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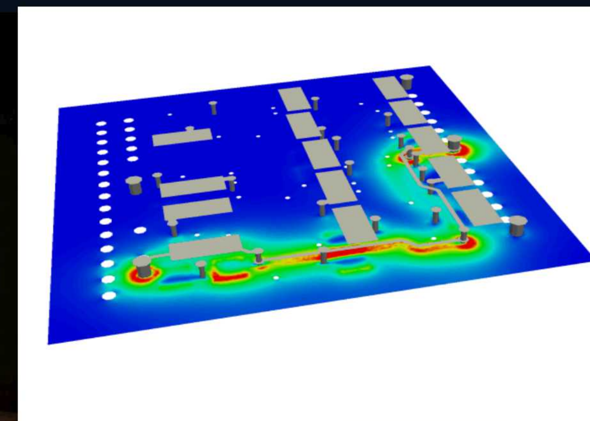

Electrical Sciences at Sandia National Laboratories

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International AP-S/URSI 2018
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Outline

- SNL overview
- Electrical Sciences Overview
- Example (current) Applications
- Summary

SNL=Sandia National Laboratories

Sandia is a U.S. National Lab

- Science labs
- Nuclear energy lab
- Fossil energy lab
- Energy efficiency and renewable energy lab

Sandia has two main locations

Sandia New Mexico - *Albuquerque*

On-site workforce: ~10,500

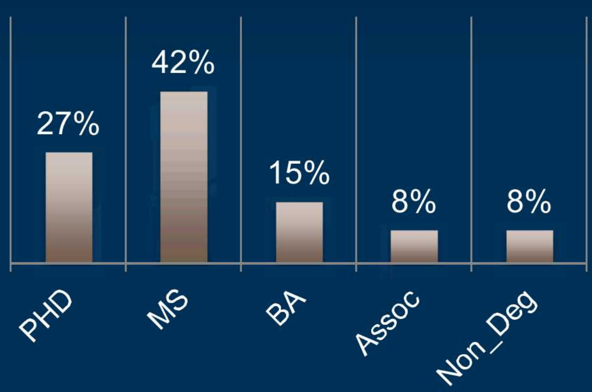
R&D staff: ~3,500

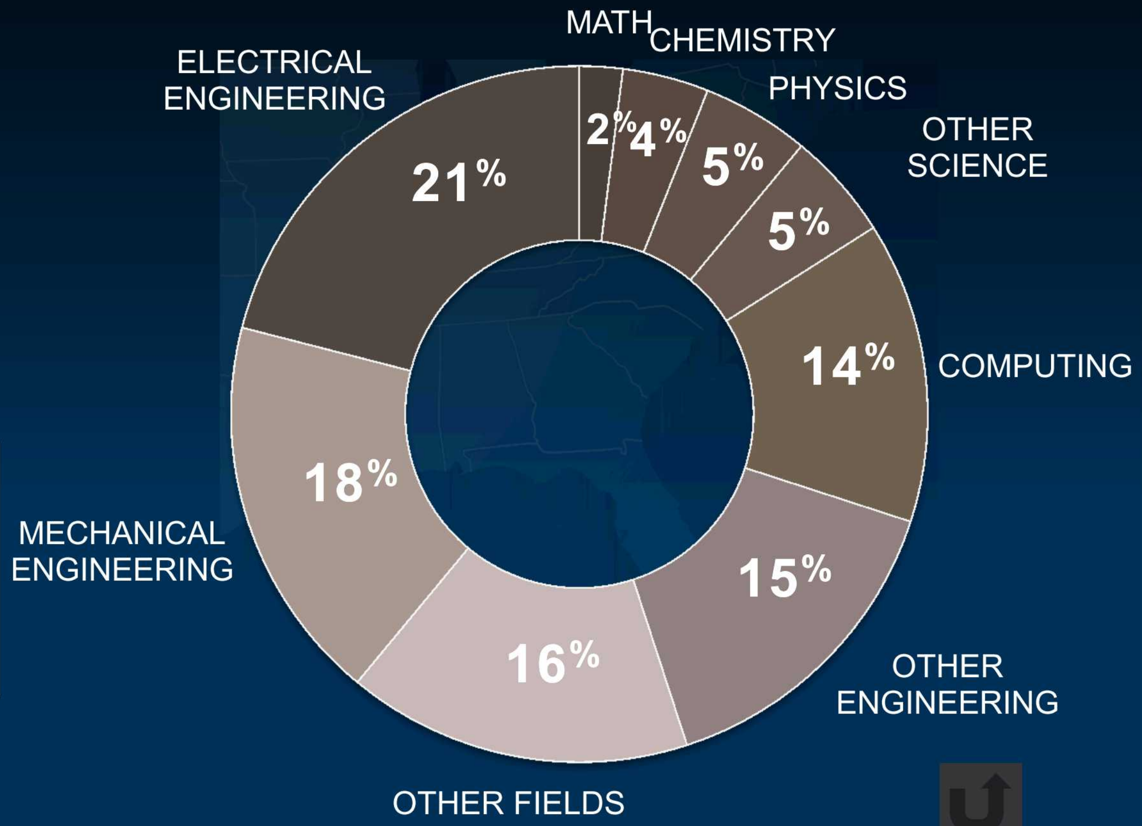
(excluding R&D Tech)

Distinguishing research capabilities:

- Renewable Energy
- Micro-electronics/Semiconductors
- Cyber Security
- Homeland Security *and more*

Degree Level

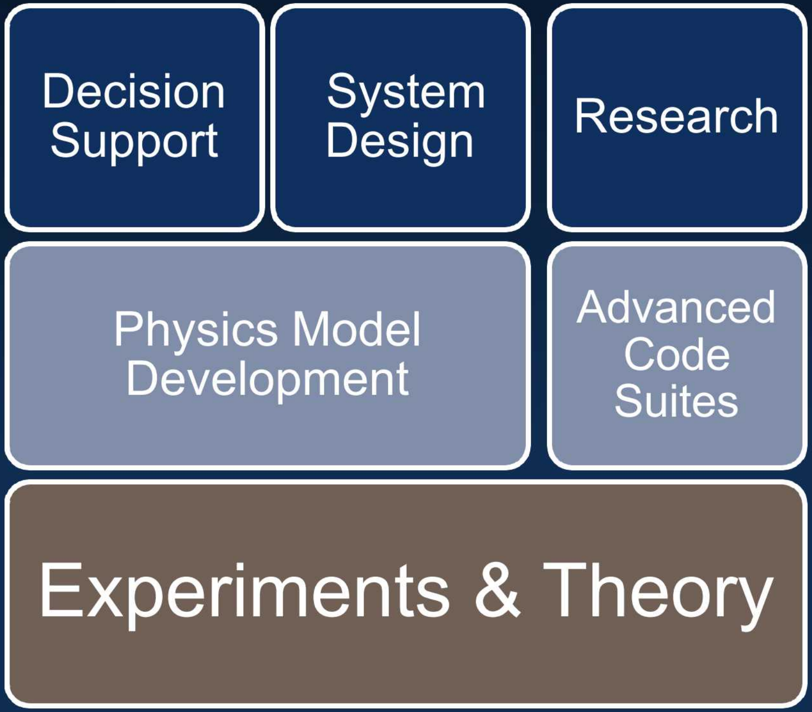




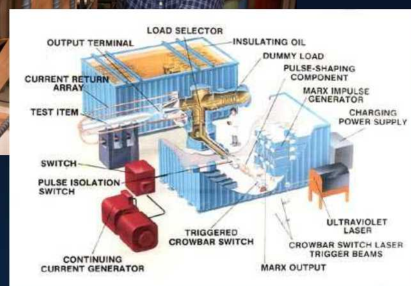
SNL Electrical Sciences

Anticipate and advance the science, engineering, and technology needed to understand the control electrical energy in complex engineered systems

- ❑ Linear Electromagnetics
- ❑ Plasma Physics
- ❑ High-Voltage Sciences
- ❑ Circuits and Devices
- ❑ Power System and Electronics



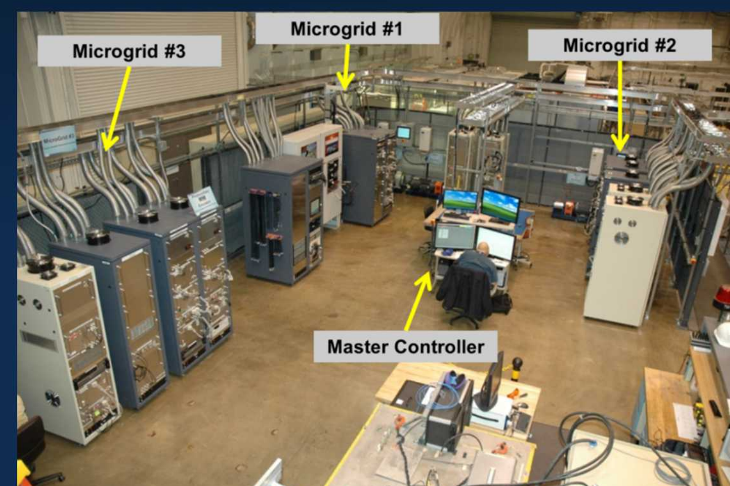
Electrical Science Testing Capabilities



Lightning Sim

GTEM

Reverb chamber



Scalable microgrid test bed

Electrical Sciences Code Capabilities

- EIGER: Electromagnetic/Electrostatic
  - Integral Equation, Method-of-Moments

Next-Generation Codes In Development: Gemma and EMPIRE

- EM
  - Finite-Element Method
  - Time-Domain

- CHARON: TCAD Device Carrier Transport/Recombination
  - Finite-Element Method
  - Time-Domain & Frequency-Domain (in development)

- XYCE: Spice-like Analog Circuit Simulator
  - Non-linear Differential Algebraic Equation (DAE) solver
  - Time-Domain & Frequency-Domain

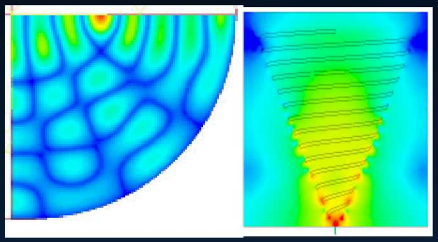
Summary of SNL Electrical Capabilities

Code	Environments	Description	Usage
EMPHASIS /EMPIRE	EMP, SREMP, SGEMP, Lightning	Full-wave EM, MPP → high rigor	System Certification, R&D
EIGER/Gemma	EMR, EMP, Nearby Lightning	Full-wave EM, MPP → high rigor	System Certification, R&D
ALEPH	Electrical Breakdown	PIC+DSMC, MPP → high rigor	R&D
Breakdown Alpha	Electrical Breakdown	Reduced-Order Model → quick turnaround	Component Design, Significant Findings
ATLOG	EMP, SREMP, Nearby Lightning	Transmission Line Code → quick turnaround	Consequence Assessment
Charon	EMP	HB Device, MPP → high rigor	R&D (in development)
Xyce	EMP, HPM	HB Circuit, MPP → range of rigor	R&D (early implementation)

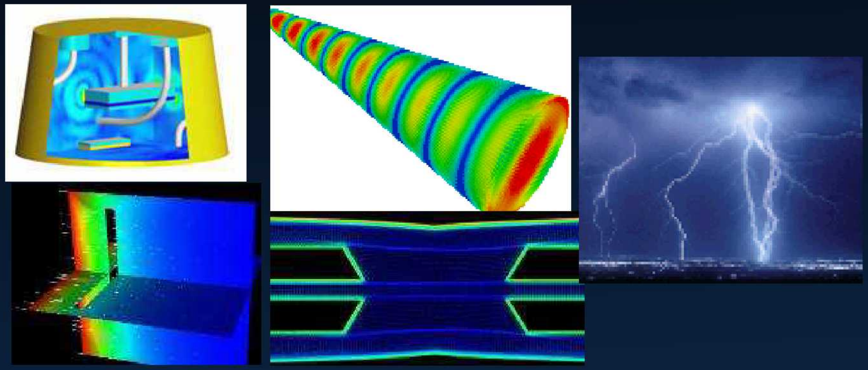
DSMC: Direct Simulation Monte-Carlo
HB: Harmonic Balance
HPM: High Power Microwave
MPP: Massively Parallel
PIC: Particle-In-Cell
SGEMP: System-Generated EMP
SREMP: Source-Region EMP

We Support Many Applications and Customers

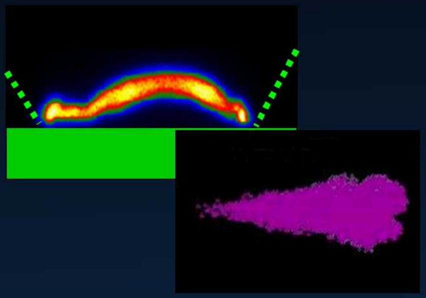
New EM environments & devices



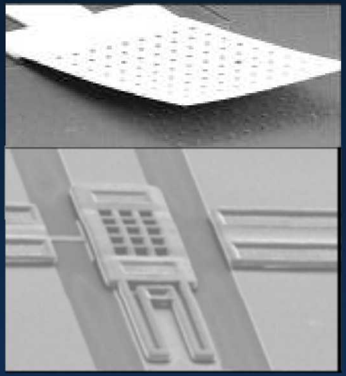
System response to EM, lightning, high voltage & SGEMP Environments



High Voltage Sciences

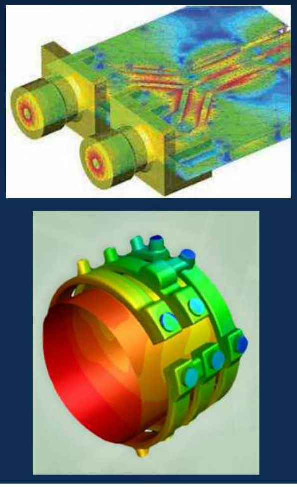


HV Standoff, Arcing, Leakage Currents, Electrostatic Discharge

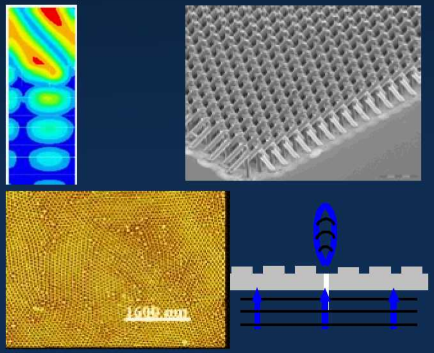


High-Frequency Cavity/Aperture Response, Advanced Antennas, RF-MEMS devices

Components

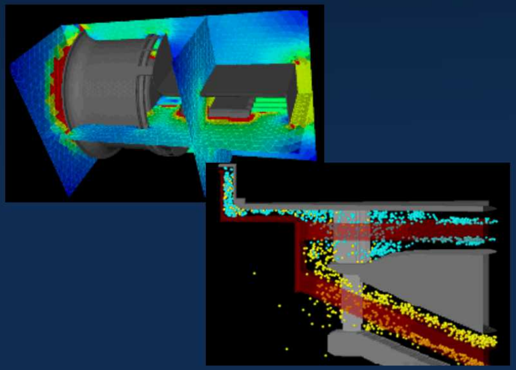


Engineered Materials



Photonic Band-gap Devices; Plasmon Structures; Metamaterials

Fast Pulsed Power



Z-pinch apps for NW, Mat'l Dynamics, Fusion Energy

Theory and Numerical Simulation

- In-house codes offer the advantages that
  - Models and capabilities have been tailored to our problems
  - Physics models are known and documented
  - Models, algorithms can be easily accessed by the analyst

- Theoretical analysis is often used when
  - Detailed models, parameters are not available
  - Bounding calculation is desired
  - Advance our in-house code suites

CST MICROWAVE STUDIO®

Building a toolbox with a wide range of capabilities for decision support, experimental support, system design, and research is essential.

EM-Circuit-Device Code Coupling

- ❑ Different application drivers have different requirements (e.g. physics fidelity, geometric fidelity, computational speed, etc.)
- ❑ Hierarchy of electrical model abstractions have been developed for ionizing radiation – the same will be needed for EM along with coupling

Increasing Fidelity

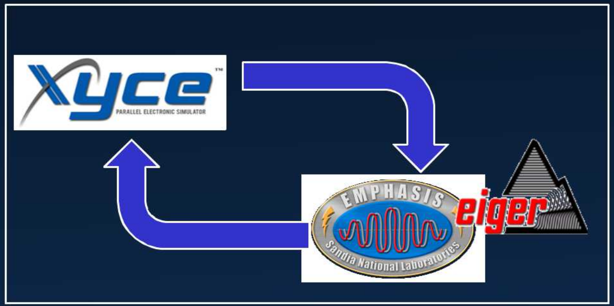
Empirical Based
(Data Model)

Analytical Physics Based
(Compact Model)

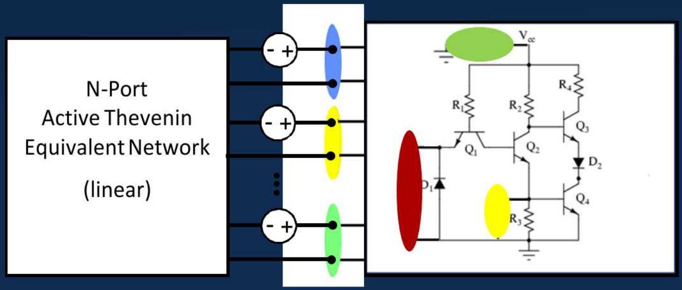
Physics Based
(TCAD)

Increasing Comp. Speed.

Hierarchy of Model Abstraction



Code-to-Code Coupling

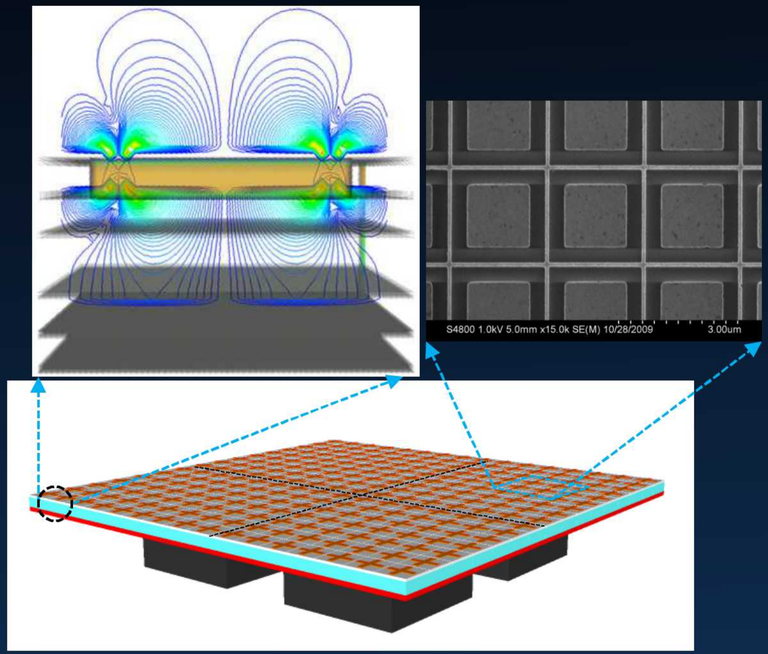


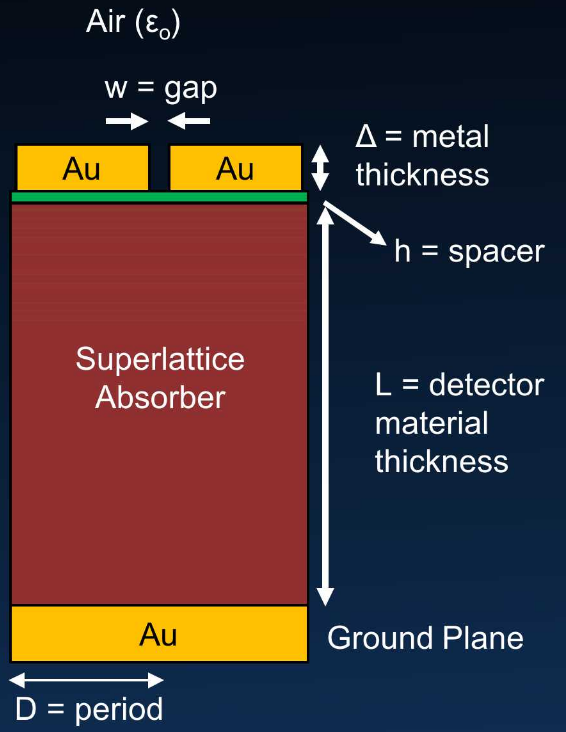
Equivalent Circuit

Emulates circuit response to EM

Hierarchy of Coupling

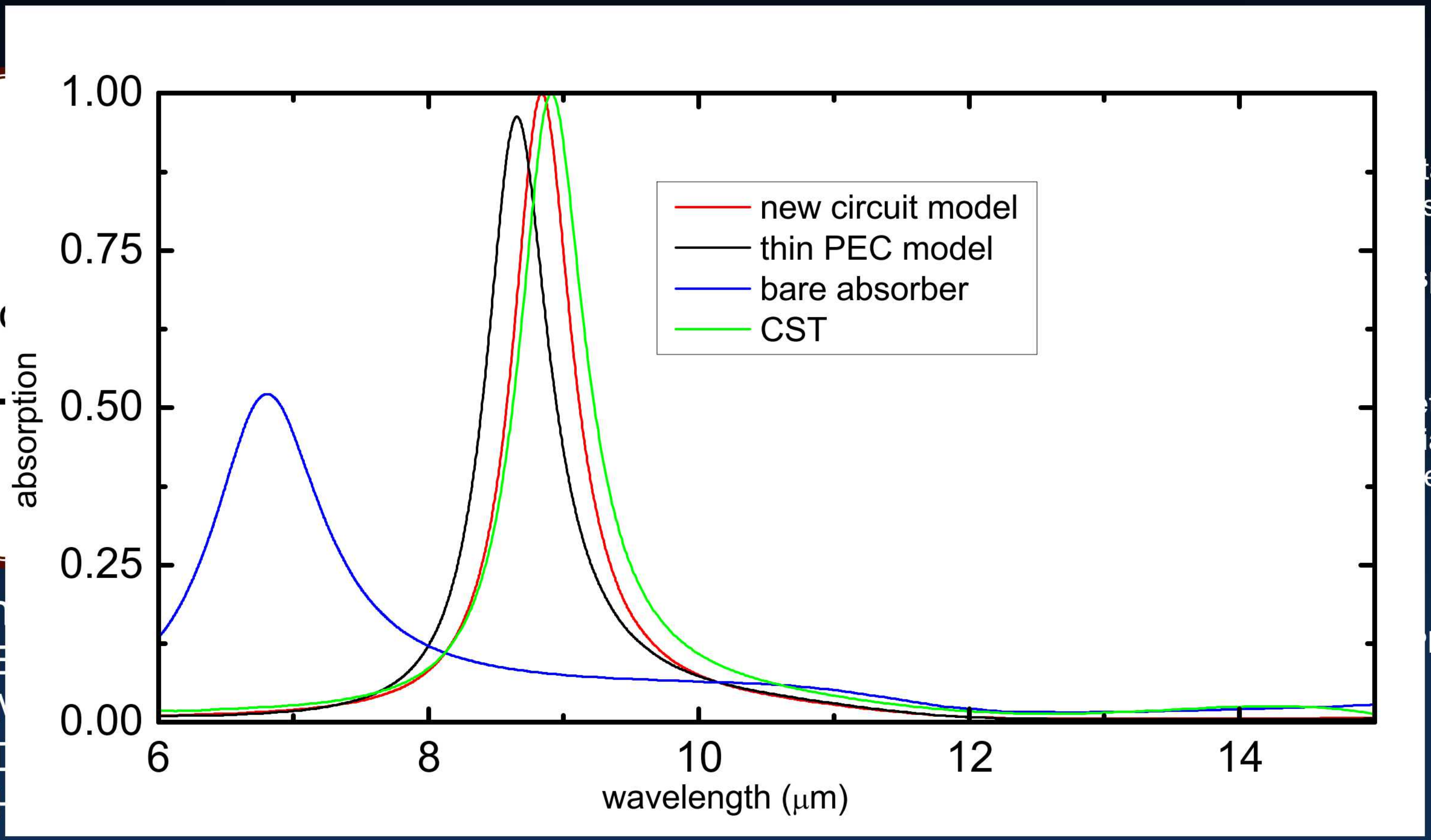
Application #1: Nanoantenna Enabled Detector (NED) Design





- ❑ Use a nanoantenna array (metasurface) to couple incoming radiation to the thin detector
- ❑ Realize maximum-absorption design; facilitated by a tool that allows for
  - Design intuition
  - rapid and accurate survey of the multidimensional parameter space

Advanced Circuit Modeling Enables Optimized NED Design



Nanoan

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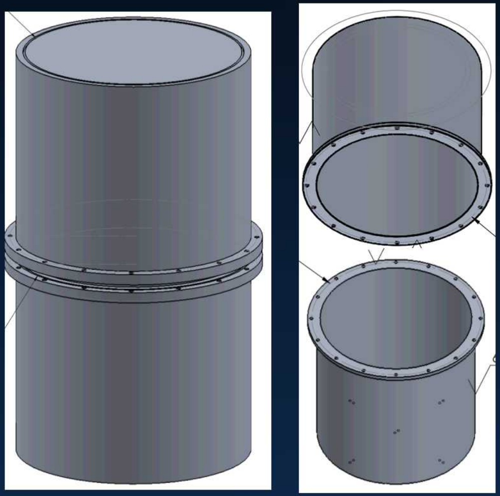
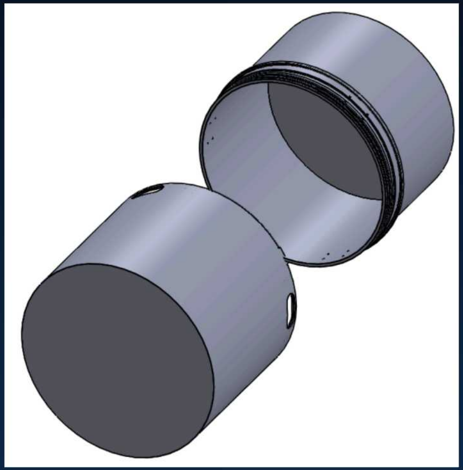
❑ Rigorous analytic circuit model enables faster-turnaround NED design with nearly 100% absorption

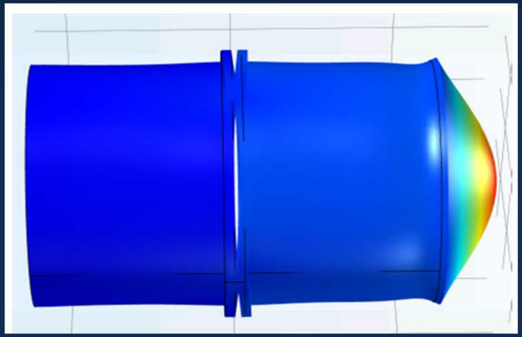
Addressing Combined-Environment Responses: EM + Vibration

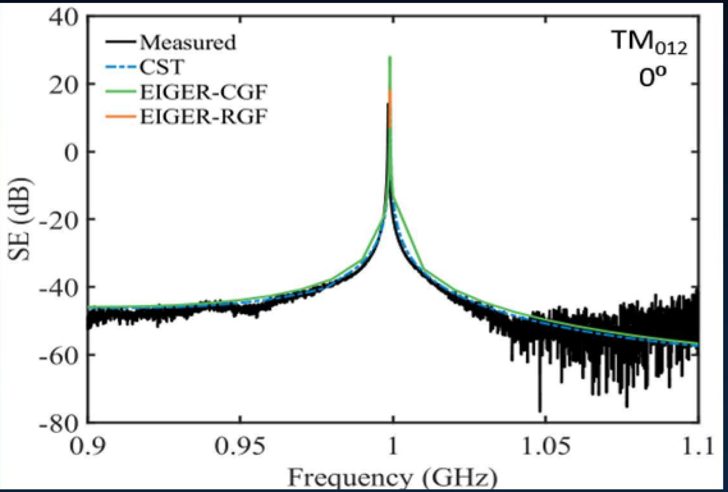
Bolted-Joint Vessel

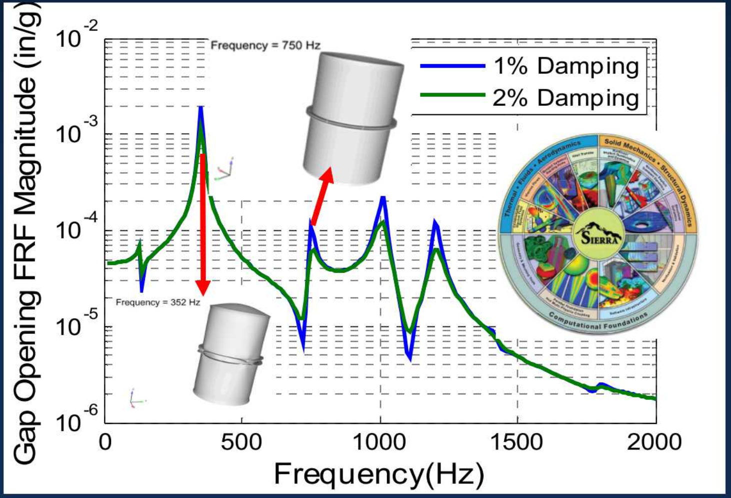


Breach-Joint Vessel

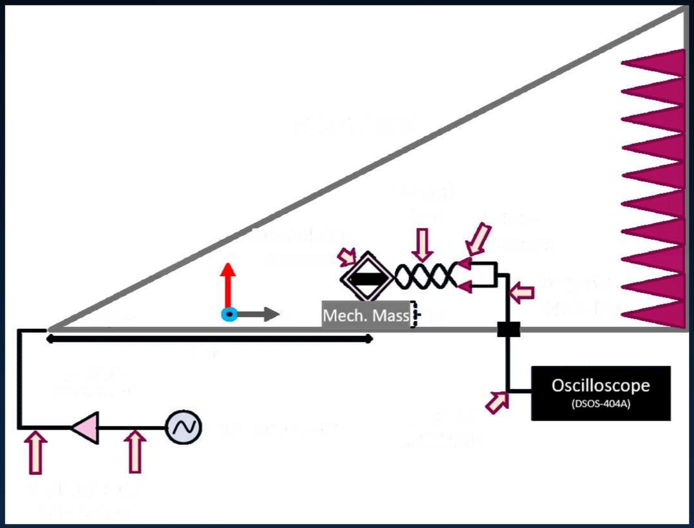


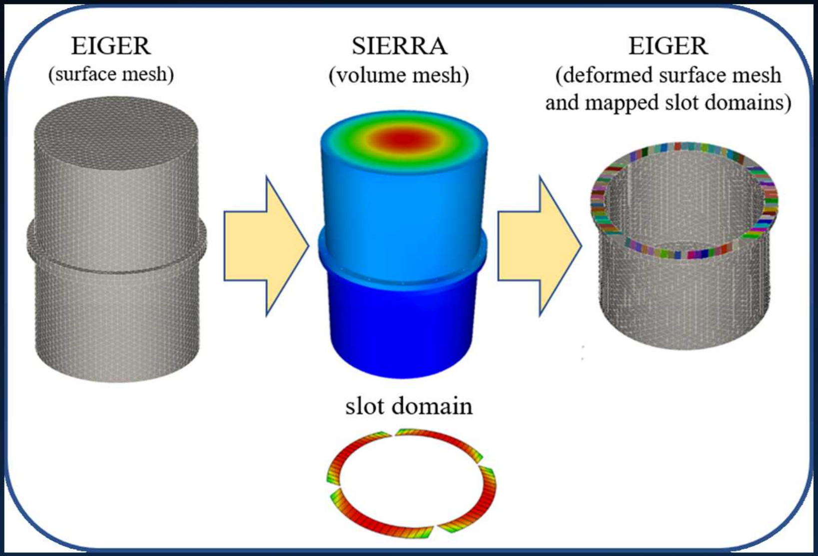


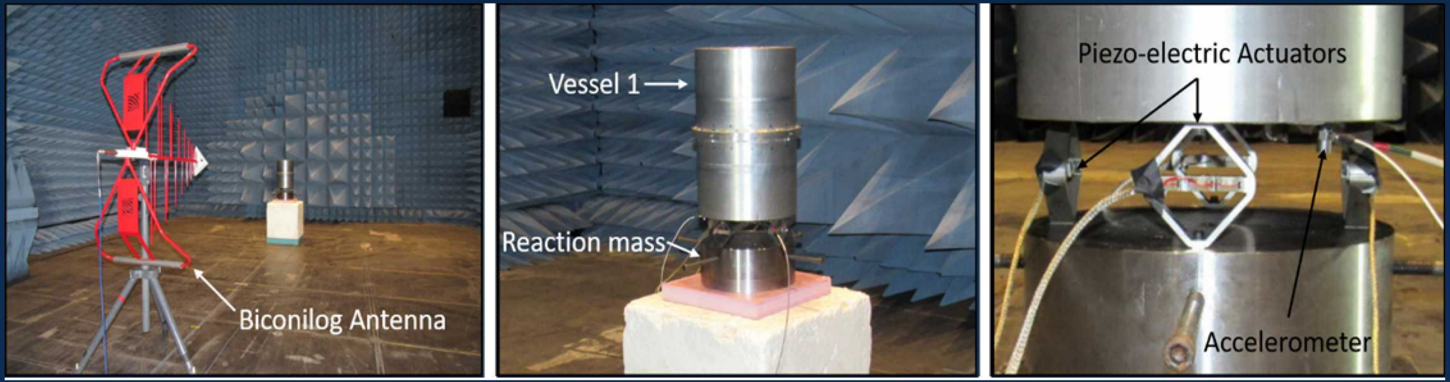




Interplay between Simulation and Testing for Advancing Understanding







Summary

- Electrical Sciences is an organization at SNL that focuses on:
  - Electromagnetics
  - Plasma Physics
  - High-Voltage Sciences
  - Circuits and Devices
  - Power System and Electronics

- Within Electrical Sciences, subject-matter expertise covers:
  - Electrical Engineering
  - Physics
  - Computer Science
  - Mathematics

- “Integrated” Projects:
  - Multidisciplinary Research (material scientists, mechanical engineers,..)
  - Experimental and ModSim/Analysis Efforts

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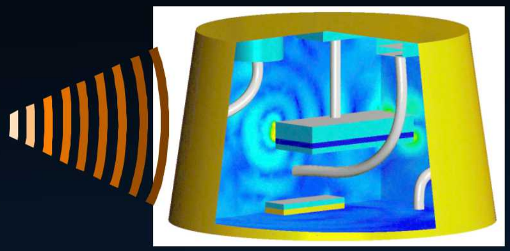
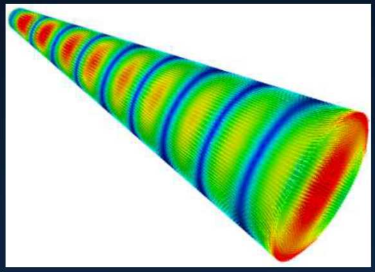
NW Mission Decision Support

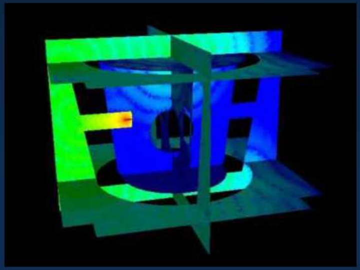
System Response to EM Fields



EM Environments

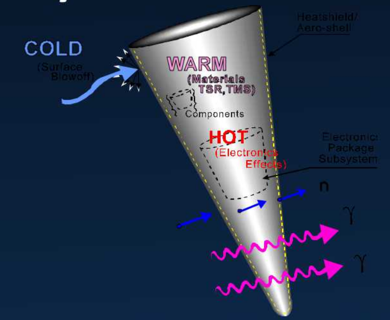


EMR, EMC, EMI

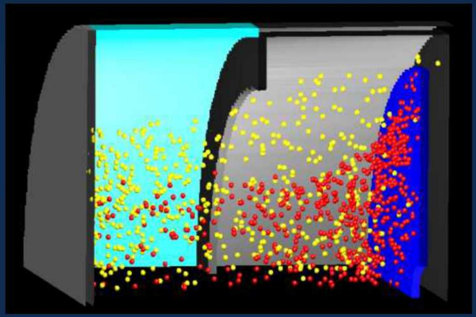


Radar:
Signal coupling to system

X-ray Environments



Cable, Cavity, Box SGEMP, SREMP



PIC Emission

- Advanced electromagnetics (EM) and plasma physics addresses:
  - STS normal EM environment
  - Radar/A&F design and performance
  - STS hostile (SGEMP) environment
  - NG ion optics
  - Microsystems
  - High voltage weapon components
- EMPHASIS Capabilities: full-wave time-domain with full coupling to particle-in-cell (PIC) plasma modeling, hybrid grids and solvers, coupling to XYCE
- EIGER Capabilities: 2D/3D full-wave frequency-domain & electro/magneto-statics

Sandia California - *Livermore*

On-site workforce: ~1,300

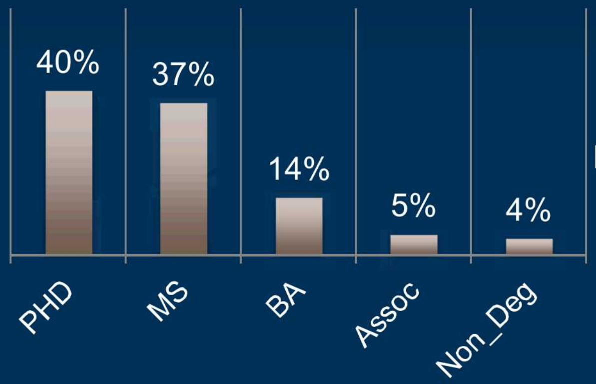
R&D staff: ~500

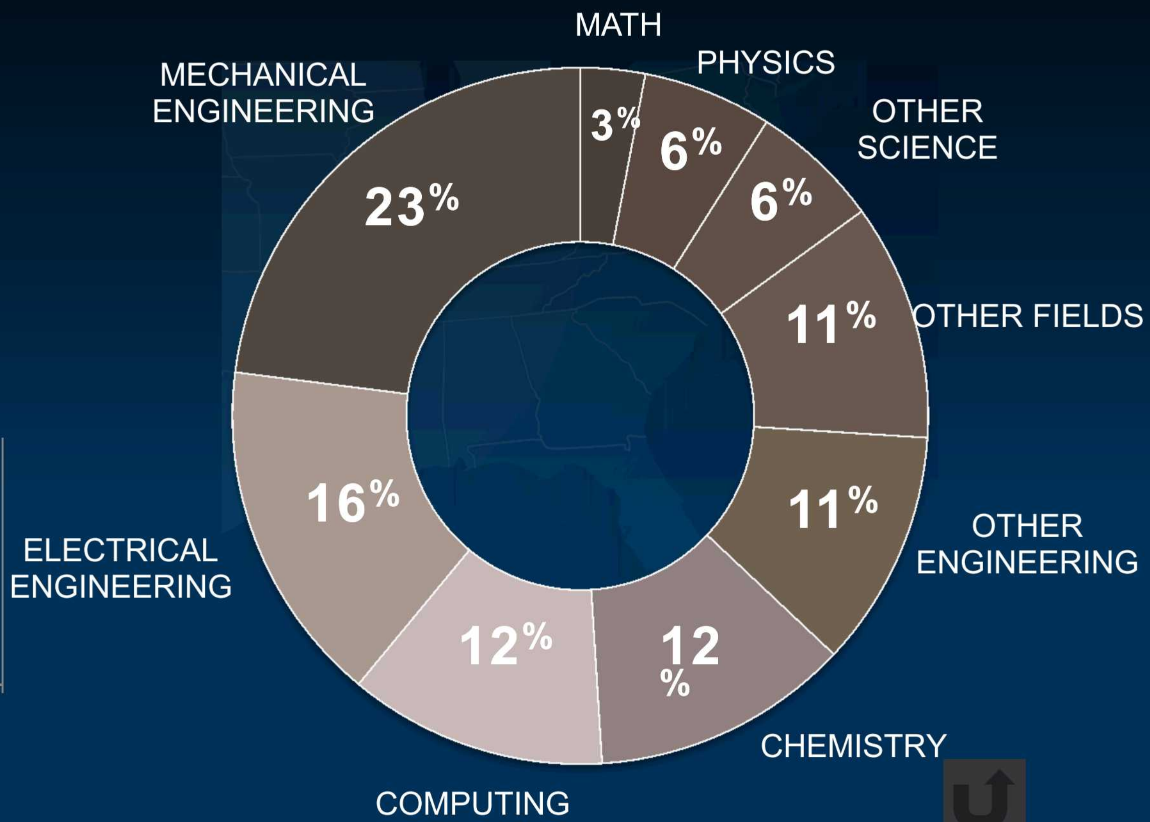
(excluding R&D Tech)

Distinguishing research capabilities:

- Applied Biosciences
- Combustion Research
- Information Systems
- Micro & Nano Technologies and *more*

Degree Level





High-Performance Computing

EMR computational needs are driven by frequency ranges and QMU.

Frequencies, QMU

- **Wide frequency ranges: kHz to W-Band**
  - Higher frequencies → Higher mesh density
- **QMU and high-*Q* drive needs for large number of runs**
  - Data ensembles to support QMU
  - High-resolution frequency sampling driven by high-Q cavities

Memory (PetaBytes)

- **Memory requirement – system matrix ($\propto N^2$)**
  - Higher frequencies → Higher mesh density → More DoFs (N)

For a typical system, boundary-element coupling simulations up to the W-band

10s to 100s of PetaBytes RAM

10-20 Petaflops / matrix solution
*For **each** frequency or excitation*

Computation (PetaFLOPS)

- **Compression techniques may be required at Exascale**
  - Compression reduces both memory and computation requirements
  - Needs rigorous V&V for applications