., "Faster and More Accurate Transport Procedures for HZETRN," NASA Technical Paper 2010 – 216213 (2010).

ITI Response to RFI for the Europa Jupiter System Mission

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Statement of Capabilities, Qualifications, Experience, and Maturity:

Implementation Technology, Inc. (ITI) is a small, woman owned business incorporated in the state of California. The ITI team consists of a core of Company capabilities augmented by access to numerous nationally know Subject Matter Experts (SMEs) assembled to focus on a particular problem or task. This team has extensive experience and can provide expert capabilities across all radiation hardening design and qualification considerations. These capabilities are required to support the design and development of the EJSM spacecraft in order to operate within the ionizing radiation, single event, and displacement damage environments expected for the EJSM mission. This includes the radiation hardening system engineering disciplines to develop radiation hardening design, qualification and hardness assurance requirements flowdown; component/circuit hardening analysis and design support; radiation shielding analysis and design; spacecraft charging assessment and mitigation; and special hardening assessment and mitigation capabilities unique to sensor/instrument payloads, including degradation and noise mitigation techniques.

ITI team members have applied these capabilities to space systems and missions over the years, including previous Jupiter missions, i.e., Pioneer, Voyager, and Galileo missions, as well as numerous military satellites such as DSP, DSCS II, DSCS III, FleetSatCom, UHF FollowOn, - - -, GPS and satellites built for three letter agencies.

In the area of project management and oversight, ITI has recently developed unique project management tools (MATRIX) that has been applied to assist in the management and implementation of the Project Radiation Hardening Program. The tool provides, in a single location, the context sensitive information necessary to conduct each activity. It also is applicable to additional disciplines (such as Reliability, Safety, QA, - -) that have definable requirements and activities that must be addressed or conducted at one or more assembly levels of the system. This tool has been utilized recently on the Mission Assurance effort of the Juno Project.

ITI assisted in the organization and is currently participating in the Radiation Advisory Board support to the Juno Mission Assurance Manager. Previously, ITI participated in, and chaired, an earlier technical peer review committee for the assessment of systems engineering and radiation hardening issues and mitigation approaches for the earlier Europa Explorer Mission Concepts study.

As cited in the RFI, the estimated Total Ionizing Dose, TID, range for the JEO mission (i.e., 2900 kRad(Si) behind 100 mils Al shielding to 817 kRad(Si) behind 320 mils Al shielding) will pose an extremely difficult hardening challenge. Also, as noted in the RFI, the minimum die-level part TID capability is expected to be 100 kRad(Si) behind 100 mils shielding for the JEO mission. This anticipated die-level TID capability is probably achievable for many piece parts, however, it is likely to pose a significant challenge for many other parts; i.e., power devices, analog devices, etc. This may be particularly daunting when considering the likely additional requirement for a design margin (usually a factor of 2). The anticipated peak dose rate of about 2.3 Rads(Si)/sec., behind 100 mils Al shielding, as noted in the RFI, will also pose a significant challenge to deal with the radiation-induced transient and noise effects which can alter various spacecraft and instrument functions critical to mission performance and success. It should be noted that some sensors, by their nature, cannot be placed behind 100 mils of aluminum

and will see higher total dose and dose rates. Additional mechanisms, such as, Single Event Effects (SEE) and Enhanced Low Dose Rate (ELDRS) effects will likely be of significant concern.

To meet these challenges, judicious trades between radiation shielding, hardened piece parts/components, circuit design, software driven mitigation techniques, and operational/functional flexibility will be required. Spacecraft charging, both external and internal, will also be a significant concern. This will require detailed modeling and analyses to define the environmental and design requirements and mitigation techniques. A stringent hardness assurance program will be required in order to ensure the hardened designs are implemented in the flight hardware and software.

The ITI team can address all of these major challenges, as well as, support the overall EJSM radiation hardening program. Specifically, the ITI team has been involved in the development and/or utilization of numerous applicable radiation hardening design analysis tools and procedures that have been used in various spacecraft and rad-hard technology development programs. For example, the ITI team supported the development of the Defense Threat Reduction Agency (DTRA) Hardened Sensor Design and Test Protocol (ITI was also the overall editor), as well as, the companion Testable Hardware Design Protocols for Space Systems. In the area of analysis and design tools to support rad hard designs, the ITI team has experience in utilizing various circuit analysis and design tools, i.e., SPICE, VHDL, SEE, Silvaco, etc.; spacecraft charging modeling and analysis tools, i.e., GEANT 4, ECEMP Charging Analysis & Hardening Tool; integrated radiation shielding codes which couple CAD models directly into radiation transport and response codes. All of these tools are mature, operational tools suitable for use on the ESJM Radiation Hardening Program. The team has experience in supporting “hardened-by-design” techniques, particularly in relation to electro-optic sensor devices, such as, CCD FPAs, Hybrid FPAs and Active Pixel Sensors , as well as, working closely with specialized device design organizations and foundries to fabricate, evaluate and radiation test hardened devices. The ITI team has extensive experience in the area of radiation testing, including testing for permanent damage (TID, DD) and in the particularly difficult area of the measurement of performance (transient/noise) of analog circuits/components, such as focal plane arrays, utilizing advanced fiber optic test instrumentation.

The management tool MATRIX, (Mission Assurance Tracking Requirements In eXcel) is tailored for each program to provide a systematic decomposition of the system and arrays system elements with the associated activities and requirements of the element. A separate sequence is provided to reflect the specific requirements and activities of each discipline using the tool. MATRIX answers questions such as:

- *From a discipline management point of view*

  What is the status of this discipline? How many actions must be performed? At this point in time, How many are there of each status category (identified, ongoing, complete, problems, - -, not applicable)? At what assembly level do these status evaluations appear? What design elements is associated with each status evaluation? What is the background information supporting these status evaluations? More.

- *From a discipline technical point of view*

  As above but data are presented and summarized for a specific test, analysis, or evaluation requirement.

MATRIX is maintained current through interaction with the discipline lead or designee. It **Does Not** independently make judgments of status, acceptability, applicability, etc. This remains the prerogative of the radiation discipline lead. MATRIX can automatically generate reports and presentation material with this information.

ITI’s experience in implementing radiation hardening programs and providing radiation hardening oversight to system hardening programs, including the prior Europa Explorer Mission Concepts study and the on-going Juno Project, would be directly applicable to the ESJM Project. The ITI team has over 150 years experience in the radiation effects arena and knows the players, facilities, and tool well. ITI can add additional capability as needed or desired by an ITI customer.

Radiation Analysis Services Center (RASC) Capabilities

S.J. Manson[1], B.L. Willits[2], H.J. Barnaby[3]

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[2]Raytheon Space and Airborne Systems, 2000 East El Segundo Blvd., El Segundo, CA 90245.
[3]Arizona State University, GWC 316, MC 5706, Tempe, AZ 85287.

Abstract

I. Summary

This paper summarizes the radiation analysis capabilities of the Radiation Analysis Services Center (RASC), a consortium in formulation between Raytheon Missile Systems (RMS, Tucson, AZ), Raytheon Space and Airborne Systems (SAS, El Segundo, CA) and Arizona State University (ASU, Tempe, AZ). RASC is forming under the auspices of a Master Sponsored Research Agreement between RMS and ASU. Raytheon and the RASC have a broad range of unique technical expertise and capabilities that that are applicable to the EJSM including radiation shielding design and optimization, radiation transport analysis, and radiation testing.

II. Capability and Qualifications Statement

RMS brings to RASC high fidelity radiation shielding analysis via the state-of-the-art proprietary TopAct radiation analysis tool. TopAct converts standard Computer-Aided Design (CAD) drawings into MCNP(X), NOVICE, ITS, and TART input decks up to three orders of magnitude faster than traditional methods and with the full fidelity of the source CAD drawings. The resulting models are used to perform shielding analysis and optimization through computation of highly-accurate predictions of radiation effects at any point in a complex system. When coupled with detailed device modeling capabilities, this allows unprecedented capabilities to predict overall system performance under radiation conditions. SAS brings to RASC the Component Engineering Department (CED) for qualification, failure analysis, and radiation testing. CED has over 17,500 ft² of space, >$20M in capital investment, and over 100 technical staff responsible for performing radiation survivability testing, radiation environment and transport analysis, design verification testing, destructive physical analysis (DPA), microcircuit and discrete component test and evaluation activities, and failure analysis (FA). The CED supports all piecepart test, evaluation and screening, design verification testing, part qualification, radiation survivability analysis and test, environmental test, failure analysis, destructive physical analysis, non-destructive test and analysis for Raytheon programs. ASU brings to RASC extensive expertise in device level modeling, conducting radiation effects research from the physics of radiation transport and material interactions to the impact of radiation damage on the operation of electronic components at the transistor, circuit, and system level. This expertise includes TID effects, DD, ELDRS, packaging issues, and RHBD.

III. Detailed Description

TopAct provides an end-to-end translation capability. It accepts as input part files in standard STEP and Parasolid formats. A pre-processor reads in part files and analytical surface data are extracted. TopAct then computes an efficient zoning statement for part geometry and any void space. The final optimized zoning statement and surface prescriptions are output in the desired code formats. TopAct has been validated via laboratory experiment [1]. TopAct allows radiation transport analysts to fully participate with mechanical designers as a design is evolved. When translations are performed by hand, cost and schedule precludes multiple iterations. This may lead to inelegant design patches when transport calculations reveal system shortcomings. Because TopAct drastically reduces translation time, it allows designers and analysts to evolve their high-fidelity models in parallel, and to discover weaknesses early.

This cooperative arrangement often leads to more elegant, efficient, superior delivered components and systems.

The CED laboratories are equipped with test and analysis equipment to perform integrated circuit (IC) test systems, and include a wafer probe station, semiconductor and microwave test systems, thermal imaging, real-time x-ray equipment (Phoenix, Fein Focus, and North Star), conformal scanning acoustic microscope, a scanning electron microscope, and energy dispersive x-ray analysis equipment. The computed radiation environment serves as input to the System Radiation Response Module (SRRM) developed by ASU. SRRM enables statistical predictions of an electrical system's response to radiation. SRRM considers ionization and displacement damage as well as transient single events. The module serves as both a comprehensive, expandable test database and simulation tool for modeling radiation effects in semiconductors, ICs, and hybrid systems. ASU has developed a unique capability for modeling radiation effects in discrete COTs applications. The approach, radiation-enabled macromodeling, allows for efficiently simulating the radiation response of a hybrid electronic system [2]. This system level simulation facilitates design optimization prior to assembly, thereby reducing cost, shielding requirements, and supporting higher functionality design (i.e., risk margin reductions). In addition to COTs system modeling, SRRM can significantly reduce the design and fabrication costs associated with hardened ASICs, avoiding expensive development of chips that will be well behind the state of the art. ASU's extensive experience in RHBD positions it well to support the design of hardened ASICs in advanced commercial flows. Moreover, ASICs designed in some trusted foundry processes (e.g. IBM) can build upon the cell libraries already developed by ASU with its industrial partners. The device modeling team at ASU will also build radiation enabled transistor models to support design and layout of ASICs based on targeted radiation specifications. These specifications may include LET thresholds and total dose levels provided as inputs from TopAct. ASU has demonstrated this capability on numerous research activities.

IV. Maturity Level/Past Experience

TopAct was developed beginning in 2000 when existing modeling capability could not support schedule for shielding design for the Exoatmospheric Kill Vehicle. Since that time, Raytheon has supported numerous internal and external customers. CED is a mature capability. The ASU group brings decades of industry and academic research experience to RASC.

V. Application to the EJSM

Since the EJSM will be required to enter Europa orbit and operate for >2 years in the Jovian radiation environment, it will be necessary to do the best possible optimization of its design to enable system architecture, shielding design, materials choices, and component selection to ensure performance while minimizing mass and cost. RASC offers a full complement of services from academic research to industrial production to perform the radiation testing and analysis that will be required for EJSM. The demands for high functionality and performance in the extreme Jovian environment suggest the need to build more sophisticated, custom hybrid systems. RASC can work in concert with system designers to conduct transport modeling throughout the design phase. RASC will work with EJSM designers to propose system layouts, synergistic subsystem choices, and materials options to enhance native shielding schemes such that the added shielding mass is as small as possible. Furthermore RASC analyses will enable a comprehensive shielding strategy by adding a shielding material only where it is necessary.

References

[1] K. Ketola, J. Chow, S. Nguyen, B. Harris, G. Casteel, E. Williams, S. Manson (2008) "TopAct-A New Software Tool for Construction of High Fidelity Radiation Transport Geometry Models, " 24th Aerospace Testing Seminar Proceedings.

[2] W. Chen, J. Oder, B. Vermeire, and H. J. Barnaby (2006) "Modeling Single Event Transients (SETs) with Linear Macro-models," in Single Event Effects, Long Beach, CA.

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ABSTRACT

IRRADIATION EQUIPMENT AND SERVICE

J L Shepherd and Associates manufactures a wide range of Category I Self-Contained and Category II Panoramic Co-60 irradiators designed to irradiate components/systems used in space environments in accordance with Mil-STD 883G Method 1019-7 and European Space Agency Test Method 22900. We also offer in-house irradiation service for instrumented components.

Category I Self-contained irradiators are available for Low Dose (ELDRS) testing at 10 $mRad_{Si}$/second, High Dose testing at 50-300 Rad_{Si}/second or for a combination of High and Low Dose testing.

Units are also available for Ultra-High Dose testing at 2,800 $Rads_{Si}$/second. Cavities are available to accommodate boards 10”x 10” or as large as 16” x 16” with irradiation tunnels 1 meter long for variable dose rates.

Category II panoramic irradiators with up to 48,000 Ci. Co-60 loadings are available to irradiate large components/systems.

For in-house testing we have available Model 484 Irradiators which accommodate boards to 10” x 10” for both High and Low Dose testing as well as a Hot Cell in which large assemblies may be irradiated and a Sr-90/Y-90 beam irradiator which delivers up to 600 R/hr high energy betas.

Institute for Space and Defense Electronics at Vanderbilt University
Contact:
Barry Templeton
2014 Broadway, Suite 200
Nashville, Tennessee 37203
615-322-3833
615-343-9550 Fax
www.isde.vanderbilt.edu

The Institute for Space and Defense Electronics (ISDE) at Vanderbilt University performs analysis, modeling, simulation and testing of radiation effects on electronics and develops radiation-hardened devices, integrated circuits, and electronic subsystems. ISDE was launched with support from the U.S. Navy SSPO and Draper Laboratory. ISDE currently supports the NASA Goddard Space Flight Center, NASA Marshall Space Flight Center, the Defense Threat Reduction Agency, the Air Force Office of Scientific Research, Arnold Engineering Development Center, ATK, Boeing/DARPA, BAE Systems, and other commercial companies and government agencies.

The Radiation Effects and Reliability (RER) Group at Vanderbilt University was established in 1987 and is the largest university-based radiation effects program in the world. The RER Group is actively involved in radiation effects and reliability research, testing, analysis, and other areas. In January 2003, Vanderbilt University established ISDE to extend the capabilities of the RER Group to serve government and commercial customers. There is close cooperation between the RER Group, ISDE, and ten professors on the electrical engineering and physics faculty who serve as ISDE Fellows.

The ISDE facility is located adjacent to the Vanderbilt University campus and provides a professional office environment conducive to engineering and project management activities. The Institute has full access to the University's laboratories and meeting facilities located on campus just a short walk away. The ISDE office is a secure, limited access facility, allowing only approved personnel to enter without an ISDE employee escort. ISDE is approved by the University to work with material controlled under ITAR and EAR regulations.

The mission of ISDE is to contribute to the design and analysis of radiation-hardened electronics, develop test methods and plans for assuring radiation hardness, radiation effects characterization and qualification testing, and the development of solutions to system-specific problems related to radiation effects. ISDE engineers help to identify radiation-related issues at the device, circuit, and subsystem/system levels, propose and implement design solutions, and devise and conduct radiation experiments.

ISDE uses an array of commercial and custom software tools for simulating radiation effects and designing integrated circuits, a high performance parallel computing cluster, several types of radiation sources, and extensive electrical characterization capability. ISDE and the RER Group have also developed many microelectronics test chips, including bulk silicon CMOS, silicon-on-insulator, and bipolar technologies.

ISDE has access to an extensive suite of test and characterization equipment for radiation-effect analysis, including an ARACOR 10-keV x-ray irradiator, two ^{137}Cs isotopic irradiators, and a 4-MeV proton source. ISDE engineers have extensive experience conducting single-event tests at facilities including Texas A&M, UC Berkeley, Brookhaven National Laboratory, Michigan State University, and Indiana University. Vanderbilt also has a Cooperative Research and Development Agreement (CRADA) with NAVSEA-Crane that provides access to a suite of radiation sources and a fully equipped parts analysis laboratory. An array of test equipment is available to facilitate the characterization of irradiated devices and ICs.

Vanderbilt's Advanced Computing Center for Research and Education (ACCRE) houses VAMPIRE, a 1200+ processor Beowulf cluster supercomputer used to execute several Technology Computer Aided Design (TCAD) suites and Vanderbilt's custom radiation transport codes.

One of ISDE's key software tools is MRED (Monte Carlo Radiative Energy Deposition), a custom radiation-transport code based on the Geant4 libraries developed by the high energy physics community. MRED is a framework for treating particle or ion energy deposition in semiconductors. The simulation software describing radiation interactions and transport in matter is a built-in Monte Carlo binary-collision code. The code is comprehensive in the treatment of all forms of radiation interacting with materials and provides interfaces for smooth operation with related programs that handle related tasks such as radiation transport, induced charge in semiconductor devices, or the analysis of circuit-level radiation effects. Space radiation environments are easily accommodated in MRED, as well as full solid-angle directionality of incident particle strikes. MRED is thoroughly calibrated to data and has a strong record of predicting both terrestrial and space experimental radiation results. Through support from NASA/MSFC and NASA/GSFC, ISDE has developed a web-based interface to MRED that allows access to the basic functionality of MRED. Through this interface, users are able to predict single event upset rates of electronic parts using MRED.

ISDE also has extensive experience in TCAD finite-element analysis of radiation effects in individual transistors and groups of transistors. These device simulations can be coupled to circuit and VHDL simulations of large electronic systems to evaluate the effects of single events on system performance. ISDE also has expertise in modeling the effects of total dose accumulation and displacement damage on individual parts and systems. ISDE has implemented radiation effects models into process design kits (PDKs) for several technologies to facilitate the efficient design of radiation hard electronics.

ISDE engineers work closely with customer technical staff throughout the radiation characterization and hardening efforts and throughout the design process. From technology identification, through design and test, and finally to documentation and qualification of rad-hard systems, ISDE and Vanderbilt provide a critical mass of aptitude, capabilities and experience for the implementation of rad-hard devices and systems

TOTAL IONIZING DOSE TESTING AT THE SCIENCE AND ENGINEERING GAMMA IRRADIATION TEST FACILITY

T.J. Shepherd[1], C.W. Meline[1]

[1]Defense Microelectronics Activity, 4234 54th Street, Building 620, McClellan, CA 95652-2100.

BACKGROUND:

The Science and Engineering Gamma Irradiation Test (SEGIT) Facility has been in operation since 1994, when it was part of McClellan Air Force Base (AFB). The Defense Microelectronics Activity (DMEA) was formed in 1997 under the Office of the Secretary of Defense (OSD) to address microelectronics obsolescence; the SEGIT Facility has been operated by DMEA since that time. DMEA is located in northern Sacramento, on the grounds of the former McClellan AFB (which closed in 2001).

FACILITIES:

The SEGIT Facility has two self-contained J.L. Shepherd & Associates Model 484 self-contained irradiators: the High Dose (HD) irradiator for high dose rate work, and the Low Dose (LD) irradiator for low dose rate testing. The HD irradiator has Co-60 sources; the LD irradiator has Co-60 and Cs-137 sources. Both irradiators have a 16" wide x 16" high x 40" long irradiation chamber, with multiple pass-thrus to route power/signal cables, etc. to Devices Under Test (DUTs). Each irradiator has its own Dose Enhancement Chamber (DEC) for compliance with ASTM E 1249, which reduces the usable size of DUTs to approximately 14" square x ~16" deep. Both irradiators are equipped with a GN_2 purge system to displace the ozone created during irradiation. The SEGIT Facility has its own test equipment (power supplies, multimeters, function generators, and oscilloscope); customers are able to bring in their own test equipment as well.

CAPABILITIES:

The SEGIT Facility has been accredited by the American Association for Laboratory Accreditation (A2LA) since 2001, and its Scope of Accreditation currently includes Test Method (TM) 1019 of MIL-STD-883 and -750**.** Dose rates currently attainable with the SEGIT Facility irradiator DECs are as follows: **HD irradiator: 1.75 to 36,000 rad(SiO_2)/minute**

LD irradiator: 0.24 to 25 rad(SiO_2)/minute (Co-60 source)

Testing to other standards (e.g., ESCC Basic Specification No. 22900) is also possible. For synergistic testing, Dewar Temperature Systems (DTSs) are available for use with the HD irradiator. Depending on the DTS used, the gamma radiation environment can be combined with temperature, vacuum and/or relative humidity to better simulate the real-world environment that DUTs will operate in.

Dosimetry is done with NIST-traceable, ISO/IEC 17025-calibrated ionization chambers. These chambers were specifically designed for the wide range of dose rates attainable within the SEGIT Facility irradiators.

MATURITY/EXPERIENCE:

The SEGIT Facility performs dozens of experiments every year for DoD, government and commercial customers. While the HD irradiator is utilized extensively for MIL-STD-883/-750 Test Method 1019 Condition A & C testing, the LD irradiator is optimized for Enhanced Low Dose Rate Sensitivity (ELDRS) testing per Condition D of MIL-STD-883 TM 1019.

WORKING WITH DMEA:

DoD and other government customers are able to work with DMEA using a Military Interdepartmental Purchase Request (MIPR) or similar funding vehicle. Commercial customers have the option of either setting up a Cooperative Research and Development Agreement (CRADA) directly with DMEA, or working with existing CRADA Collaborators to arrange/execute testing at the SEGIT Facility.

Defense Microelectronics Activity (DMEA) Science and Engineering Gamma Irradiation Test (SEGIT) Facility

4234 54th Street, Building 620
McClellan, CA 95652-2100
Cary Meline, Branch Chief
(916) 231-1596

ISO 17025 Accredited Laboratory
IEEE 1156.4 Compliant
EIA/TIE FOTP-64 Compliant

ASTM F1892-98 Compliant
MIL-STD-750, TM1019 Compliant
MIL-STD-883, TM1019 Compliant
ASTM E1614-94 Compliant

DMEA Irradiators

- High Dose J.L. Shepherd 81-22/484
  - Co-60 sources
  - 2.9 rad(SiO_2)/min to 145 krad(SiO_2)/min
  - 16"x16"x40" Custom 484 Tunnel
  - Screw-drive Automatic Cart
  - Dewar Temperature System I and II Capable
- Low Dose J.L. Shepherd 81-22/484
  - Co-60 and Cs-137 sources
  - 1.4 rad(SiO_2)/min to 87 rad(SiO_2)/min
  - 16"x16"x40" Custom 484 Tunnel

Synergistic Test Capabilities

- Installs inside High Dose Irradiator
- Dewar Temperature System I
  - -150 °C to +150 °C (±1°C)
  - 10-2 to 10-3 Torr Vacuum
  - 8.3" Inner Dia x 11" Deep Chamber
- Dewar Temperature System II
  - -150 °C to +150 °C (±1°C)
  - 10-3 to 10-6 Torr Vacuum (Controllable)
  - Rate Controllable to 100 °C/hr
  - 20% to 80% Humidity
  - 8.3" Inner Dia x 11" Deep Chamber

Design services

FEATURES AND CAPABILITIES

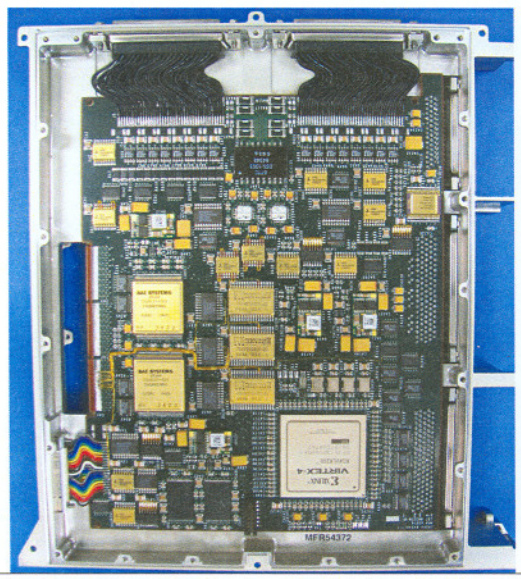
BAE Systems' integrated design team offers mission design services at any stage, from early architecture to testing. This team has a history of delivering high-quality design services, efficiently and within budget. With more than 500 computers in space, BAE Systems has the experience, expertise, facilities, and technology that it takes to deliver the best solution possible.

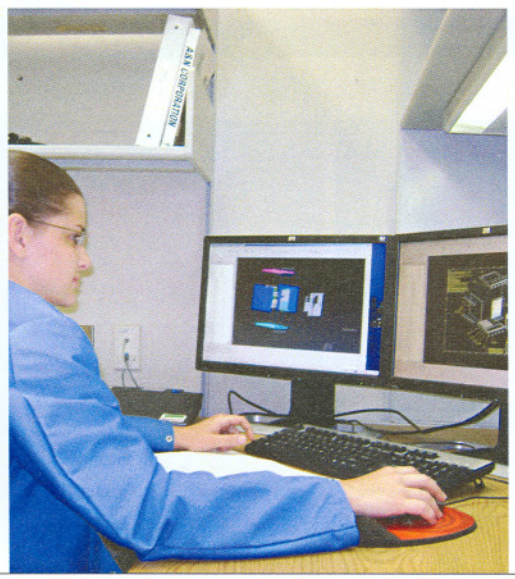
Architecture and algorithm development
- Map algorithm into space-suitable hardware
- Modeling to optimize power
- Trade-offs in implementation for enhanced radiation hardness
- Generation of hardware specifications
- Knowledge of future technology roadmaps

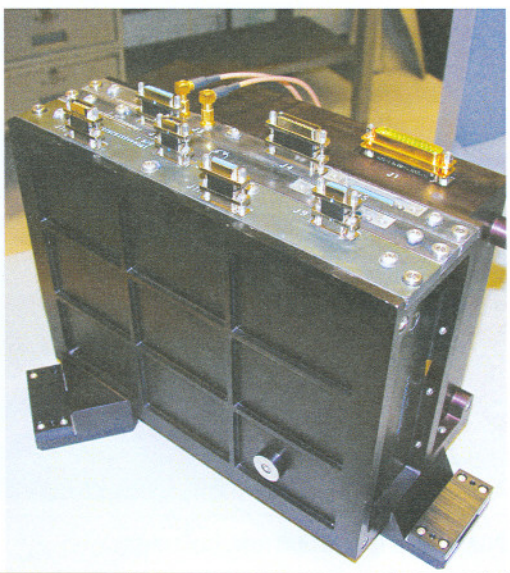
Logic design
- Box, card, ASIC, and FPGA specification
- Partitioning of design to enhance shielding, power distribution, and fault tolerance

Physical design
- Proprietary design libraries (low-power, mixed-signal, radiation-hardened)
- Mapping VHDL into appropriate technology and verifying timing, function and power

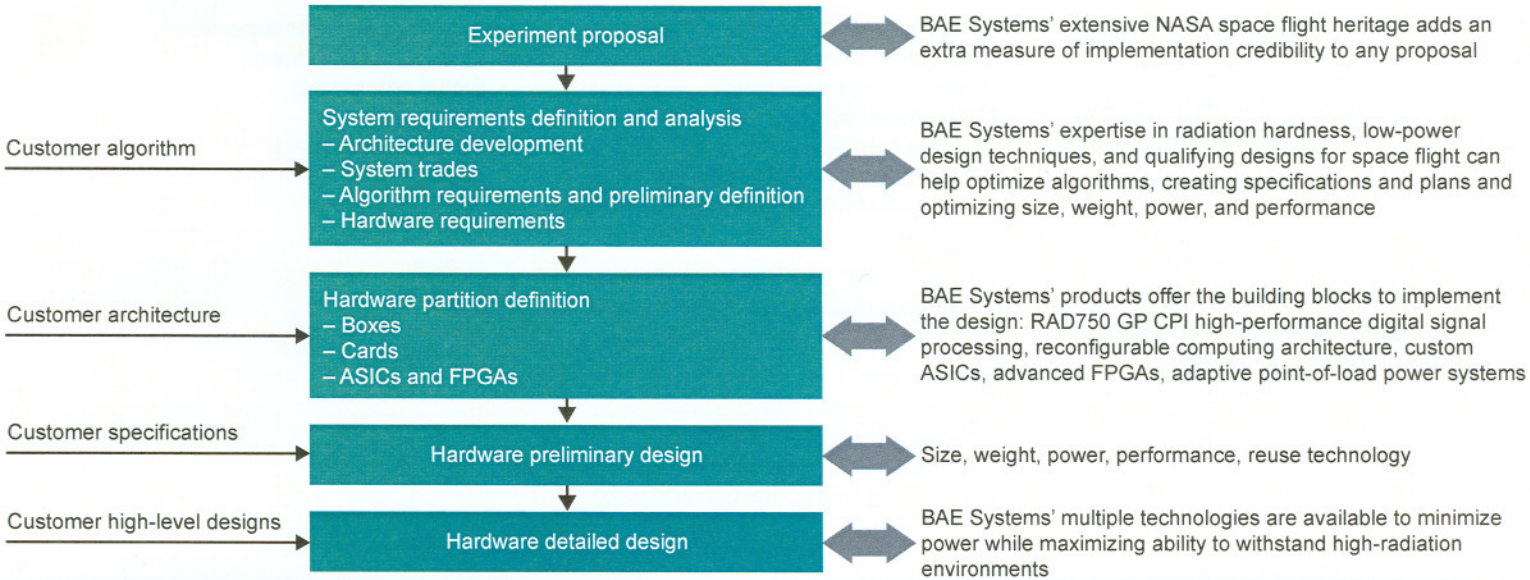
The design team has expertise in:
- Systems architecture
- Signal processing
- ASIC design
- Card and box design
- Mechanical
- Software
- Power
- Analog
- Reliability



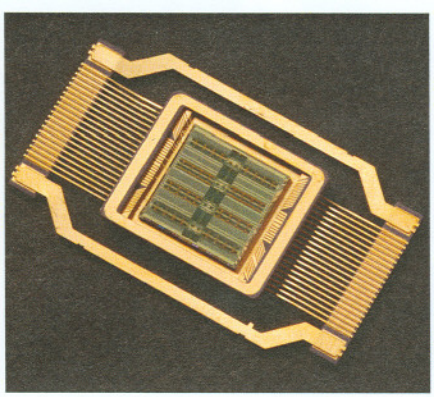
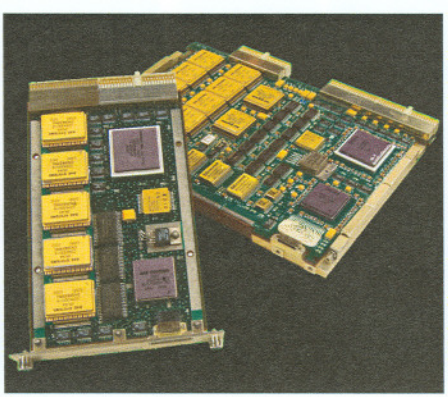




INTEGRATED DEVELOPMENT CYCLE



BAE Systems' integrated design team can help at any stage, from architecture to test and inspection

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Space material management

FEATURES AND CAPABILITIES

BAE Systems has a long history of delivering reliable space products. The company's highly qualified engineers are experienced in determining material screening needs based on mission requirements and have developed a customized material tracking system, called DataView, to track material availability and screening status and store data to demonstrate traceability and compliance.

The company's material management expertise includes:

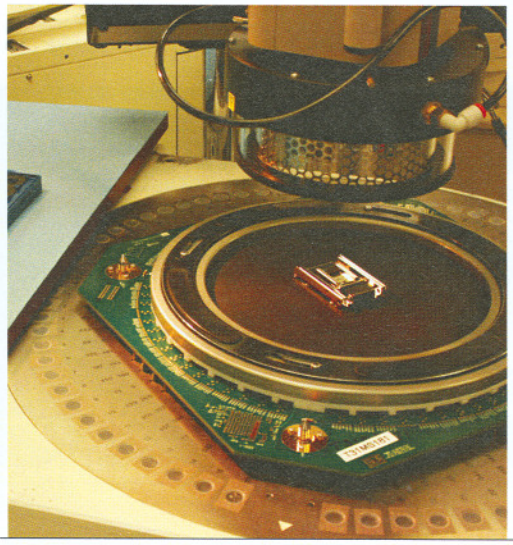
Determining required material screening based on mission requirements
- Compliance with Technical Operating Report requirements
- X-ray florescence testing
- Destructive physical analysis
- Enhanced low-dose rate effects
- Radiation lot acceptance testing

Executing required material screening
- X-ray florescence testing
- Destructive physical analysis
- Enhanced low-dose rate effects
- Radiation lot acceptance testing

Guaranteeing material quality
- Standard clausing and inspection at time of receipt
- Recommendations of alternatives for parts that have become obsolete
- Screening for counterfeit parts
- Government-Industry Data Exchange Program monitoring
- Quality conformance inspection
- Strategic supplier quality audits

Data review, management, and retention
- Analysis of test results
- Verifying completing of required screening
- Storing material data in a standard digital format for easy retrieval

Leveraging relationships with qualified space suppliers
- Strategic partnering



INTEGRATED MANUFACTURING CYCLE

Customer specifications

Sample BAE Systems capabilities
- Mission-specific material screening
- Guaranteed material quality
- Data review, management, and retention

Space material management

BAE Systems' expertise in determining material screening needs based on mission requirements has yielded excellent material reliability.

Customer designs

Sample BAE Systems capabilities
- QML ASIC fabrication line

Wafer fabrication

BAE Systems' expertise in radiation hardness, low-power design techniques, and qualifying designs for space flight can assist in optimizing algorithms, creating specifications and plans, and estimating size, weight, power, and performance.

Customer designs

Sample BAE Systems capabilities
- QPL packaging line

Component manufacturing

BAE Systems products offer the building blocks to implement the design — e.g., RAD750 GP CPU, high-performance DSP, reconfigurable computing architecture, custom ASICs, advanced FPGAs, adaptive point-of-load power systems.

Customer designs

Sample BAE Systems capabilities
- Space card assembly line

Space circuit card manufacturing

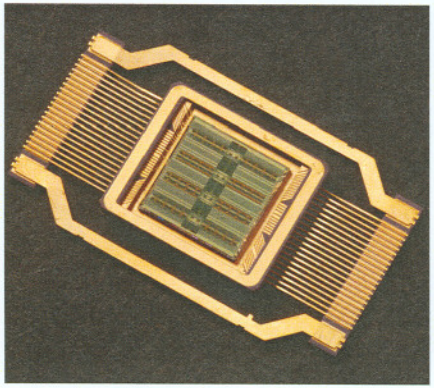
BAE Systems' semiconductor manufacturing line and flight card assembly line are co-located within the design facility, allowing interactive optimization of design, schedule, and cost criteria.

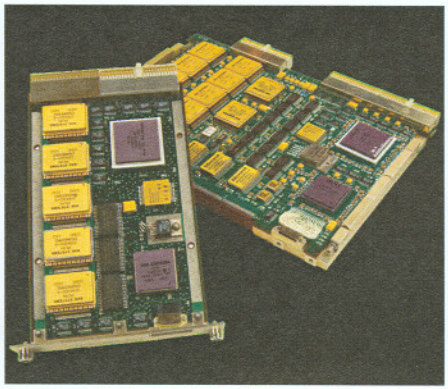
Customer designs

Sample BAE Systems capabilities
- Environmental test facilities

Testing

Flight-certified test equipment and facilities accommodate test of materials and assemblies at all stages of manufacturing.





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Circuit card assembly

FEATURES AND CAPABILITIES

BAE Systems has more than 30 years of experience assembling circuit cards for a wide range of highly complex electronic products. The company maintains highly flexible procurement, qualification, and assembly operations and, with more than 500 computers in space, has the expertise, experience, and technology to service almost any assembly need. BAE Systems processes and products are qualified to J-STD-001 Class 3, IPC-610 Class 3, NASA-STD-8739.3 and other customer standards.

Leading-edge processes and equipment to cover circuit card assemblies from component preparation through testing and conformal coating including:

- Lead-forming and enhancement
- PROM programming
- Automated surface-mount and through-hole soldering capabilities
- Automated optical and X-ray inspection
- Core bonding
- Automated adhesive dispense for component bonding
- Flying probe, ICT, and functional testing
- Precision hot-gas rework
- Conformal coating: acrylic, urethane, and Parylene
- Automated spray coating
- Comprehensive assembly, inspection, and test strategy
- Dedicated new-product Introduction team.
- Rapid prototyping (as quickly as two weeks)
- Sustaining product support
- Quick response to engineering and design changes
- Focus on continuous improvement using —
  - Demand-flow technology
  - Visual management systems
  - Flexible manufacturing layout
  - An empowered work force

INTEGRATED MANUFACTURING CYCLE

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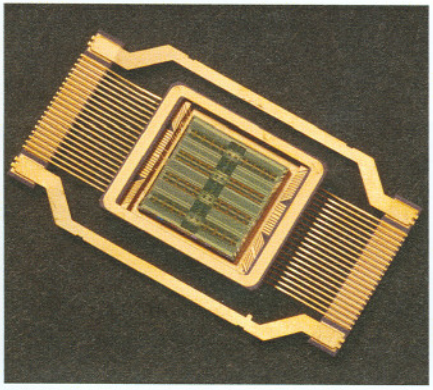
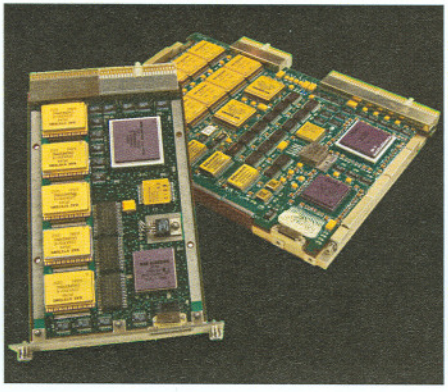
Flight-certified test equipment and facilities accommodate test of materials and assemblies at all stages of manufacturing.





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A RADIATION HARDENED HIGH PERFORMANCE SYSTEM-ON-A-CHIP (BRE440)

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Abstract

With a proven history of delivering space flight hardware avionics and instrument electronics, Broad Reach Engineering has developed a general purpose processor for space applications. Although a number of solutions exist for computing platforms in space, none of the solutions simultaneously address the need for high performance, high reliability, low power, low mass and implementation simplicity while maintaining compatibility with existing software and providing a very high level of radiation performance. Broad Reach Engineering has addressed this issue by developing a single system-on-a-chip solution, the BRE440, which provides a processing core and a number of common peripheral functions. The PowerPC™ processor based system is built on the well characterized Honeywell HX5000 150nm SOI process and represents a significant advancement in functionality and integration for radiation hardened processing platforms. *(The PowerPC name is a registered trademark of IBM and used under license there from.)*

Introduction

The BRE440 is the result of years of design and development based on the simple approach of taking known good intellectual property (IP) modules and coupling that with known good fabrication techniques. Architectural studies included a number of available processor cores and on-chip busses. The PowerPC 440 core was chosen for superior performance, availability, superior IP quality and access to a variety of peripheral components ready for integration with the core.

The design flow for the ASIC started with register transfer level (RTL) descriptions of the IP modules. The IP modules were integrated, simulated and then synthesized to the target silicon library. The physical layout was customized for the ASIC using a typical design approach for a standard cell library targeting the Honeywell HX5000 ASIC library.

Radiation Hardness

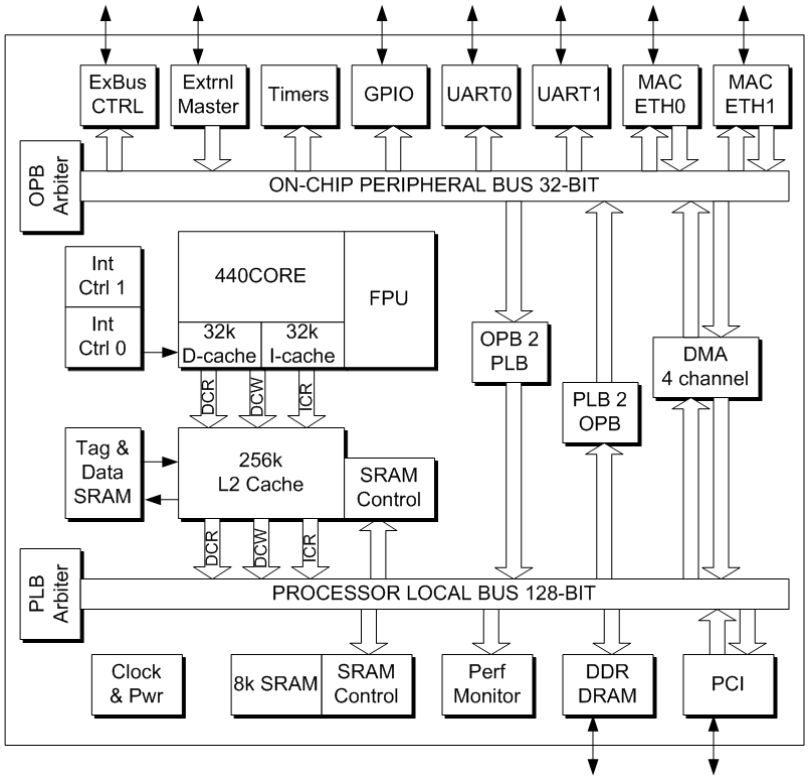
The HX5000 technology is QML qualified and provides a number of advantages over bulk CMOS. SOI devices are fabricated in a thin film of silicon on top of a buried oxide insulator on top of a standard silicon wafer. SOI has a proven history of resistance to SEU and immunity to SEL. These advantages simplify fabrication steps, improve density and reduce a variety of parasitic capacitances. SOI also supports lower threshold voltages, compared to bulk CMOS, which equate to higher performance. Characteristics of the BRE440 are given in the following table.

Total Ionizing Dose > 1 MRad (Si)		Core Supply Voltage = 1.8 V +/- 0.15 V
Metal Layers = 6		Drawn Gate Length = 0.15 µm
Raw Gate Density = 94K gates / sq. mm		Total RAM Cells = 1,504,768
Soft Error Rate*	SEU2 cells < 3E-10 SEU4 cells < 7E-14 SEUT cells < 1E-11 Singleport SRAM < 1E-10 Dualport SRAM < 1E-12	Flip Flop Count: SEU2 register =14,055 SEU4 register = 54 SEUT register = 181,734
Register Upset Rate*	@ 133 MHz < 9.278 E-5 @ 83 MHz < 6.049 E-5 errors/day @ 0 MHz < 6.897 E-6 errors/day	RAM Cell Upset Rate* 3.361E-5 (5% write cycle ratio)
*(Adams 90% worst case environment, static clock conditions)		

Chip Features

The PowerPC 440 core is a widespread processor with an abundance of IBM and third party software support and is compliant with *Book E* of the Enhanced PowerPC Architecture. The BRE440 utilizes the popular 440 core with a rich mix of peripherals by implementing IBM's high speed CoreConnect™ technology. The PowerPC 440 is a dual-issue, superscalar, 32-bit RISC CPU core providing 2.0 DMIPS/MHz performance. Highlights of the BRE440 architecture include a double precision floating point unit and an on-chip 256kByte RAM used for L2 cache or general purpose memory.

Other features include a four channel scatter/gather direct memory access controller, two 10/100 ethernet media access controllers, two programmable UARTs, a double data rate DRAM controller and a variety of timers and general purpose input/outputs. A PCI bridge provides data movement between the internal processor bus and an external PCI bus. The PCI bridge can also act as the system controller. A separate 32-bit address, 32-bit data external bus provides access to memories or other external peripheral chips. A block diagram of the BRE440 chip is shown below.



Typical power consumption is dependent on software activity but measures ~2.5 Watts at 83MHz and ~3.5 Watts at 133MHz. The BRE440 is packaged in a hermetic 566 pin ceramic column grid array.

Project Status

The first engineering units of the BRE440 were completed mid 2009. The units were integrated on single board computer test platforms and are currently undergoing test and validation. The first 40 flight units were completed in early 2010 with high reliability screening procedures consistent with Class S requirements. Initial testing demonstrated proper operation of all of the testable blocks in the BRE440. The first flight is expected in 2011.

Summary

The BRE440 system-on-a-chip is built specifically to operate in severe radiation and other harsh environments. The BRE440 represents a new class of processors available to the rad-hard/space industry. The first of its kind, the BRE440 enables a new generation of systems by providing a higher level of integration and functionality.

BALL AEROSPACE RADIATION CAPABILITIES

N.E. Nickles, P.D. Atcheson, R.R. Demara, P.G. Warren, J.E. Hubbs

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For 50 years, Ball Aerospace has played a major role in the development of advanced spacecraft and instrumentation for scientific pursuits. We offer all the services and expertise necessary to take challenging mission requirements and develop them into robust precision flight hardware.

1. Europa Star Tracker (NASA/JPL Contract 1219580)

Ball Aerospace conducted a detailed Europa radiation-hardened star tracker study for Jet Propulsion Laboratory (JPL) during 2000 and 2001, completing a preliminary design review (PDR) in early 2001. Subsequently, the Europa program was terminated. As a result of this and other work, Ball Aerospace is highly qualified to support future missions to the outer planets, including the most challenging radiation locations. The study provided important results in two areas; 1) design concepts that can provide reliable star tracking in the Jovian environment and 2) investigation of the available mechanical, optical and electronics materials suitable for fabrication of a tracker and methods that can be used to provide shielding and other mitigation for an electro-optics instrument that will be used in a demanding environment. The latter information is of general interest to instrument designers. In subsequent work for NASA, JPL and the Department of Defense (DOD), Ball Aerospace has continued the process of providing solutions for the outer planets environment by presenting solutions for low mass shielding, introduction of new electronics architectures (including rad hard ASIC processors and CMOS APS focal planes) and continued testing of commercial electronics products.

Maturity Level

Ball Aerospace's assessment is that its design for the Europa tracker reached technology readiness level (TRL) 5-6 (depending on the element of technology being considered) during the study. Nonetheless, Ball Aerospace is starting from a leadership position and stands ready to assist NASA with this challenging assignment.

2. Radiation Analysis Group

The radiation engineers at Ball Aerospace have been modeling the effects of the Jupiter system for the past decade. Ball Aerospace worked closely with JPL as the team grappled with the unique issues faced during the early Europa Orbiter work. Ball Aerospace has remained at the forefront of work on Jupiter's radiation effects by participating in nearly all of the proposals for Jovian missions (e.g., Europa Orbiter, Inside Jupiter, Jupiter Icy Moons Orbiter [JIMO], and Juno). The Ball Aerospace radiation group is comprised of 11 full-time employees with over 150 years of combined experience, including three PhDs.

Ball Aerospace pioneered the radiation testing of low-intensity, low-light solar arrays for Jupiter with high-energy (100 MeV) electrons to properly simulate the untested aspects of the environment. Ball Aerospace also remains committed to state-of-the-art radiation modeling. On internal R&D funds, we developed an analysis code that combines forward Monte Carlo radiation transport (Geant4) with software for specific imager functionality in order to generate realistic scenes of radiation hit noise which uniquely addresses the high-energy Jovian background. Ball Aerospace has also developed the RadSAT™ utility which allows boxes or entire space vehicles to trade the impacts of mass, cost, and schedule against a variety of mitigation strategies (e.g., part replacement, box-level versus spot shielding, lot testing, circuit hardening, etc) in any radiation environment.

3. Detector Technology Center

The Ball Aerospace Detector Technology Center (DTC) has expertise in radiation-hardened detectors and provides expertise and services for radiation-hard detectors and focal plane arrays for defense, commercial and civil programs. The DTC offers customers a photons-to-bits detector solution with detector experts in each of five sub-areas:

- detector design and development
- focal plane array packaging design and development
- focal plane electronics
- focal plane integration and test
- focal plane array systems engineering.

The 14,600 ft² center in Boulder, CO was constructed in 2006, including 1,804 ft² of Class 5 clean rooms and 1,832 ft² of Class 7 clean rooms. The DTC staff varies depending on the requirements of on-going programs. Typically the DTC is staffed with 75 people, 12 of whom hold doctorates. This staff has experts in all areas of detector engineering. The DTC is led by a dedicated leadership team averaging 22 years of aerospace and detector experience.

The DTC employs state-of-the art methods to produce detectors and focal plane electronics designs for the anticipated radiation environment. Custom modeling software including the TRAPPER model of charge transfer efficiency and the Monte Carlo simulation tool, STAM allows the simulation of detector performance during operation in transient environment and hot pixel population growth.

4. Ball Aerospace IRREL Team

In 1987, the InfraRed Radiation Effects Laboratory (IRREL) was established at what is now the Air Force Research Laboratory (AFRL) and tasked it with (1) the independent characterization of the radiometric and radiation hardness performance of visible and infrared focal plane arrays (FPA) developed under various government programs, and (2) the development of innovative techniques to advance the state-of-the-art in FPA characterization to allow program requirements to be met.

Ball Aerospace has operated the IRREL since its inception. The Ball Aerospace IRREL team brings an in-depth knowledge of the IRREL and has established a track record of responsiveness to the IRREL's requirements, delivery of high quality data products and continued commitment to customer satisfaction.

Over the past 20 years, the current IRREL staff has written over 30 technical reports documenting both clear and radiation characterizations of FPAs, presented over 40 papers at radiation conferences IRIS/MSS, HEART, SPIE), and have had six publications in refereed journals. They have characterized FPAs in gamma, neutron, and proton environments, and under high dose rate conditions (Flash X-Ray). The techniques and procedures developed by the Ball IRREL team during these experiments have established the state-of-the-art in FPA characterization techniques and have become the industry standards for characterizing FPAs in both clear and radiation environments.

The IRREL test system, used to provide performance testing on readout integrated circuits (ROIC) as well as visible and infrared FPAs in a variety of nuclear environments, is portable and was specifically designed to interface to nuclear radiation facilities around the country. The test system has been used to perform radiation characterization testing on both analog and digital FPAs, ranging in size from 64x20 to 8Kx8K, and data rates up to 80 MHz. The Ball Aerospace IRREL team have used this system for total ionizing dose (TID) and debris gamma tests at the AFRL ^{60}Co radiation facility at Kirtland Air Force Base (AFB) NM, Flash X-Ray tests using the Febetron at Kirtland AFB, the Pulserad 1150 at L-3 Communications Pulse Sciences (formerly Physics International) in San Leandro, CA, as well as the former Blackjack 3 facility at Maxwell Laboratories in San Diego, CA. Electron beam testing has been performed at Hill AFB's Survivability and Vulnerability Integration Center outside Ogden, UT. Neutron fluence testing has been performed at the Fast Burst Reactor on White Sands Missile Range, NM, and proton fluence tests are performed three to four times a year at Crocker Nuclear Laboratory on the campus of the University of California at Davis.

Z- Shielding: an electronics enclosure demo and fiber metal laminate evaluation

D. Laurence Thomsen III[1], Francis F. Badavi[2], Roberto J. Cano[1], Brian J. Jensen[1], Stephen J. Hales[1], Joel A. Alexa[3], and Robert F. Hodson[4]

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Abstract

The incorporation of high density metals into spacecraft electronic enclosures and spot shielding have been utilized to increase the radiation shielding performance versus weight. The Space 104 is a conduction cooled aluminum stackable enclosure for space avionics based on the PCI-104 form factor used for the Z-shielding demonstration. Preliminary studies have been performed to incorporate the Z-shielding onto 100 mil Space-104 electronic enclosure aluminum endcaps by affixing high density tantalum on the aluminum endcap top surface and casting low density engineering polymer coating on the aluminum endcap underneath. This high-Z, low-Z grading using the Space-104 endcaps has been modeled for radiation performance and has shown a reduction of radiation exposure to approximately 5500 rad/day silicon (ref. 105 day Europa mission fluence spectra) for each endcap. In addition to traditional metal sheeting methods for radiation shielding, evaluations of fiber metal laminates have been done to explore the feasibility of incorporating shielding into fabrics and shaped laminates. These fabrics and resulting laminates may demonstrate a utility in non-traditional shielding arrangements, designs, and/or structures. Carbon fiber fabrics that have been plasma spray coated with various metals have been prepared for the buildup of Z-grading. These hybrid carbon/ metal fabrics have been demonstrated to be amenable for out-of-autoclave, vacuum assisted resin transfer molding (VARTM) processing. This Z-shielding approach with fabrics has the potential to build spot shields and cable shields in areas where shielding can improve instrumentation performance and data transfer. The incorporation of engineering resins into Z-shielding and coating applications makes evaluation of preliminary resistivity measurements and surface energies important for charge dissipation performance and adhesion, especially when fillers are added to improve charge dissipation properties. Both Z-shielding approaches have the potential to increase the radiation shielding effectiveness as a function of weight with a broad range of applications based on material processes created from sheet or fiber metal laminates.

30 Gb/s Radiation Hard SERDES

Vladimir Katzman, Vladimir Bratov, Jeb Binkley, Armando Otero

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ABSTRACT for the Europa Jupiter System Mission Instrument Workshop.

Current and future near-Earth and deep space exploration programs undertaken by international space community requires the development of robust, intra-spacecraft, high speed, serial data transfer utilizing electrical or optical interconnects that are compliant with an open system architecture. The developed modules must be reconfigurable, fault-tolerant, and have the ability to operate effectively for long periods of time in harsh environmental conditions. Existing wired data transfer systems based on state-off-the-art (SOA) electrical serial data transfer protocols or passive backplanes are slow, power hungry, and poorly reconfigurable. They provide low speed data link solutions, limited expandability, and a low level of tolerance to radiation effects including total ionizing dose (TID) and single-event effects (SEEs), which pose as harmful threats to modern sub-micron electronics.

The majority of spacecraft electronics require integrated circuits (ICs) with a certain level of radiation tolerance depending on the specific mission. Current trends in NASA, the military, and commercial airspace applications favor the integration of commercial off-the-shelf (COTS) parts into avionic equipment. However, SOA COTS electronics usually fail to meet both SEU (single-event upset) and SEE requirements. Space Community is therefore looking for novel, radiation-hardened (RH) application-specific ICs (ASICs) and systems-on-chips (SOCs) that utilize RH-by-design (RHBD) and RH-by-architecture (RHBA) techniques to use in their satellite and aircraft data processing and interconnect systems.

Space plug-and-play avionics (SPA) is an emerging technology that can alleviate serial data interconnect shortcomings in NASA and DOD present day solutions. It is based on a switching fabric (SF) active backplane architecture with robust high-speed serial interfaces. Electrical and/or optical transponders operating with Space Wire (SW), optical SW (SW-Fiber), Fire Wire (FW), or Ethernet/Gigabit Ethernet (ETN) protocols are required to support the associated high-speed data interconnects.

Over last decade ADSANTEC had developed variety of radiation hard by design technique, which had been proven through radiation test. ADSANTEC became a qualified supplier for Boeing and Lockheed Martin. On March 30 2010 ADSANTEC was granted US Patent No **7,688,112** Anti-SEE protection techniques for high-speed ICs with a current-switching architecture, for Protection against anti single event effects associated with strikes of energetic particles is provided in current-mode logic (CML) or similar integrated circuits (ICs) using a current-switching architecture. ADSANTEC has more than 50 high speed space tolerant parts, which can be easealy integrated on a single chip platform, utilizing our libraries of rad hard proven cells in Silicon CMOS and BiCMOS SiGe processes. All parts are manufactured in US.

Founded in 2002 ADSANTEC has more than 15 employee and more than 80 space and commercial ASICs.

ADSANTEC sells commercial ASICs worldwide, including US, Japan, Germany, France, etc. Space ASICs were sold to qualified customers inside US.

High Speed Space Qualified SERDES was delivered to NASA and will be used in several NASA missions. The die was manufactured at Tower Jazz Semiconductors, utilizing SBC 18 HX SiGe process, the surface mount package was developed by Kyocera America Inc. SERDES qualification and assembly was performed by Teledyne Microelectronics at Los Angeles, CA. Space Qualified SERDES are available for delivery with terms 6 month ARO.

EUROPA SURFACE ELEMENT PENETRATORS

R.A.Gowen[1] on behalf of Penetrator Consortium

[1]*Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey RH5 6NT, U.K.*

Abstract

A poster which provides an update on kinetic penetrators proposed as surface element for Europa will be presented.

Such penetrators would provide a significant science contribution beyond orbital instruments, for which there is considerable international interest in their potential inclusion in the mission, and would have significant architectural and resource implications on the mission.

Outcomes of the recent ESA system study will be presented which included the penetrator descent system, and penetrator shell and subsystems for a model payload. Europan impact sites and materials were studied, and appropriate technologies and risk items identified, and required resources determined.

Progress of candidate instruments will also be presented.

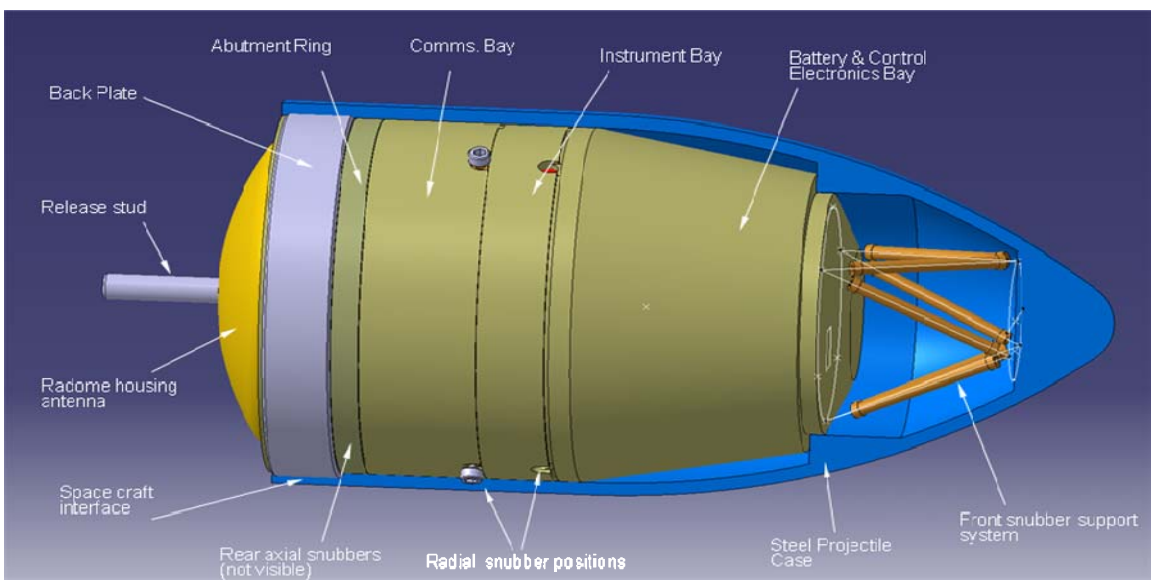

Figure 1: Europan Penetrator design

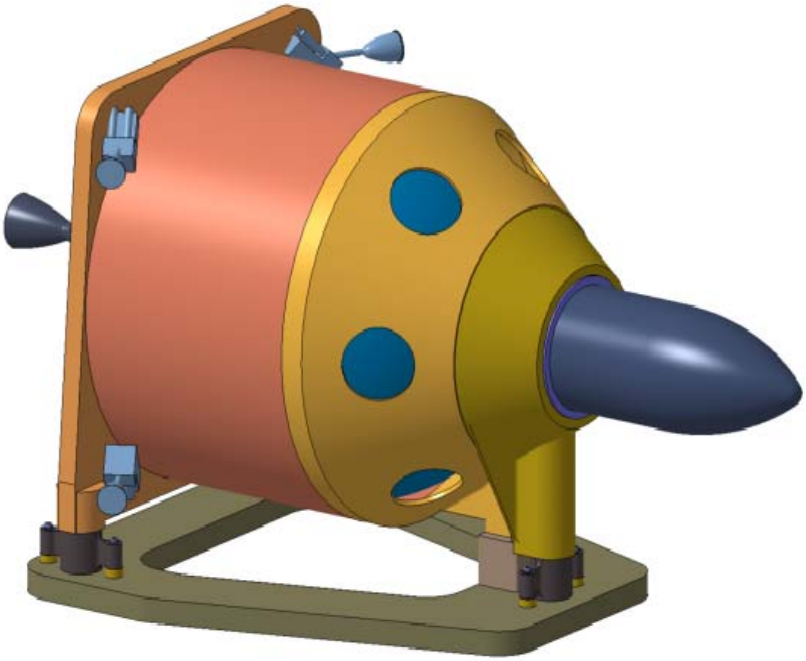

Figure 2: Europan Penetrator Descent Module (monopropellant delivery system) and spacecraft attachment plate (bottom) *[Design by Astrium Ltd.]*

SPEX Spectropolarimeter design: a first look at EJSM thermal and radiation environement

F.Snik[1], T.Karalidi[2], J.H.H.Rietjens[2], D.M.Stam[2] , J.M. Smit[2], C.U.Keller[1], A.L. Verlaan[3], E.C. Laan[3], R.Voors[4], K.Wieringa[5], S.G.Moon[6]

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Abstract
The optical elements that enable polarimetric measurements with our spectropolarimeter SPEX have been analyzed for their temperature sensitivity and for their susceptibility to high energy particle radiation. By using a composite of two birefringent materials, the retarder component is made to be a-thermal. The residual thermal behavior of the composite is measured and compared with its theoretical temperature dependence. High energy particle radiation encountered in the Jovian system may induce changes in transmission and refractive indices of the polarimetric optics. The possible loss in accuracy and sensitivity is assessed using our SPEX instrument simulator, in preparation of radiation tests.

SPEX spectropolarimeter
SPEX (Spectropolarimeter for Planetary EXploration) is an innovative, compact instrument developed for spectropolarimetry. SPEX is capable of full linear spectropolarimetry by encoding the degree and angle of linear polarization of the observed light in a sinusoidal modulation of the intensity spectrum by the polarimetric encoder optics. The polarimetric encoder optics comprise an achromatic quarter-wave retarder, an a-thermal multiple-order retarder and a polarizing beam-splitter in the entrance pupil [1]. A single measured flux spectrum thus provides the spectral dependence of the degree and angle of linear polarization. Polarimetry of scattered sunlight has proven to be an excellent tool to study the microphysical properties (size, shape, composition) of aerosol and/or cloud particles in planetary atmospheres and/or of surface particles [2],[3]. The current design of SPEX is tailored to a low circular orbit at fixed height above a planet or moon, compatible with the circular phases of the EJSM JGO and JEO: a compact module with nine apertures to simultaneously measure flux spectra from 400 to 800 nm, in different viewing directions along the flight direction, including two limb viewing directions (note that a design with a single, scanning aperture is also possible). The instrument is currently being prototyped in a Dutch collaboration under national funding. A cross section of the instrument design is shown in Figure 1.

Technology Development Activities
High energy radiation: SPEX' critical technologies with respect to the Jovian radiation environment are the detector at the focal plane, the electronics, and the polarimetric encoder optics, all of which are potentially vulnerable to high energy particle radiation. The polarimetric encoder optics are unique to SPEX and therefore currently under scrutiny to evaluate their radiation tolerance. Using our detailed instrument model we will present an assessment of the possible impact of radiation on transmission and changes in birefringence/refractive indices, discuss the tolerance of the design with respect to such changes, and discuss possible mitigation strategies.

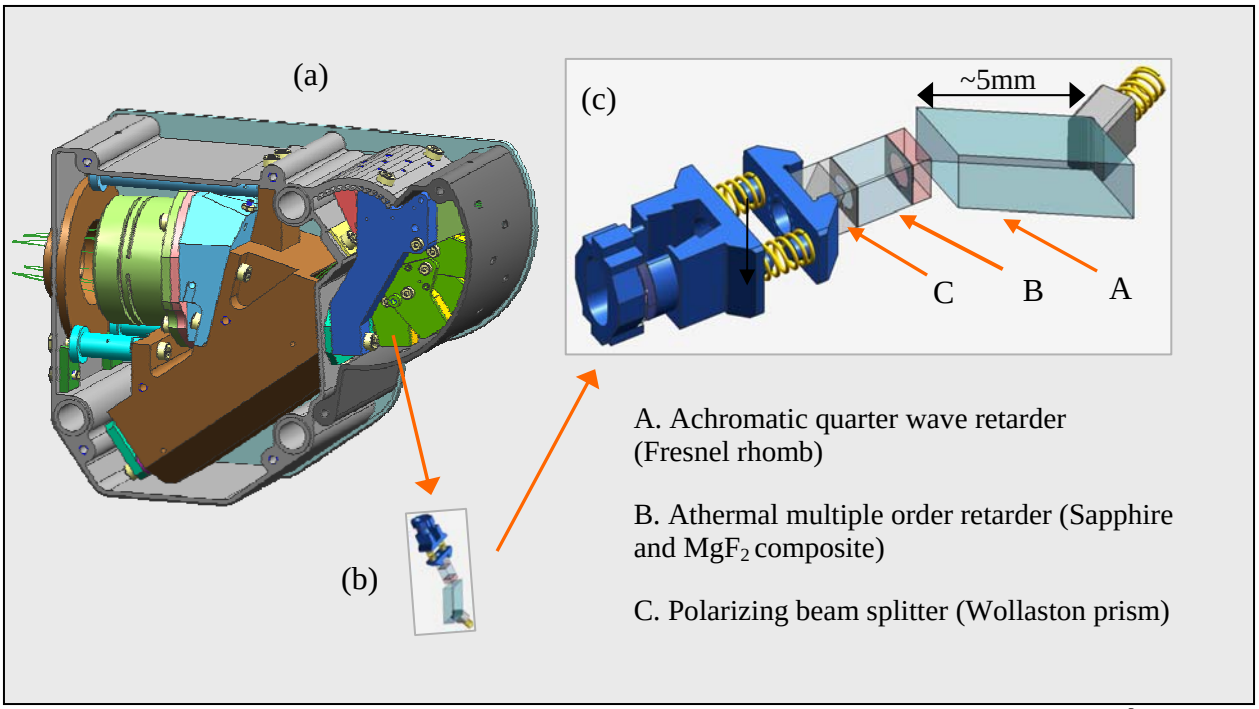

Figure 1: SPEX Design. Left, (a): Opto-mechanical design. The dimensions of this design are 15 x 12 x 6 cm^3 and the mass is 0.98 kg (excluding detector and electronics). There are nine apertures providing multi-viewing angle capability for collection of scattered light from nine different viewing directions. Behind each aperture is a setup of polarizing encoder optics (b) for modulating the flux spectrum. The modulated spectra are imaged onto a single spectrometer slit. The inset (c) shows the opto-mechanical design of the polarizing optical encoder units which are mounted in separate elements (credit: Mecon).

Temperature environment. Another point of interest is the potential susceptibility of the SPEX design to temperature fluctuations. The intrinsic temperature dependence of the birefringent elements of the polarimeter encoder optics would, without special measures, result in unacceptable systematic errors in the polarimetric measurements. By using a composite of two carefully selected birefringent materials, Sapphire and Magnesium Fluoride, which have counteracting temperature dependencies, an a-thermal retarder can be manufactured [1]. We present the residual thermal behavior of the composite as measured over SPEX' spectral range and compare it with its theoretical temperature dependence.

References

[1] Snik, F, Karalidi, T, Keller, C.H., Baker A.B. et al. (2009) Spectral modulation for full linear polarimetry, *Appl.Opticss.*, 48, no.7, 1337-1346.
[2] Hansen, J. E.; Travis, L. D., Light scattering in planetary atmospheres, *Space Scie. Revs.*, Vol. 16, pp. 527-610 (1974)
[3] Mishchenko, M. I.; Travis, L. D., Satellite retrieval of aerosol properties over the ocean using polarization as well as intensity of reflected sunlight, J. Geophys. Res., Vol. 102, pp. 16989-17014 (1997)

Natural radio emission of Jupiter as interferences for radar investigations of the icy satellites of Jupiter

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Abstract

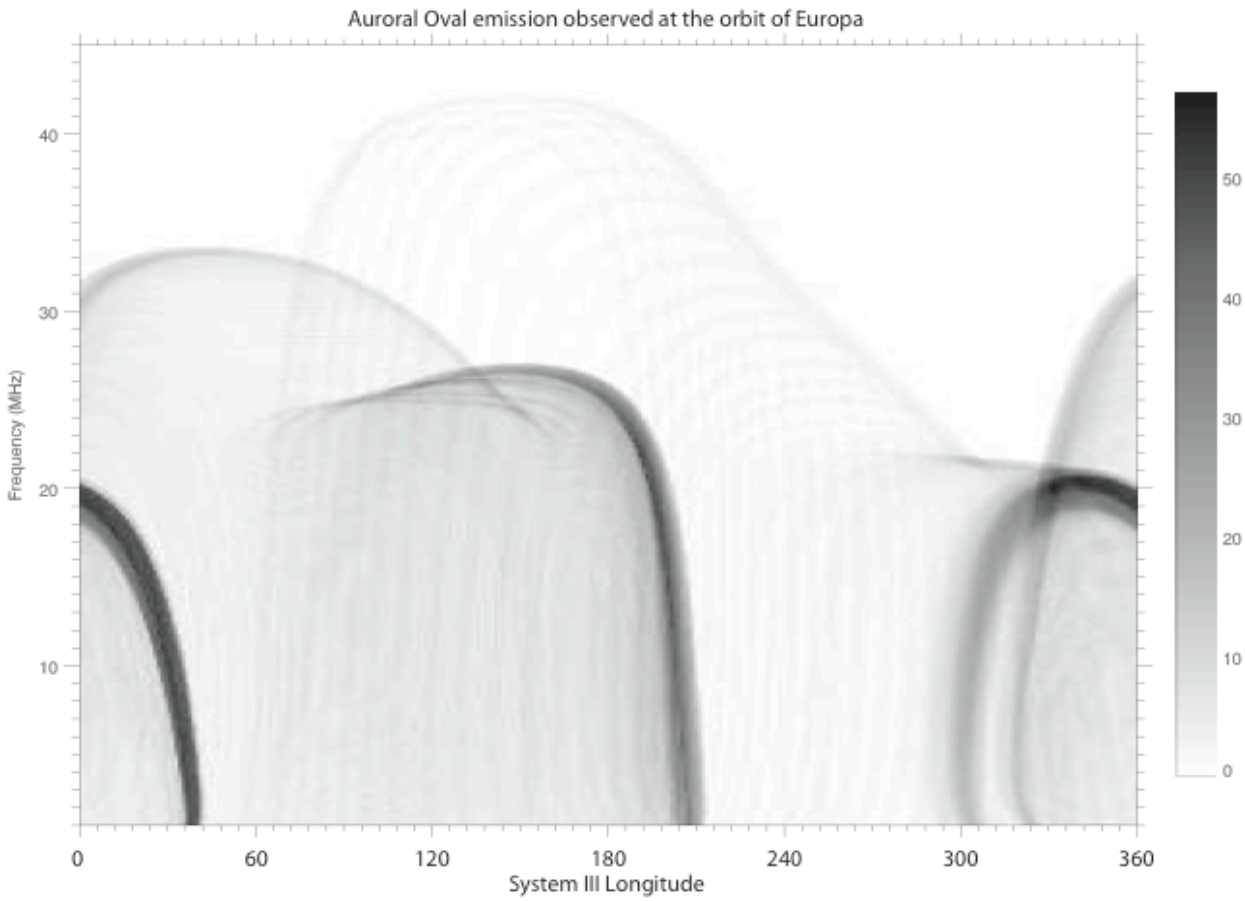
Radar instruments are part of the core payload of the two Europa Jupiter System Mission (EJSM) spacecraft: NASA- led Jupiter Europa Orbiter (JEO) and ESA-led Jupiter Ganymede Orbiter (JGO). At this point of the project, several frequency bands are foreseen for radar studies between 5MHz and 50MHz. While the high frequencies (above ~40 MHz) are clean bands since natural jovian radio emissions show a high frequency cutoff at about 40 MHz, lower frequencies are right in the middle of the intense decametric (DAM) radio emissions. We present a review of spectral intensity, variability and sources of these radio emissions. As the radio emission are beamed, it is possible to model the visibility of the radio emissions, as seen from the vicinity of Europa or Ganymede. We have investigated Io-related radio emissions as well as radio emissions related to the auroral oval. One result from these simulations is that some portion of the orbit of Europa is clean from Non-Io DAM emissions above 22 MHz. We also review the radiation belts synchrotron emission characteristics. This study clearly shows that a deep understanding of the natural radio emissions at Jupiter is necessary to prepare the future EJSM radar instrumentation.

In the frame of the future ESA-NASA EJSM (Europa Jupiter System Mission), currently in competition with two other missions, instrumental studies have been initiated by ESA to evaluate the technical feasibility and science objectives of the different instrumental packages. The EJSM/Laplace is composed of two spacecraft: NASA-led JEO (Jupiter Europa Orbiter) and ESA-led JGO (Jupiter Ganymede Orbiter). The study of sub-surface layers of Europa and Ganymede is clearly one of the first science objectives of the space mission. Unfortunately, the radio environment of Jupiter is dominated by strong natural radio emissions, which will interfere with radar measurements near Europa or Ganymede.

The jovian radio emissions were discovered by Burke and Franklin in 1955 [1]. Since then, decades of ground based and space based observations provided a good knowledge of the characteristics of these emissions. Ground based observations are limited by the ionospheric cutoff, which reflects out waves with frequencies lower than 10 MHz. Space based observations are usually limited at high frequencies because of the limited resources available on space missions. The jovian radio spectrum is composed of several components [2] that will be reviewed in this paper. These radio emissions dominate the galactic background, which is usually the only source of noise for planetary radar measurements.

The radar instrumentation that is developed for the EJSM mission is foreseen to transmit at frequencies ranging between 5 MHz to 50 MHz. This frequency range can be split into two ranges at ~40 MHz. Below that limit, the radio spectrum is dominated by very intense and sporadic cyclotron radio emissions with sources located along high latitude field lines, close to the planet. Special attention shall be placed on

the fine structures of these radio emissions, which are comparable to that of the radar chirps. At higher frequencies, the radio noise will be the combination of the galactic background and the synchrotron radiation emitted by the jovian radiation belts.



Modeled visibility (using SERPE [3]) of the Io-DAM radio emission as seen from the orbit of Europa as a function of frequency and jovian longitude. This figure shows the clean frequency ranges for each longitude of the system III.

In this paper, we will first review the different natural sources of radio interferences. In a second section, the flux density of these radio waves is compared to the predicted signal strength of radar soundings at the different jovian icy satellites. We present then visibility modeling of radio sources, inferring time intervals and frequency ranges clean from natural radio emissions. We will also discuss various ways to mitigate the natural radio emissions. We finally discuss the results of the study and conclude.

References

[1] B. Burke, K. Franklin, Observations of a variable radio source associated with the planet Jupiter, *J. Geophys. Res.* 60, 213, **1955**.

[2] P. Zarka, Auroral radio emissions at the outer planets: Observations and theories, *J. Geophys. Res.* 103, 20159–20194, **1998**.

[3] S. Hess, B. Cecconi, P. Zarka, Modeling of Io-Jupiter Decameter Arcs, Emission Beaming and Energy Source, *Geophys. Res. Lett.* 35, **2008**.

NASA SBIR/STTR AS AN EJSM RESOURCE

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The NASA SBIR/STTR Program

Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) are Congressionally mandated programs administered by the U. S. Small Business Administration (SBA) Office of Technology. All Federal agencies with an extramural research and technology (R&T) budget >$100M (SBIR) or >$1B (STTR) are required to participate, and must reserve 2.5% of their extramural R&T budget for SBIR and 0.3% for STTR. NASA participates in both SBIR and STTR.

An SBIR project is led by a small business; an STTR project is led by a small business in collaboration with a nonprofit research institution, college, university, or federally funded research and development center (FFRDC). SBA ensures through SBIR and STTR that small, high-tech, innovative businesses are a significant part of the Federal Government's R&T efforts.

All ten NASA Centers, including JPL, actively participate in the SBIR/STTR program and reinforce NASA's objective of infusing SBIR/STTR developed technologies into its programs and projects. NASA funds SBIR/STTR in two Phases. Phase 1 verifies the scientific, technical and commercial merit of the proposed innovation ("proof of concept") and the quality of the company's performance. Phase 2 comprises development, demonstration, and delivery of the innovation. Companies that successfully complete their Phase 1 objectives are eligible to compete for Phase 2. Historically, the ratio of Phase 1 proposals to awards is about 6:1; about 45% of successful Phase 1 projects lead to Phase 2 awards. [1]

Phase 1 Contracts	**SBIR**	**STTR**
Maximum Contract Value	$ 100,000	$100,000
Maximum Period of Performance	6 months	12 months
Phase 2 Contracts	**SBIR**	**STTR**
Maximum Contract Value	$600,000 (2009); $750,000 (2010)	$ 600,000
Maximum Period of Performance	24 months	24 months

NASA HQ issues one proposal Solicitation per year, normally in early July, with Phase 1 proposals due in early September. Existing Phase 1 contracts serve as the RFPs for follow-on Phase 2 proposals [1]. The Solicitation, when issued, will be publicly available on the NASA SBIR home page [2]. The Solicitation details the proposal process and describes each technical subtopic. During the period when a Solicitation is not active – normally late November through early July – NASA and JPL personnel are welcome to discuss the subtopics with interested parties, including specific technical details, applications, technology infusion prospects, programmatic needs and timeframes. However, when the solicitation is active, discussion is limited to publicly available information.

Technologies in the Solicitation are intended to complement other NASA technology investments. Each year, four NASA Mission Directorates (Aeronautics, Exploration, Science, and Space Operations) identify their high priority R&T needs for inclusion in corresponding SBIR topics and subtopics. The STTR topics and subtopics reflect selected core competencies of each Center.

Through FY 2010, the Innovative Partnerships Program Office (IPP), under the Office of the NASA Associate Administrator, provided overall policy direction for implementing NASA's SBIR/STTR programs. Starting in FY 2011, NASA SBIR/STTR will move to NASA HQ's Office of the Chief Technologist, where it will reside within Early Stage Innovation. The FY 2011 budget estimate for SBIR/STTR is $165.6M [3], of which approximately $150M is expected to be available to fund Phase 1 and Phase 2 projects selected via the 2010 Solicitation.

NASA SBIR/STTR Subtopics of Particular Interest to EJSM

Seven SBIR technical subtopics and two STTR technical subtopics in the 2010 Solicitation are of particular interest to EJSM. Although small businesses are welcome to propose to any subtopics where they have relevant technology development capabilities, they are especially encouraged to propose to these. Those starting with "S" are SBIR subtopics identified by NASA's Science Mission Directorate; those starting with "T" are STTR subtopics.

EJSM Technology Need Description	2010 SBIR/STTR Solicitation Subtopic
Extreme radiation environment and long-life technologies (electronics, processors, packaging, test methods, lifetime analysis)	S5.05, Extreme Environments Technology
Advanced Radiation Shielding Materials and Structures	S5.05, Extreme Environments Technology
Spacecraft platform technologies for high radiation environments (such as CDH, power generation, transducer)	S3.01, Command, Data Handling, and Electronics
Sensor and Detector Technologies for high radiation environments (Visible, IR, Far IR and Submillimeter)	S1.04, Sensor and Detector Technology for Visible, IR, Far IR and Submillimeter
Instrument Technologies for extreme environments (UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments)	S1.05, Detector Technologies for UV, X-Ray, Gamma-Ray and Cosmic-Ray Instruments
Surface Exploration Technologies (Penetrators, landers and in-situ sensors and remote sensing platforms)	S5.03, Surface and Subsurface Robotic Exploration
Novel planetary protection Technologies (reducing microbe load, assaying)	S5.06, Planetary Protection
Flexible Charge Dissipation Coatings for Spacecraft Electronics	T8.01, Flexible Charge Dissipation Coatings for Spacecraft Electronics
Spacecraft Internal Electrostatic Discharge (IESD) Resistant Circuit Board Materials	T8.02, Spacecraft Internal Electrostatic Discharge (IESD) Resistant Circuit Board Materials

If you do not already have NASA technical point(s) of contact, you can contact the SBIR Technology Infusion Manager (TIM) or Field Center Program Manager (FCPM) at the desired Center(s) [4]. They can provide relevant leads and points of contact, including lead and participating subtopic managers for the technical subtopics in which you are interested.

References

[1] 2009 NASA SBIR/STTR Program Solicitations, Section 1 and Section 3.3.1.
[2] The NASA SBIR public home page is located at http://sbir.nasa.gov/SBIR/SBIR.html
[3] From http://www.nasa.gov/news/budget/index.html (FY 2011 Budget Estimate by Section–Space Technology)
[4] The NASA TIMs and FCPMs are listed at http://sbir.nasa.gov/SBIR/pgminfo.htm

MONOLITHIC-MCM™ ANALOG IC DESIGN FOR SPACE
An Oxymoron Who's Time Has Come

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Abstract
As Moore's Law is poised to dramatically impact space systems, designers want to know what will improve analog design for space.

Digital Designers Benefit from Moore's Law
Moore's Law and its doubling of transistors per unit area every eighteen months has ushered in the era of FPGAs for space. FPGAs allow designers to address the size, weight and power (SWaP) of their digital designs by integrating large amounts of discrete digital circuitry into a single semiconductor die. FPGAs use more power than an equivalent ASIC implementation but the economic tradeoffs that are a part of today's missions are dictating that higher power, low NRE FPGAs be used in place of lower power but longer development time and higher NRE ASICs. These advancements and design alternatives afforded to the digital designer have thus far been withheld from their analog design counterparts.

Analog Design for Space Harkens Back to the Reagan Era
Analog design for space remains frozen in a 1980's-style methodology whereby discrete components from an approved list are assembled onto large, heavy and power hungry printed circuit boards (PCBs). Analog designs could realize significant gains in SWaP through ASIC integration but, just like in the digital realm, the long development time, high NRE and high risk associated with traditional full custom ASIC design has dissuaded most teams from such an endeavor.

Progress for the analog designer would be a technology that addresses SWaP while reducing the NRE, development time and risk associated with analog ASIC development. And, such a technology should come with excellent radiation mitigation characteristics and a development methodology no more difficult than FPGA or discrete PCB design.

Via Configurable Array Technology for Space Applications
While seemingly an overnight success, the decade-long development of via configurable array (VCA) technology has resulted in a design methodology and technology poised to deliver "FPGA-like" benefits to analog designers seeking to address stringent SWaP requirements and provide high levels of mission assurance while balancing the ever tightening budget constraints of their programs.

VCAs combine silicon proven, radiation hardened by design analog and digital resources on semiconductor die that are overlaid with a global routing fabric. A single mask layer change quickly and easily interconnects these resources resulting in reduced cost, reduced development time and significantly mitigated risk. The regular structure of a VCA will likely provide repeatable radiation effects performance for many applications reducing the qualification costs associated with using these devices thereby further accelerating their adoption in space programs.

The Monolithic-MCM™ Approach
Historically, mission teams have selected discrete analog and mixed signal devices that have performed well in ground-based radiation and environmental testing. Subsequently, these devices then gain flight

heritage and admission to an approved list of mission ready electronics. PCB assemblies built to satisfy a mission's analog and mixed signal electronics utilize components selected from such an approved list. Full custom analog IC design on the other hand begins with a new semiconductor die and crafts each transistor, resistor, and sub-circuit for the desired electrical and radiation performance. While this full-custom approach is ideal for optimizing performance, it comes with large penalties in development time, development costs, and schedule risk. Furthermore, since the entire design is new, the radiation, environmental testing and qualification process can be more expensive and time consuming than the actual design development. Discrete PCB level analog design compromises integration (SWaP) for a more conservative approach to qualification and development costs while full-custom provides excellent integration and performance but with significant expenditures in development and qualification required. A more optimal mix of performance versus design and qualification issues would allow future space missions to achieve the desired analog performance and integration while at the same time reducing the qualification effort over that required for a full-custom design.

Triad has a strong and growing history of delivering VCA solutions for commercial, industrial, and military customers. With that said, Triad does not have a long history of space flight heritage to point to as a reason to use radiation hardened VCA technology. Partners such as Sandia National Labs, Air Force Research Labs (AFRL), Microelectronics Research Development Corporation (mRDC) and the Missile Defense Agency (MDA) have invested in VCA technology because the anticipated rewards for adopting such an approach are significant. Research and implementation programs for radiation hardened VCAs date back to 2002 with deployments including 0.35-micron radiation-hardened-by-process VCAs available from Sandia National Labs, 90nm radiation-hardened-by-design VCAs developed in cooperation with AFRL and mRDC and fabricated through IBM's Trusted Foundry flow. These efforts have resulted in digital-only radiation hardened VCAs with proven electrical performance and radiation test results showing total dose performance of up to and beyond 1 Mrad (Si) TID. In addition to these efforts, Triad is working with the MDA on the development mixed signal VCAs with radiation hardened by design capabilities.

VCAs utilize known-good, Silicon-proven IP greatly improving the correlation between simulated and Silicon observed results. This correlation results in improved first Silicon performance. With the VCA approach, single layer mask changes can be re-fabricated quickly with only the additional cost and time of single mask processing allowing designers to treat their VCA design more like a PCB assembly thereby supporting system prototyping in Silicon. Since a VCA is an assembly of digital and analog tiles. A given VCA may have the exact same tile replicated on the array a dozen times. Each tile is electrically the same as the other eleven tiles on the array. The theorized outcome of radiation qualification on such structures is that circuits implemented on a given tile should have the same electrical and radiation tolerance behavior if the circuit is implemented on another tile. This concept means that once a function such as an analog band pass filter or a switched capacitor modulator or an analog to digital converter circuit is known good (electrically and environmentally), this IP block can be treated as an approved resource that conceivably could be implemented on future designs using the same VCA tiles with a major reduction in qualification effort. Additionally, circuits which span multiple tiles could likewise be characterized and as long as the circuit was implemented exactly the same way on another set of tiles of the same type this circuit too could provide for major reductions in future qualification efforts. The VCA design flow must then support the ability to "black box" known good circuits and fully lock-down their resource usage along with their routing resources. This black box can then be represented as a set of vias that can be placed at multiple relative locations within a VCA die. Some partners have referred to this approach as a Monolithic-MCM technology whereby the benefits of an MCM approach (using die with known environment heritage) are combined with the benefits of a monolithic semiconductor approach (increase integration, improved power, reduced design time and reduce total program costs).

Integrated Design & Radiation Transport Analysis

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Space systems must operate in environments that include significant levels of ionizing radiation. The optimization of the configuration and layout of the system components is a critical step in the design process for radiation tolerance. Many space systems get deployed with hardness capabilities that are unrecognized and underutilized due to imprecise analysis techniques applied too late in the design cycle.

Traditional Radiation Transport Analysis (RTA) is a time consuming and very expensive process. Conventional comprehensive shielding analysis is a multi-million dollar effort for first design and subsequent updates can cost hundreds of thousands of dollars. Radiation shielding has not been an integral process of the design and analysis cycle of space systems. The radiation hardening design process is performed following the completion of detailed system design. Low-fidelity radiation analyses are conducted on mature hardware models well after the design has been completed. Hardware solutions are often missed due to long analysis cycles, complexity, or limitations on system representation. Typically, fifty percent of the system weight is neglected in traditional analysis modeling methods resulting in significantly overweight shield design.

Optimum shielding design can lower launch weight as well as reduce the cost of electronic components due to decreased dose requirements. Therefore, it is critical to create the radiation analysis model accurately representing all sub-system components to support high fidelity system level analyses for survivability and operability. Historically, the complexity involved in the development of the radiation analysis models often leads to the exclusion of details, thus impacting the fidelity of the analysis. Additionally, the long time and high cost of the radiation analysis process have driven programs to perform the shielding design as late in the engineering cycle as possible, when designs have neared finalization. This leads to catastrophic consequences since often problems are found that cannot be fixed with minor changes. As a consequence parts are replaced with very expensive hardened versions and entire circuits have to be redesigned.

Radiation tolerance assessment of a candidate design or configuration requires the use of Radiation Transport Analysis. RTA is used to assess the effectiveness of a shielding design as well as the tolerance of the system components. Radiation shielding design optimization can be applied throughout the different stages of the system design (conceptual, preliminary, and detailed). Because of the long time required for processing the design geometry for creating the analytical model for RTA, performing the analyses while the design is still taking shape is not practical.

The Adaptive Modeling Framework (AMFrame) from TechnoSoft is a multi-functional engineering environment that facilitates rapid, integrated design, and radiation transport analysis. AMFrame provides a knowledge-based engineering modeling environment enabling the integration and automation of analysis and design processes. AMFrame supports multiphysics modeling and geometric reasoning; overall functionalities that are critical to the automation of product and process design. Supported fields include mesh generation, structural analysis, computational fluid dynamics, aerodynamics, hydrodynamics, electromagnetics, optics, thermal analysis, dynamic analysis, and radiation transport analysis. AMFrame incorporates user-extensible tightly coupled integration with all major COTS tools such as Nastran, Ansys, and Abaqus for structural analysis, Fluent for CFD, and MCNPX and TART for 3D radiation transport analysis, as well as proprietary custom developed tools.

The opportunity here is associated with the automation of the radiation analysis process to support the rapid assessment of innovative concepts for multifunctional designs. AMFrame supports the automation of modeling methods for high fidelity analysis supporting radiation, structural, and thermal assessment of multifunctional design concepts. These methods support capturing the detailed design features,

accurately representing component geometry and weights, and accounting for the interaction among all the various systems' components, boards, and enclosures structures. AMFrame integrates algorithms that support the optimization of the layout of components and the shielding design. This unique integrated design and multidisciplinary analysis environment enables the rapid evaluation of subsystems in support of radiation tolerance and shielding design for the Europa Jupiter System Mission (EJSM).

AMFrame introduces radiation assessment for optimum shielding design at the earliest stage of the engineering process. It automates the high fidelity analysis for assessing radiation tolerance at the components, subsystems, and system levels. Radiation design flaws can be mitigated during the early design phase leading to integrated and increased shielding while optimizing the board level configuration and eliminating costly over-designs. AMFrame incorporates a broadly applicable engineering analysis modeling and simulation environment that automates total ionizing dose analysis and expedite "what if" design iterations for spacecraft electronic systems and components. Based on current results from previous deployments of AMFrame, opportunities exist for greater than ninety percent savings in engineering time while reducing shielding weights by over fifty percent. The AMFrame comprehensive modeling and simulation environment will not only reduce design cycle time and cost, but will also reduce the effort associated with compliance analysis for electronic systems. It will also reduce electronics costs through lowering hardness requirements while enabling use of lower cost COTS components.

AMFrame facilitates optimal layout of systems through enabling repositioning of components and rapid radiation tolerance assessment of such alternative designs. During the layout process, the softest parts can be placed in the most shielded locations. This reduces the need for unnecessary costly hardened parts, and can also result in lower shielding weight. The AMFrame high fidelity analysis modeling capability will enable spot shielding of soft components instead of high cost plating of entire enclosures. Ultimately, the radiation hardness of the system will be entirely developed where the impact of each subsystem will be factored into the radiation effects in all others. The shielding design and analysis will be an integral part of the overall system engineering process eliminating costly reworks replacing designs made of expensive components that are poorly collected and banded together.

AMFrame capitalizes on facilitating rapid creation of the analysis model capturing one hundred percent of the design geometry features and material. Interactions between design models (geometry) and analyses are fully automated to reduce engineering time and cost while facilitating trade studies and design explorations. When the detailed design is complete there are no hidden issues waiting to be discovered, no massive redesigns over hardening concerns, and no expensive parts replacements. The detailed design is ready for a single round of verification testing because the radiation performance of the system will be a known quantity, evolved throughout the design process, and not an unknown waiting to be uncovered. This will allow for reduced system weight and costs, compressed schedules, enhanced radiation tolerance, and greater design margins.

AMFrame leverages years of software development, design, and analysis domain knowledge. TechnoSoft, an engineering software company, is currently involved in several government engineering programs related to integrated product and process design and automation. The TechnoSoft engineering team includes specialists with domain knowledge as well as expertise in tools, systems design and analysis knowledge, and engineering software framework and application development. TechnoSoft has developed and deployed many applications on AMFrame that are currently used by NASA, DoD, DoE labs, and international corporations. TechnoSoft has a strong twenty-year record of technology innovation and domain expertise that can be easily applied to the various analyses needs of the EJSM program.

Radiation Hardness of AlGaN Photodiodes

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Abstract
We will report on the demonstration of radiation hardness of new AlGaN photodiodes. The photodiodes are NSTec custom-designed and fabricated for the detection of 255 nm UV light in a strong radiation environment including protons, neutrons, fast electrons, gamma rays, and hard X-rays. We have tested their radiation hardness using a 65 MeV proton beam line. The photodiodes retained ~50% responsivity up to $3x10^{12}$ protons/cm^2 fluence.

Introduction
The Europe Jupiter System Mission (EJSM) mission requires instrumentation radiation hardness at an unprecedented level. A total fluence of 10^{12} protons/cm^2 or higher is expected during the mission lifetime. Hefty radiation shielding is required for Si and GaAs based electronics and optoelectronics devices. Recently we have experimentally demonstrated the extreme radiation hardness of AlGaN UV LEDs up to $2x10^{12}$ protons/cm^2 [1-3]. We will report on the radiation hardness tests of AlGaN photodiodes up to $3x10^{12}$ protons/cm^2. Both UV LEDs and photodiodes are currently designed for 255 nm UV light generation and detection; however, other wavelengths are also accessible. These new devices are well suited for the EJSM mission.

The Radiation Hardness of the AlGaN Photodiodes
We have recently conducted a radiation hardness test at the University of California (Davis) Croker Proton Facility. The experimental setup is illustrated in Figure 1. The photodiodes are placed in the 65 MeV proton beam line with a cross section of 44 mm x 38 mm, and are illuminated with 255 nm light generated by UV LEDs mounted outside the proton beam line.

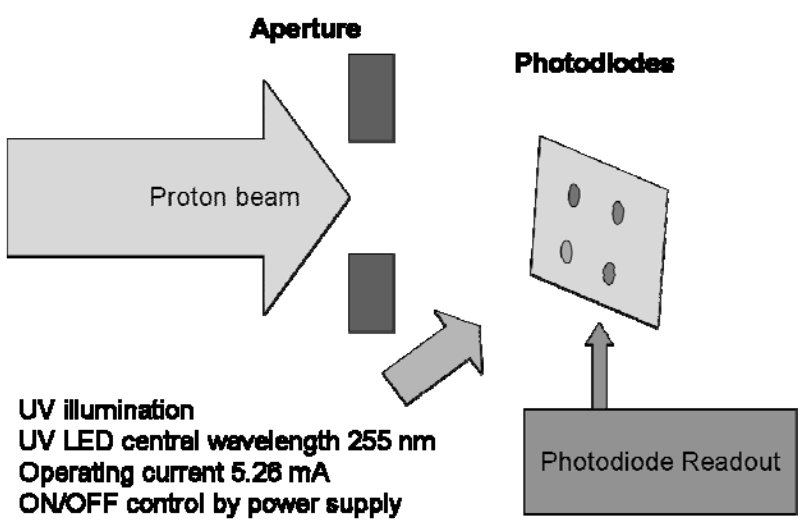

Figure 1: Experimental setup for proton radiation hardness testing

The photodiode is operated in photovoltaic mode. The voltages across the photodiode corresponding to On/Off states of UV light are recorded. The difference between photodiode voltages between the UV On and Off states is defined as the photodiode response and is presented in Figure 2. As shown, the normalized photodiode response retained ~50% value from the peak response, up to the fluence $3x10^{12}$ protons/cm^2.

A more detailed observation shows that the photodiode response versus proton fluence curve becomes flatter after the fluence level $1x10^{12}$ protons/cm^2. Such a plateau region may extend to a higher fluence level. Furthermore, the 65 MeV proton energy level is much higher than the typical ~1 MeV protons cited in some deep space missions, and the tested hardness level using 65 MeV may prove to be better for the 1 MeV proton irradiation.

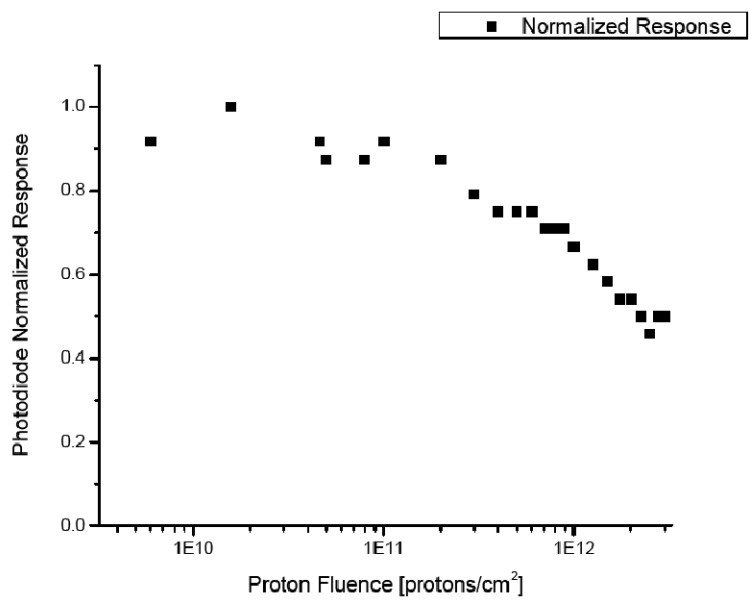

Figure 2: Normalized photodiode response versus proton fluence

Capabilities

The NSTec team will collaborate with academic, industrial DOE, and NASA institutions to provide radiation hardness devices, tests, design, and analysis.

References

[1] K.-X. Sun, B. Allard, S. Williams, S. Buchman, and R. L. Byer, "LED Deep UV Source for Charge Management for Gravitational Reference Sensors," Class. Quantum Grav. 23 (2006) S141-S150

[2] K.-X. Sun, N. Leindecker, S. Higuchi, J. Goebel, et al. "UV LED Operation Lifetime and Radiation Hardness Qualification for Space Flights," Journal of Physics CS, doi: 10.1088/1742-6596/154/1/012028

[3] K.-X. Sun et al. "Space Qualification for Radiation Hard UV LED," NASA EJSM Workshop, Applied Physics Lab, John Hopkins University, July 7-9, 2009

Acknowledgment and Disclaimer

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