Mission-Critical Microelectronics for the DoD

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Intro to Rel-Micro

- **Reliable MicroSystems is a Tennessee-based company established in 2016 as a world-class microelectronics organization supporting the concept-to-foundry creation and maturation of high-reliability electronics for mission-critical applications.**
- **Rel-Micro expanded to WestGate Technology Park in Jan 2023**
- **Our charter is to support customer-driven needs in radiation-hardened digital engineering:**
  - The development of operational models and simulation tools for microelectronic risk assessment and failure predictions
  - The modeling of electronic circuit resiliency in hostile and mission-critical environments
  - The design of high-reliability and/or radiation-hardened application-specific integrated circuits
  - The implementation of fault-tolerant techniques at the device, circuit, and system level
- **RMS represents technical expertise with decades of combined experience in the aerospace ecosystem,**
  40 employees/contractors, growing rapidly,
  active workforce development with 18 college interns in 2023

Agenda

Part 1 – The Landscape

- **University Lecture:**

  Formal *Digital Engineering* → What is it? Is it important?

  Radiation Hardened Microelectronics → Resiliency in the face of threats

- **Background: The Challenging Path to Trusted Rad-Hard Microelectronics**

  → What's the big deal? Aren't we there yet?

Part 2 – Battle Plan

- **Concept: Private/Academic/Government partnership for Rad-Hard enablement**
- **Rad-Hard Design Integrated Services Center**
- **Components of the ISC**

Part 3 – A Sampling of Ongoing Digital Engineering Activities at Rel-Micro

- **Implementation / Status @ Rel-Micro**

Part 1: The Landscape

What is Digital Engineering?

"***Digital engineering*** **is an integrated digital approach using authoritative sources of system data and models as a continuum throughout the development and life of a system. Digital engineering updates traditional systems engineering practices to take advantage of computational technology, modeling, analytics, and data sciences."** [1]

Digital engineering **enables the DIB to accelerate innovation and transition R&D into manufacturing faster than it has in the past, increasing the speed at which industry partners can improve their overall TRL and MRL for SOTA technologies critical to our national defense ecosystem.** [2]

[1] OUSD(R&E) DCTO(MC) web site.

[2] See, for example: USING MODELING AND SIMULATION TO INCREASE SPEED TO MARKET, REDUCE RISK, AND FOSTER INTEROPERABILITY IN THE INDUSTRIAL BASE House Report 117-118, page 199, accompanying H.R. 4350, the National Defense Authorization Act for Fiscal Year 2022

Navy Digital Engineering Strategy

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Navy & Marine Corps Digital Systems Engineering Transformation (D/SET) Strategy signed in June 2020. The D/SET Strategy has five objectives: [2]

1. Formalize the development, integration and use of models
2. Provide an enduring authoritative knowledge source
3. Incorporate technological innovation to improve the engineering practice
4. Establish the supporting infrastructure and environments for the Digital Engineering practice
5. Transform the culture and workforce to adopt and support Digital Engineering across the lifecycle

[2] STATUS OF ADOPTION AND IMPLEMENTATION OF DIGITAL ENGINEERING INFRASTRUCTURE AND WORKFORCE DEVELOPMENT WITHIN THE DEPARTMENT OF DEFENSE House Report 117-118, page 69, accompanying H.R. 4350, the National Defense Authorization Act for Fiscal Year 2022

Mission-Critical Microelectronics

Where failure is not an option:

- Mil-Aero/Comm Space
- Nuclear Power
- Weapons
- Medical
- Automotive/Industrial
- High-consequence IT

Harsh environment radiation resiliency is foundational to this ecosystem

What Are These "Radiation Effects?"

Let's Ask The Oracle

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Q: Describe concisely "radiation effects on microelectronics"

"Radiation effects on microelectronics refer to the impact of ionizing radiation on electronic devices and circuits. When exposed to radiation, such as high-energy particles or electromagnetic waves, microelectronics can experience various detrimental effects. These include Single Event Effects (SEE), such as Single Event Upset (SEU), Single Event Latch-up (SEL), and Single Event Burnout (SEB), which can cause temporary or permanent disruptions, latch-up, or destruction of electronic components. Radiation can also induce Total Ionizing Dose (TID) effects, leading to gradual degradation and performance degradation over time. Understanding and mitigating these radiation effects is crucial for designing radiation-hardened microelectronics for applications in high-radiation environments."

Text Source: Online ChatGPT query 28 May 2023
Video Source: NASA

AI’s View of Rad-Hard Microelectronics

Q: What are radiation-hardened microelectronics or radiation-hardened microchips?

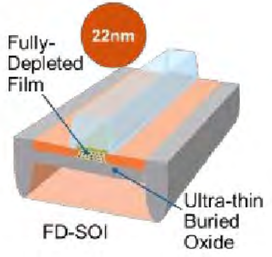
"Radiation-hardened microelectronics, also known as radiation-hardened microchips, are electronic components specifically designed to withstand and operate in high-radiation environments, such as outer space or nuclear facilities. These microchips are engineered to be resistant to the damaging effects of ionizing radiation, such as gamma rays and cosmic rays, which can disrupt or destroy standard electronic devices. By employing specialized materials, designs, and manufacturing techniques, radiation-hardened microelectronics ensure the reliable and uninterrupted performance of critical systems in extreme radiation conditions.”

Source: Online ChatGPT query 28 May 2023

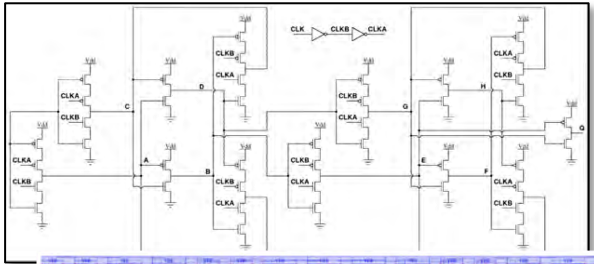
Radiation Hardening on One Page

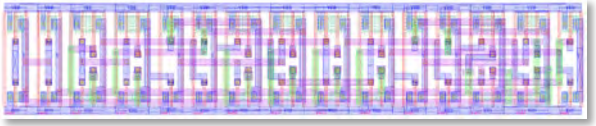
Multiple approaches may be employed (independently or in combination) to protect electronic systems

- Radiation Hardened by Process (RHBP)
  - Specific materials/layers/wafers (e.g. SOI), processing techniques
  - Examples: UTBB/SOI, dielectric engineering
  - Most appropriate for TID, SEL
  - Usually requires a dedicated rad-hard foundry fabrication line ($$$)
  - Only viable business model: U.S. government support



- Radiation Hardened by Design (RHBD)
  - ASIC chip layout or circuit modifications for charge isolation and/or information redundancy (spatial & temporal partitioning)
  - Examples: DICE cell, guard gate, interleaved layout
  - Most appropriate for SEU and SET
  - Requires rad-hard IP + fabless ASIC flow + pure-play foundry ($$)
  - DoD and 'old' space interest and support





- Radiation Hardened by Architecture (RHBA)

DoD Rad-Hard Electronics Posture

DoD and many commercial industries require trusted and reliable radiation-hardened and strategic radiation-hardened microelectronic components to support strategic and space missions. These components ensure the functionality of these systems in high radiation environments such as ambient space and in proximity to nuclear detonations. They need to withstand short bursts of intense radiation, high temperatures, and, in some cases, extreme shock and vibration in order to meet mission requirements. DoD anticipates an increasing demand for radiation-hardened and strategic radiation-hardened microelectronic components to support programs such as satellites and nuclear modernization efforts. Maintaining and expanding domestic capabilities for the production of radiation-hardened and strategic radiation-hardened microelectronics components is of vital national importance.

Source: Presidential Determination for Radiation-Hardened and Strategic Radiation-Hardened Microelectronics Production Capability. Defense Production Act Title III. 21 Dec 2021.

Commercial Rad-Hard Electronics Posture

"Increased dependence on satellite navigation and other satellite-based applications has resulted in an increase in the number of satellite launches and other space missions undertaken on a global level. This is expected to create a demand surge for radiation-hardened electronics to ensure the proper functioning of embedded systems onboard the satellites."

"However, designing a radiation-hardened electronic test-bed is a complex procedure, as the simulation of the space-based working environment requires consideration of several unforeseen factors to test for performance and reliability. With the advancement of technology and the proliferation of applications of radiation-hardened electronics, the cost of conducting extensive R&D for emerging applications is significantly higher and does not ensure profitability and returns."

Source: Mordor Intelligence Rad-Hard Market Analysis, 2023

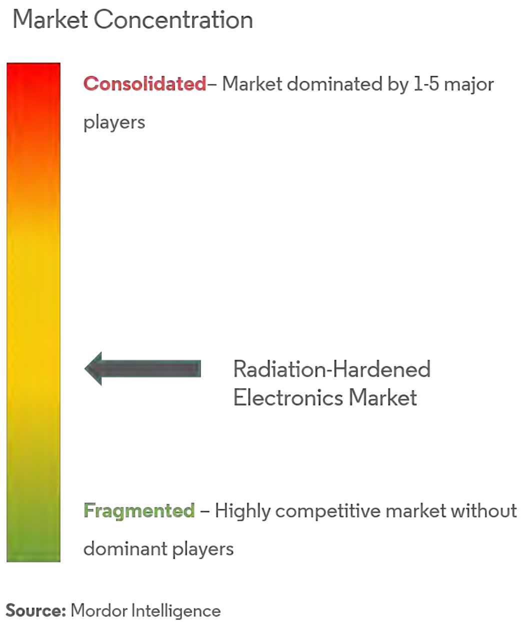
AI's View of Rad-Hard Ecosystem Dominance

Q: Which country is the leader in radiation-hardened microelectronics?

"The United States has traditionally been considered a leader in radiation-hardened microelectronics. The country has a long history of developing advanced technologies for space exploration and defense applications, which often require robust and reliable electronic systems in high-radiation environments. The U.S. government, along with various aerospace and defense companies, has invested significant resources in research, development, and production of radiation-hardened microelectronics. However, it's worth noting that other countries, such as Russia and certain European nations, also have expertise in this field and contribute to advancements in radiation-hardened microelectronics.

Source: Online ChatGPT query 28 May 2023

Two Particularly Challenging Issues



Inefficiencies of R&D fragmentation toward the DoD mission

Rising market dominance of China

The Bottom Line

Our warfighters and our strategic systems require rad-hard chips that perform like this

"System integrators want space systems with high-performance signal processing payloads that can survive in a variety of high-radiation environments for longer periods of time than ever before." [Military Embedded Systems, 11 Jan 2020]

Not like this

What's the Holdup ?

Challenges with the current situation and to the insertion of rad-hard state-of-the-art technologies into the mil/aero microelectronics enterprise include (not a comprehensive list):

- Appropriate rad-hard digital engineering design tools are not available or readily accessible
- Radiation effects models are academic/research in nature and not at an appropriate technology readiness level, in particular strategic radiation (strat-rad) models
- Low volumes exacerbate non-recurring engineering costs among primes and contractors
- Commercial IP and EDA design tools are often difficult to obtain or license
- Rad-hard R&D efforts are often duplicated across government agencies and DIB stakeholders
- Government rights IP is often not widely socialized within the DIB
- Radiation testing facilities are oversubscribed

Part 2: Battle Plan

Concept for Rad-Hard Enablement

Private / academic / government partnership to *empower* radiation hardened *digital engineering* activities

- **Economies of scale**
- **Power of collaborations**
- **Focus of a common mission**
- **Efficiency and risk-reduction to the USG**

Vision

A radiation-hardened design integrated services center providing accessible:

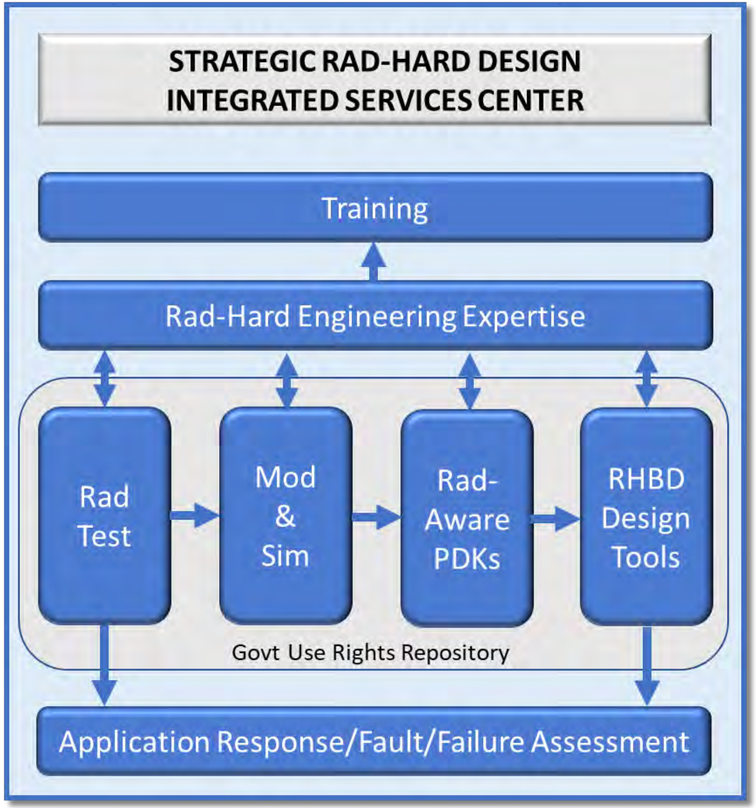
- radiation-effects modeling,
- vertically-integrated radiation-hardened design engineering, and
- radiation-hardened-by-design infrastructure to a wide user base;

all in partnership with the DoD and the Defense Industrial Base (DIB).

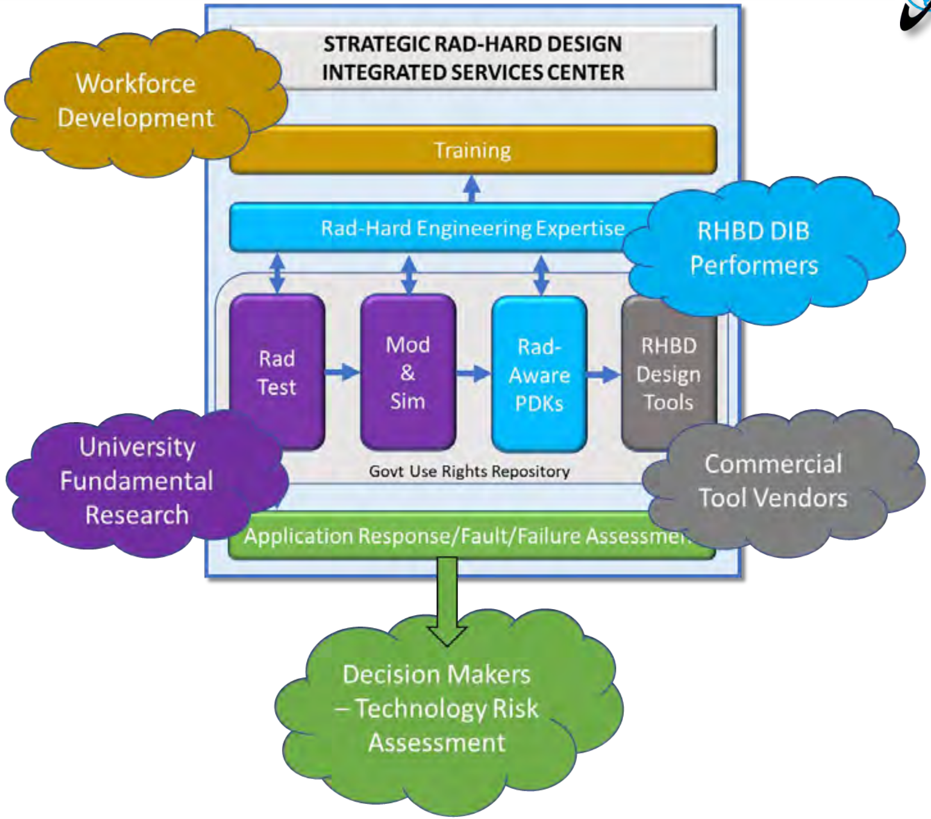
Additionally, this integrated services center will coordinate DIB access to:

- intellectual property (IP),
- research and development (R&D) tools,
- testing infrastructure, and
- verification and validation (V&V) assessments.

Rel-Micro DISC Prototype



DISC Connections to the Community



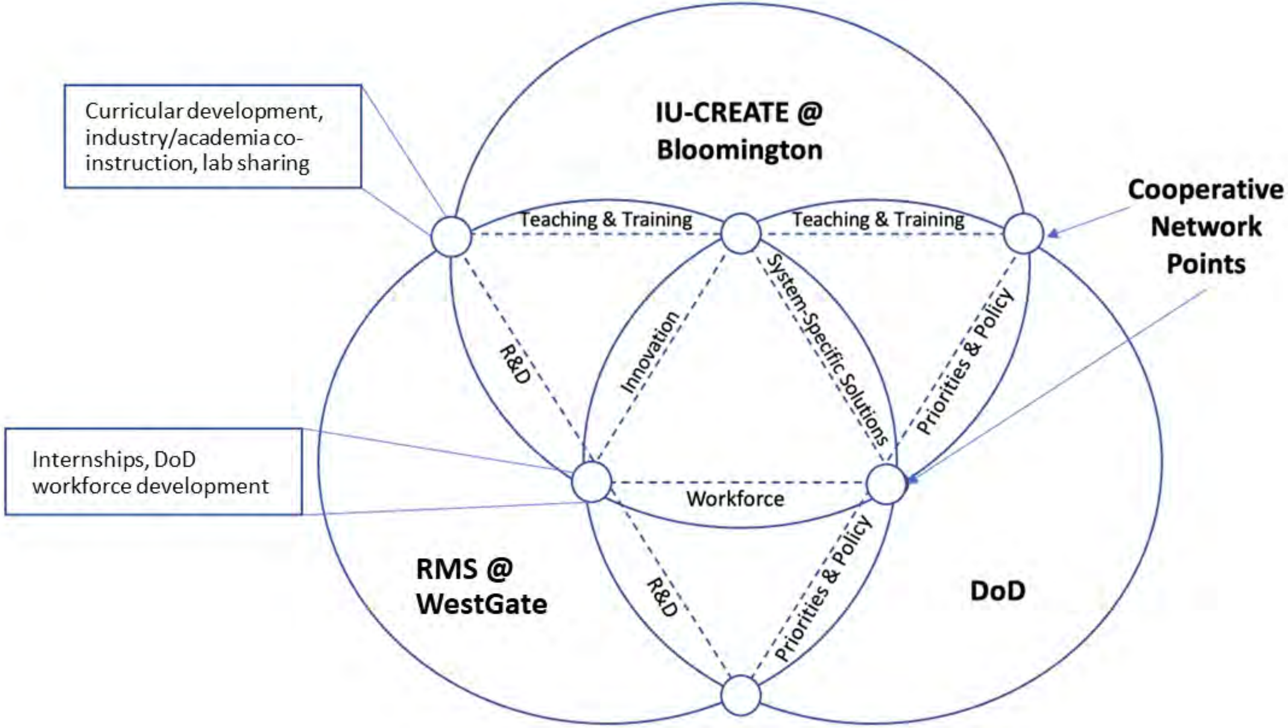
RMS WestGate Center

In January 2023, Rel-Micro established a facility at the WestGate Technology Park to support Strategic Design Services

Rel-Micro is providing the DoD and the DIB access to modeling and simulation resources such as:

- Radiation Testing and Response Databases
- Radiation Hardened by Design Techniques
- Advanced Electronic Design Automation Tools
- Model-Calibration Technology Characterization Vehicles
- Next Generation Radiation Tracking Vehicles
- Design-for-Test Activities

Early Construction – IU/RMS/Crane Team



Source: Dr. Daniel Loveless, IU-CREATE Director

Next-Gen DISC Coalition Building

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Academic

LUDDY
SCHOOL OF INFORMATICS, COMPUTING, AND ENGINEERING

SCALE Workforce Development
A PROGRAM FOR COLLEGE STUDENTS
PURDUE UNIVERSITY

EVERSPIN TECHNOLOGIES
The MRAM Company

Reliable MicroSystems

TRUSTED Semiconductor Solutions™

NHANCED SEMICONDUCTORS

Business

Silicon Technologies, Inc.

LATTICE SEMICONDUCTOR

QuickLogic

Primes

DRAPER

Booz | Allen | Hamilton

Govt

USDR&E
UNDER SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING
DEPARTMENT OF DEFENSE

NAVSEA
WARFARE CENTERS
CRANE

Naval Information Warfare Center
PACIFIC

EDA

cadence

Part 3:
A Sampling of Current Rel-Micro Activities Supporting Rad-Hard Digital Engineering

Characterization of Advanced Domestic Integrated Circuit Technologies

- **Assess, monitor and track the intrinsic radiation vulnerabilities of domestic advanced technologies to support RHBD maturation and assurance for DoD and DIB**
  - Extract data-driven radiation parameters to calibrate and validate radiation-aware models
  - Validate RHBD techniques
- **Partner with the RHBD community to develop RTCV structures to support multiple T&AM programs with data, analysis, and models**
  - Partners: Draper (GRADSoC), BAE (Aardvark), Boeing, Sandia, Scientic (Seaport-E), STI, ASU
  - GF12LP RTCVs (Yellowstone and Lamar Valley) leverage community input to identify circuits, structures, and devices variants for radiation characterization
  - Characterization structure designs and testing support have been provided for the Draper Baxter (12LP, GRADSoC) and BAE Aardvark (Intel 16) test chips
  - Participate in strategic-radiation-hardened SRAM working group
- **Inform decision makers of design/technology risks and mitigation tradeoffs**

Characterization of Advanced Domestic Integrated Circuit Technologies

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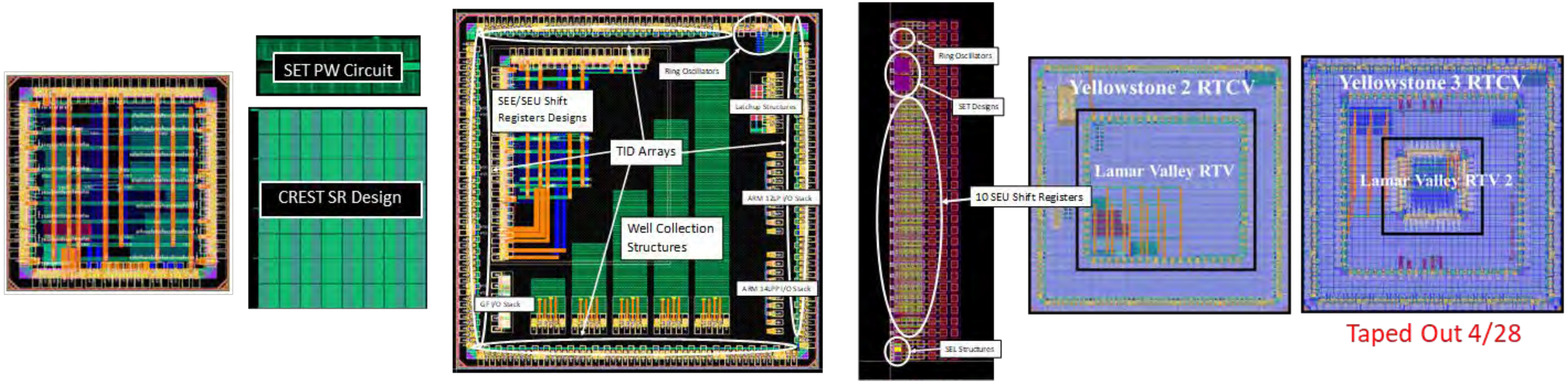
GF12LP TCV-1 | GF12LP Baxter | GF12LP Yellowstone | Intel16 RTCV | Yellowstone 2 | Yellowstone 3

Draper GRADSoC | *BAE Aardvark* | *Draper GRADSoC & BAH*



Taped Out 4/28

In-House / Tested | In Testing | Packaged | In Fab | In Fab

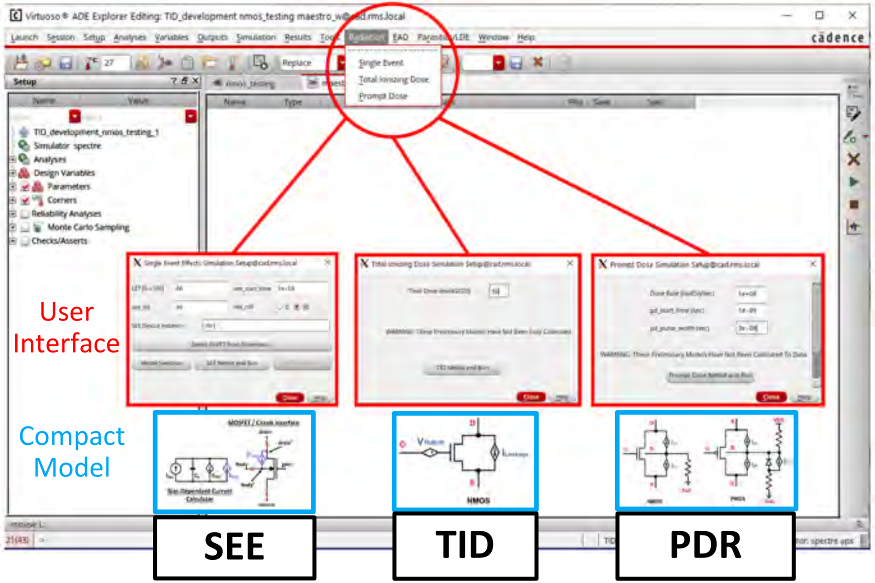
Rel-Micro RTCV Timeline: Increased Accuracy, Efficiency & Capability

2020 | May 2022 | Sept 2022 | Oct 2022 | Apr 2023

Rad-Aware Model Development and Deployment

Benefit: The Rel-Micro compact model implementation supports the EDA engineering flow utilized by ASIC designers.

- **Radiation-enabled models**
  - Single Event Effects (SEE)
  - Total Ionizing Dose (TID)
  - Prompt Dose Rate (PDR)
- **Integration with PDK electrical models**
  - Retain electrical performance fidelity
  - IP-protected install script
- **Deployed through custom developed tools and analysis capabilities**



The Challenge of Integrating Rad-Hard Into the IC Design Ecosystem

Radiation effects intersect design in two disparate domains:

- **Radiation interacts at the *physical layer***
- **Radiation effects are manifest at the *functional layer***

RHBD spans a disjoint design space :

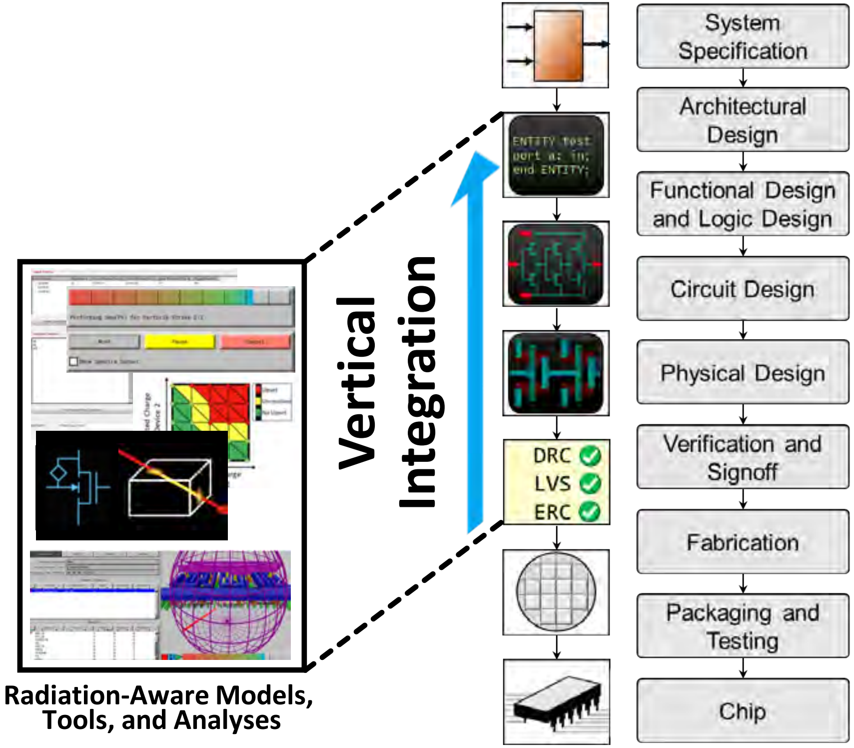
- **Phenomenology (*free carriers to state variables*)**
- **Abstraction formalities (*energy bands to nodal admittance matrix*)**
- **Model structure (*stochastic mechanics to Boolean equations*)**
- **Simulation algorithms *(statistical methods to nonlinear PDEs)***
- **User entry interface *(e.g. Geant4 or Spice or VHDL or SystemC)***

IC Chip Designers ≠ Radiation Physicists (*usually*)

Vertically Integrated Radiation Aware Design

- **Utilizes a bottom-up approach for the percolation of radiation effects mechanisms throughout the design hierarchy – from the physical to the functional**
- **Integrates with existing circuit and design analysis engines within the established SOTA IC EDA ecosystem**

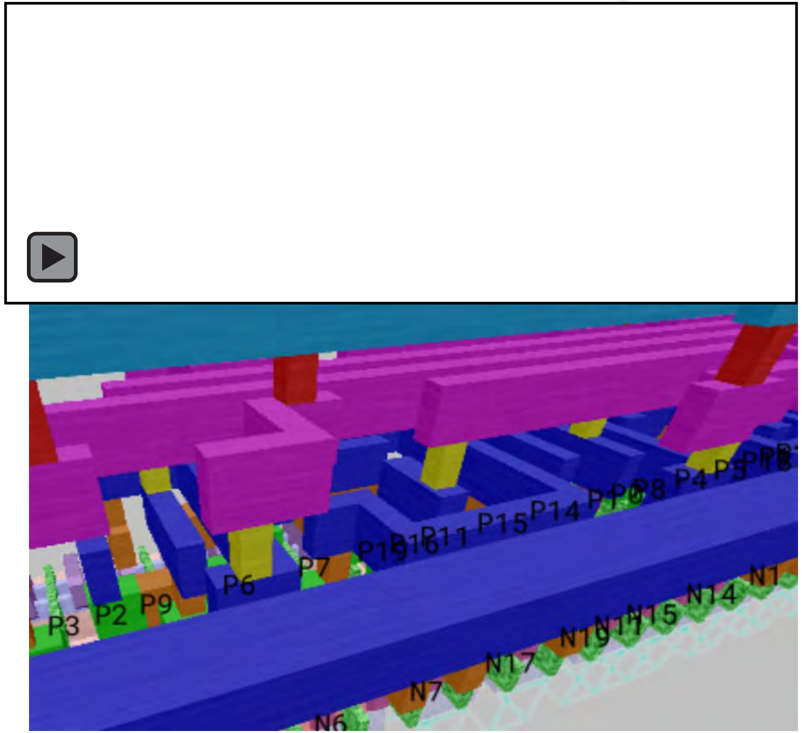
For the first time, combines functional schematic-response and physical layout-response rad-effects modeling, *without TCAD-in-the-loop*, in a seamlessly-integrated environment



VIRAD Development Status

- **VIRAD uses a collection of graphical user interfaces which guide the user through the VIRAD SET and SEU methodology**
  - Reinforces the correct interpretation of simulation results
  - Builds intuition and confidence in designer’s radiation-awareness
  - Provides rapid, actionable feedback to designers

- **June: *VIRAD Introduction and Training Session* for the DoD and DIB at the Rel-Micro, Franklin, TN location**



Training the Next-Generation Workforce

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Rel-Micro is actively engaged in workforce development and is a member of SCALE:

- **18 U.S. citizen interns in 2023 (undergrad and graduate) from:**
  - Auburn (3); GA Tech (1); IUPUI (2); Lipscomb (3); Purdue (4); Rose-Hulman (1); UTC (1); Vanderbilt (3)
- **11 U.S. citizen interns in 2021 – 2022 (undergrad, graduate, and high school)**
  - 4 interns have been employed as full-time engineering staff at RMS

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Local STEM outreach:

- Sponsoring three middle-Tennessee high school robotics programs with physical space and training:

  Ravenwood High – 3 of 4 teams advanced to Worlds Championship competition
  Brentwood High – 5 of 8 teams advanced to Worlds Championship competition
  Franklin High – launching an RMS-sponsored team in 2023

- STEM events and workshops

  'Celebrating Inspiring Women' - day camp for girls to explore STEM; Summer Robotics Camp – summer 2023; Summer STEM camp – summer 2023

Contact Info

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