SAND2019-2252PE

Electromagnetic Analysis Capabilities

RS21 + SNL Information Session

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Sandia National Laboratories

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Outline

- Background on Electromagnetic (EM) Computational Capabilities

- Current/Future Code-Development Efforts
  - Modern development
  - Capability
  - Usability
  - Credibility

eiger

EMPHASIS
Sandia National Laboratories

Gemma

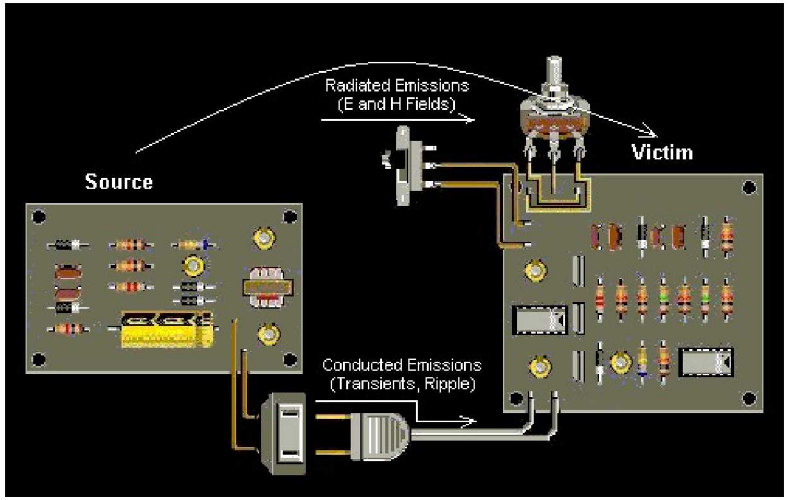
EMPIRE

Background

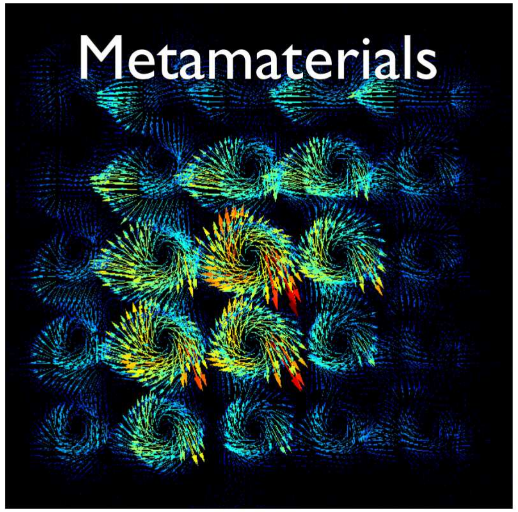
Wide breadth of activities

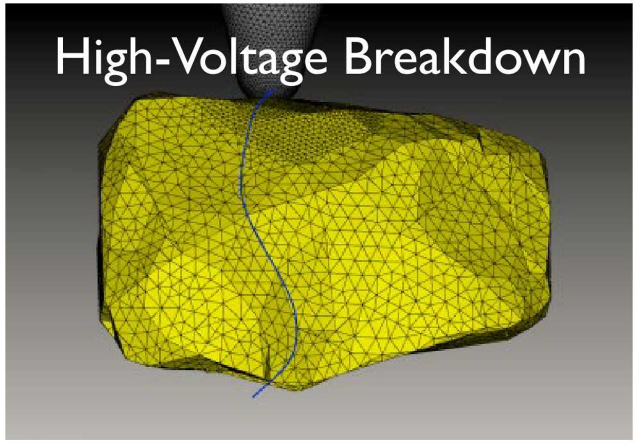
- Theoretical EM analysis and applied research
- Development of advanced modeling and simulation tools
- System design support, consultation on best practices
- Component and system-level qualification
- System "emergency" assessments

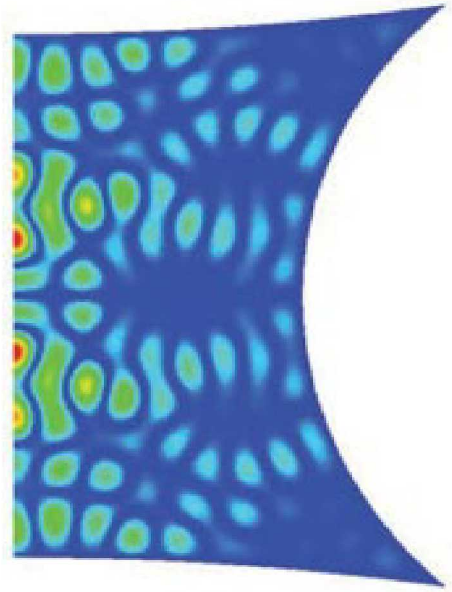
EM Interference



High-Performance Computing







High-Frequency Cavity Effects

Radiation and Electrical Sciences

- Core mission – Develop/maintain tools and facilities required to design, assess, and qualify the performance of weapon systems in electromagnetic and plasma environments.
  - Ensure that weapons are *safe and reliable* in normal and abnormal environments
  - Assess and design for *survivability* in a hostile environment
- Realizing the mission
  - Historically, testing was used for both assessing system performance and qualification
  - Currently we use a combination of validated simulations, theory, and testing

RAMSES

ITS SCEPTRE NuGET EIGER EMPHASIS Xyce Charon CHEETAH Gemma EMPIRE

RAMSES: A radiation and electrical effects code suite

Gemma EMPIRE

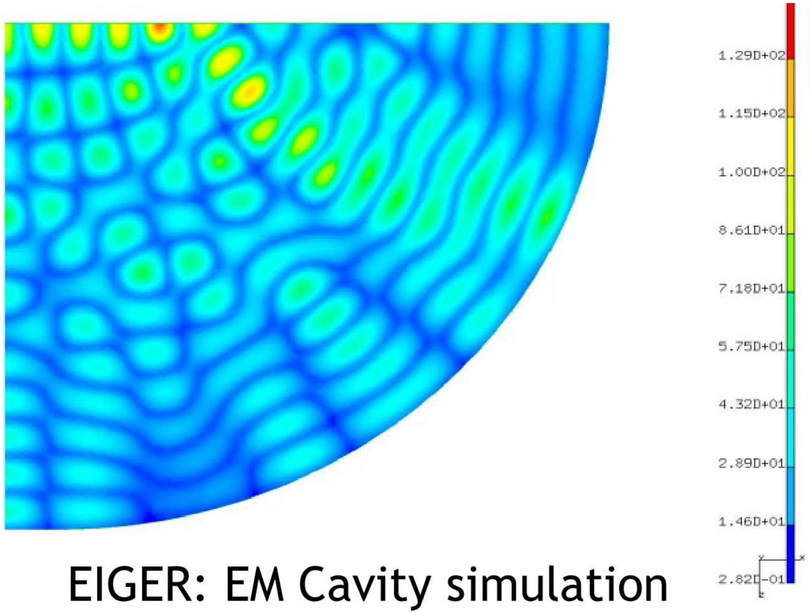
NW Electromagnetic Effects

Theoretical analysis:

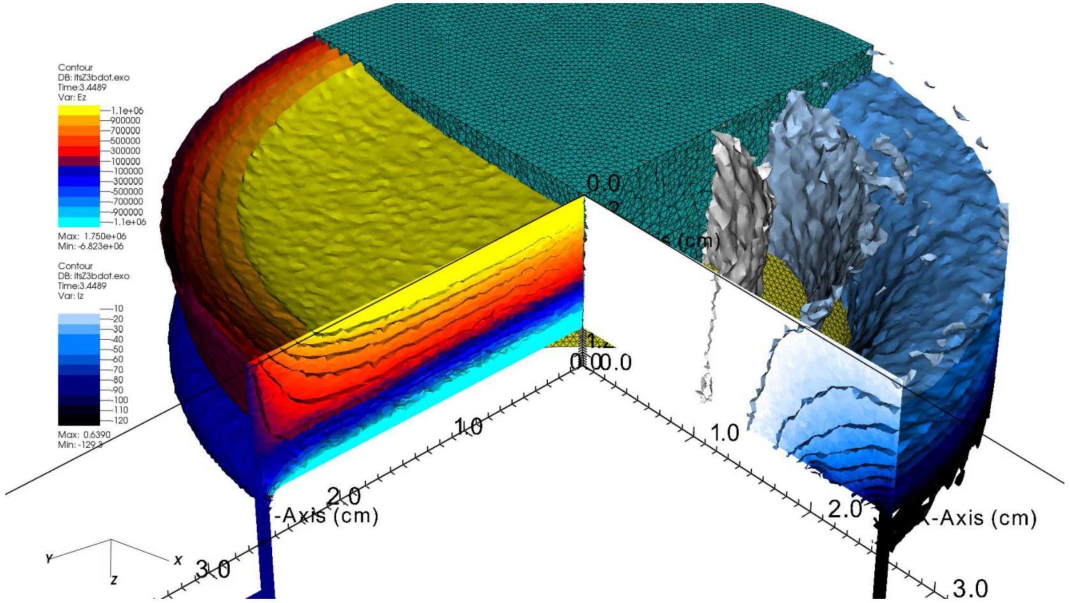
- Detailed models, parameters are not available
- Bounding calculations are required
- Support of code/model development (verification, new physics models)

Numerical Simulation:

- EIGER/Gemma: EM/Electrostatic
  - Integral Equation, Method-of-Moments
  - Frequency-Domain
- EMPHASIS/EMPIRE: EM with Particle-In-Cell
  - Finite-Element Method
  - Time-Domain

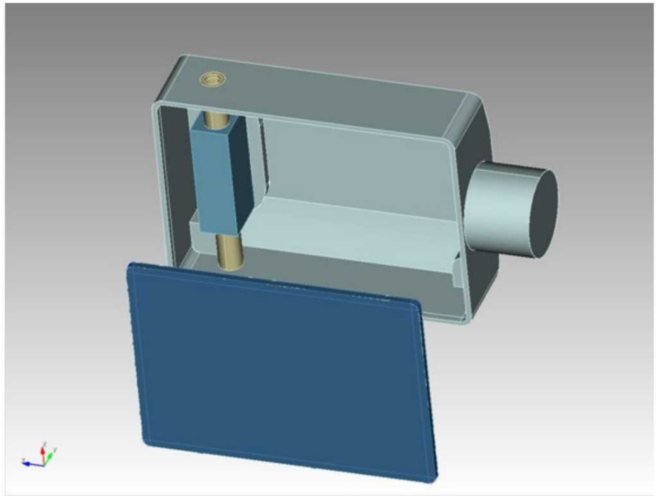


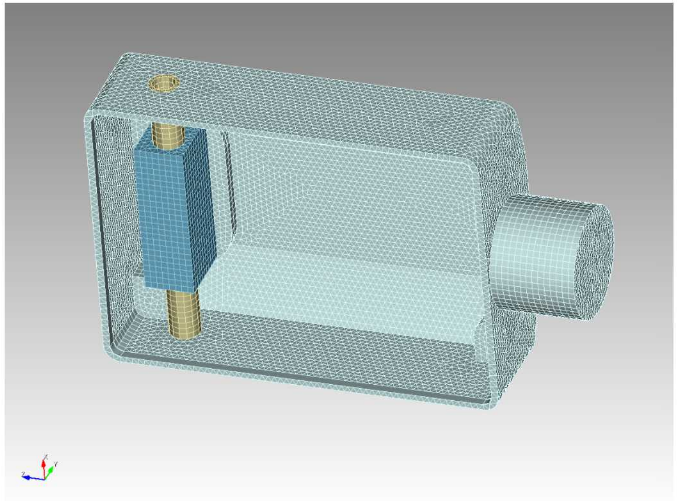
EIGER: EM Cavity simulation



EMPHASIS: B-Dot Plasma simulation

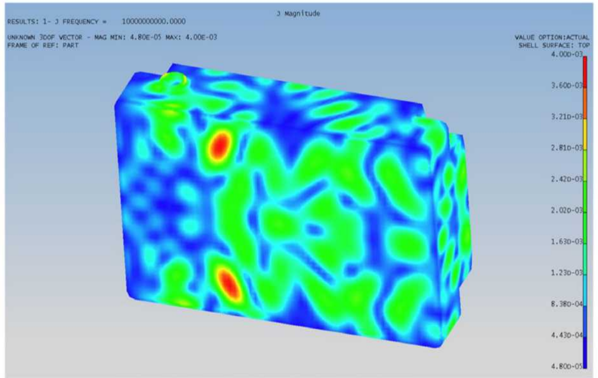
EIGER for EMR Design Considerations



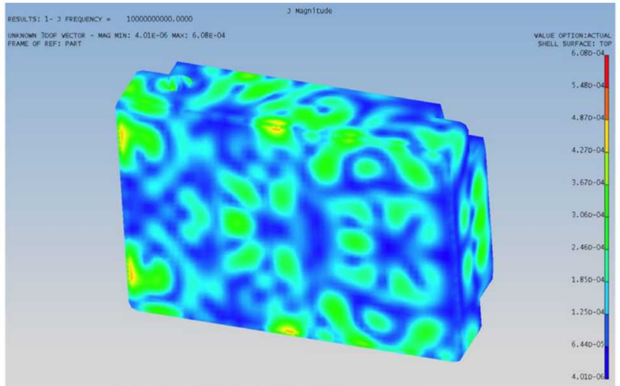


Simplified model showing lid and cotton phenolic tube points of entry: (1) Cover and case have an insulative anodic coating that prevents electrical bonding (2) Non-conducting cotton phenolic tubes penetrate into the case

- Simulated EM coupling into the case via these pathways to gauge their relative effects
- Provided general guidance on EM shielding techniques

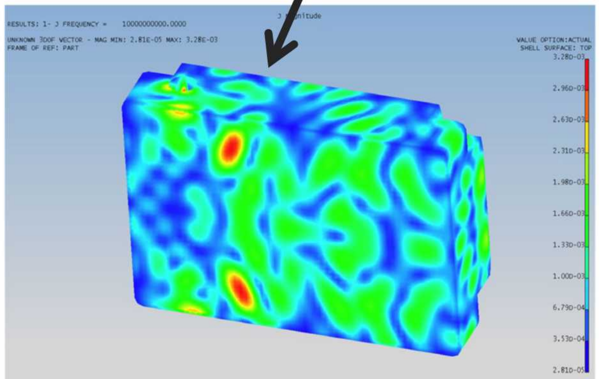


Lid and tube coupling



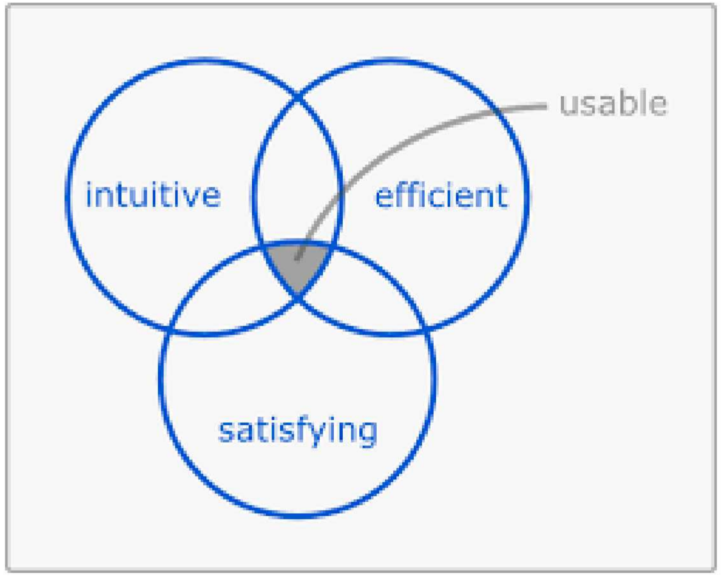
Gap coupling only

Cotton-phenolic tubes provide coupling pathway



Tube coupling only

Code Usability



- For this component-designer request, a qualitative understanding of the EMR coupling performance was requested

- In these types of scenarios, we should consider
  - Reduced-order models for quick calculations and ensemble calculations
  - Simplified workflow allowing/facilitating a larger user base

- Automated report generating to archive results and simulation parameters related to NW calculations

Suite of EM Capabilities To Meet Mission Needs

Capability	Usability	Use Cases	Accelerated R&D	UQ/V&V
SNL EM Codes	Expert Users	NW Specialized Capabilities/HPC enables large simulations	Access to Physics Models/ Implementation	Ensemble HPC Simulations
Theoretical Analysis	NA	Quick, Bounding Calculations	Feeds Code Development/ Reduced-Order Models	Model Verification
Experiment	NA	Supports SNL Code Extensions	Physics Discovery	Model Validation
Commercial Codes	User Interface/ Integrated Work Flow; Quick Ramp Up for a New User	Exceptional Feature Coverage for Non-NW Common Use Cases	Can Provide Faster Time to Solution	Benchmarking

Current NW Applications of our EM Tool Suite

Design Support

- Existing design; elucidate how quantitative coupling process works
- New design; provide guidance on characteristics require for improved EM performance

Test Support

- Pre-test analysis to guide testing
- Explanation of measured results

Qualification evidence is formed by a combination of testing, numerical simulation, and theoretical analysis

System Qualification

- Inform the environmental specifications internal to the weapon
- Extrapolation of measured response to address experimental gaps
- Combine with experimental results to increase credibility of the qualification evidence

Current/Future Code Development Efforts

Next-Generation Simulation Capability

EIGER→ Gemma

EMPHASIS→ EMPIRE

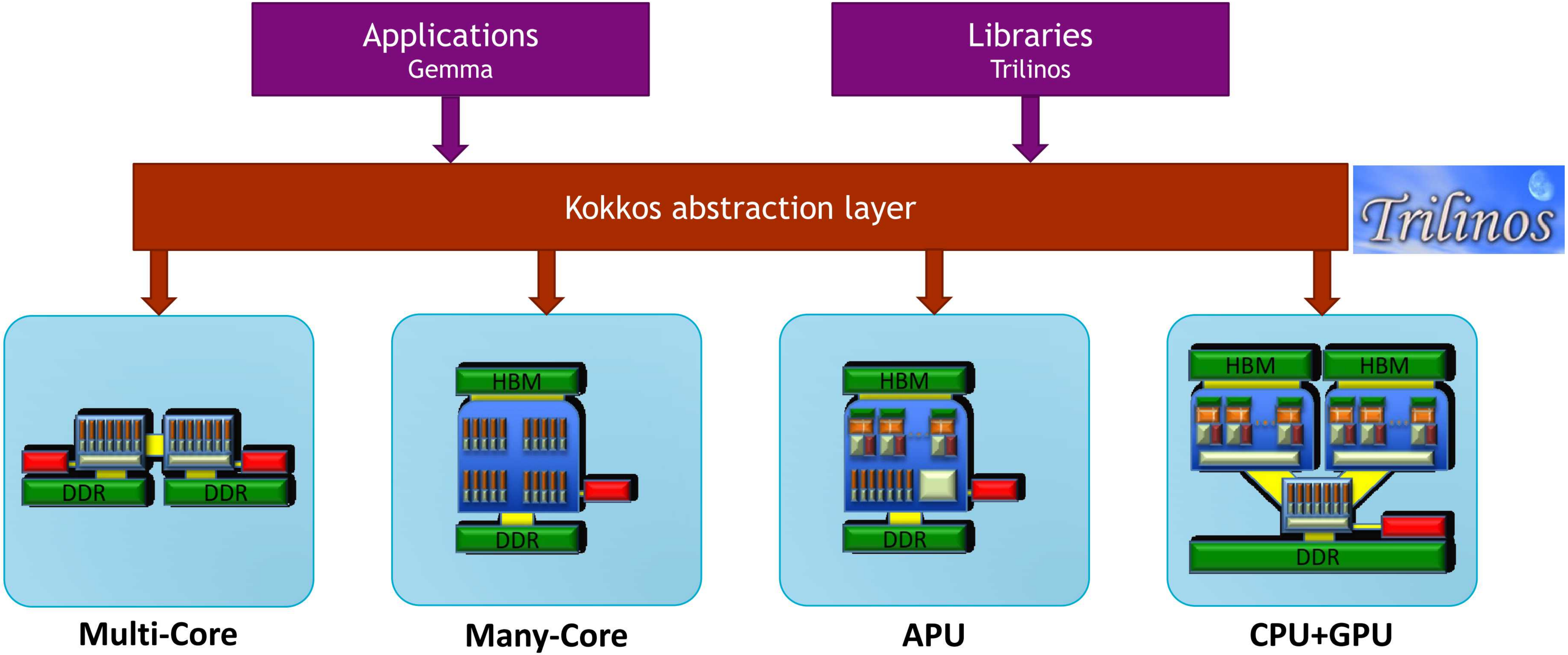
Next-Generation EM Codes

- **Modern development environment**
  - C++ 11 (driving toward newer C++ standards)
  - git + cmake environment supporting multiple target compilers and architectures
  - Templated implementation (in progress) for code readability and maintenance
  - Scrum process enabling increased communication and transparency among team members

- **Integrated, flexible, extensible physics**
  - Retain core-functional capabilities of current codes, *and extend regimes of applicability*
  - Alternative methods for flexibility
  - Capability to couple EM/plasma to other domains; eg. circuit response (mechanical, thermal)

- **Credibility**
  - Verification and validation processes (as well as expertise) baked in from the start
  - Framework and workflow developed to facilitate uncertainty quantification studies, comparison between data sets, and embedded sensitivities.

Sandia's Approach



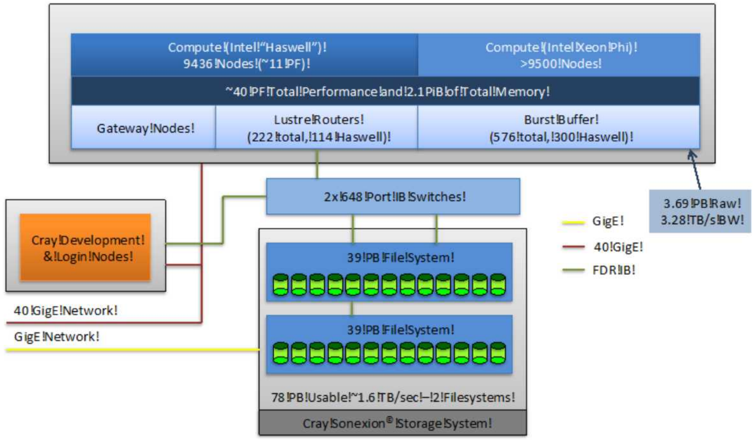
Kokkos is the cornerstone for performance portability across next generation HPC architectures at multiple DOE laboratories and other organizations.

Capability and Performance on Next-Generation Hardware

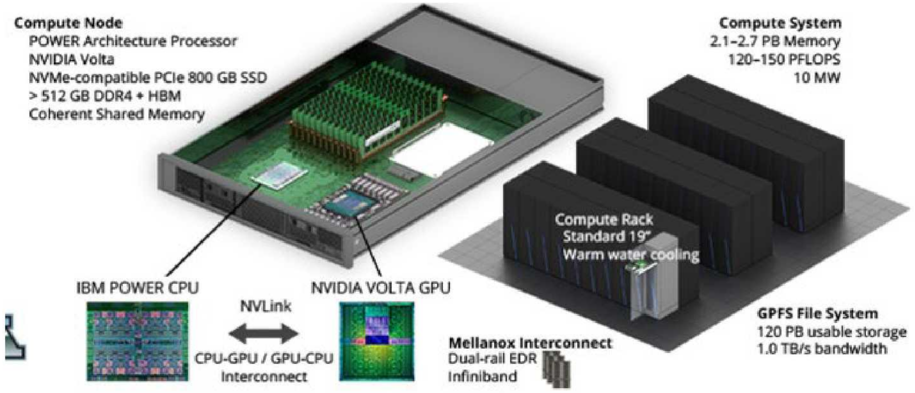
MPI Paradigm
- MPI inter- and intranode parallelism
- High processor clock speed
- High memory per processor

Heterogenous Paradigm
- MPI internode parallelism
- Threading intranode parallelism
- Low processor clock speed
- Low memory per processor

Trinity: A Mix of CPU & MIC nodes



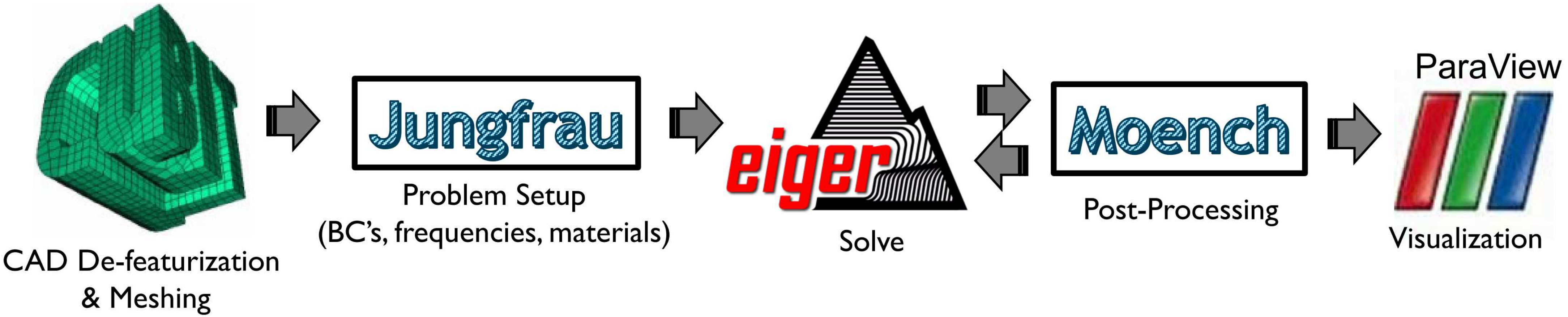
SIERRA: CPU & GPU on a single node



- Ideal Development:
  - Writing architecture independent source code
  - Using multicore technology efficiently

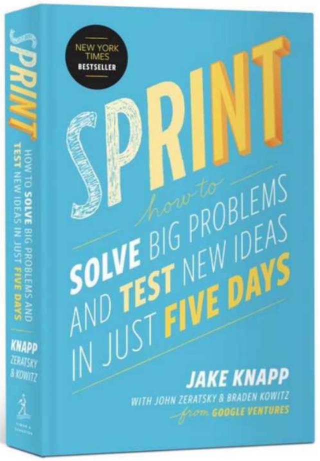
EIGER and Current Workflow

- Pre-processing:
  - Significant level of effort required in preparing the model and mesh
  - Mechanical joints are key features for calculating EM leakage into a system
  - The leakage is often dictated by the electrical contacts at the mechanical joint
  - *Resolving the mesh to capture the joint details (and frequency) is critical*



Google Venture Sprint—Enable Participants to Focus

- The sprint is a five-day process for answering critical business questions through design, prototyping, and testing ideas with customers.



Long Term Goal (5-10 years)

Deliver a user-focused, trusted solution with modular physics for use in NW design through qualification

5 Day Process

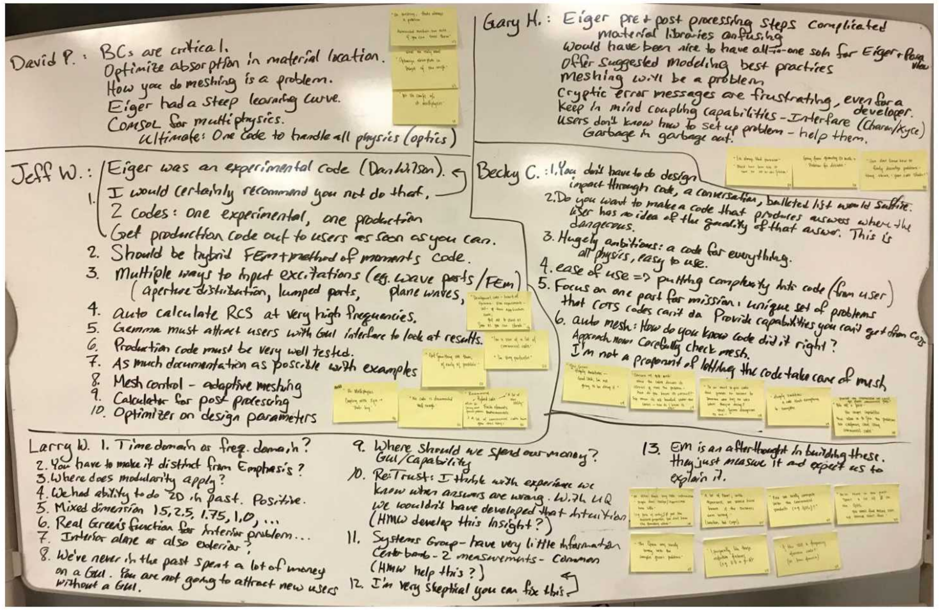
- Meet with Experts and Choose a Target
- Remix and Improve Existing Solutions
  - Comsol: Multiphysics, Documentation
  - GMESH: meshing via GUI and scripting
  - FEKO: "Guided" workflow
- Critique Solutions/Select Winning Pieces
- Build Prototype
- Test Prototype with Users

SPRINT

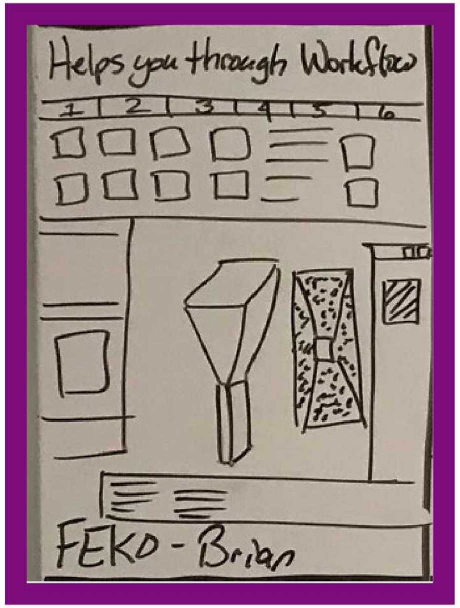
Gemma

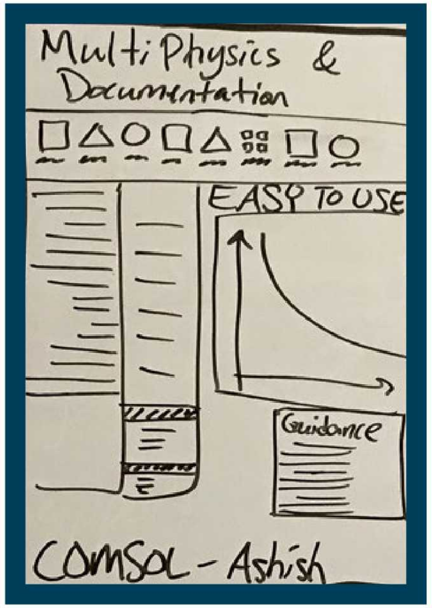
Google Venture Sprint—Process for Deciding on One Prototype to Test

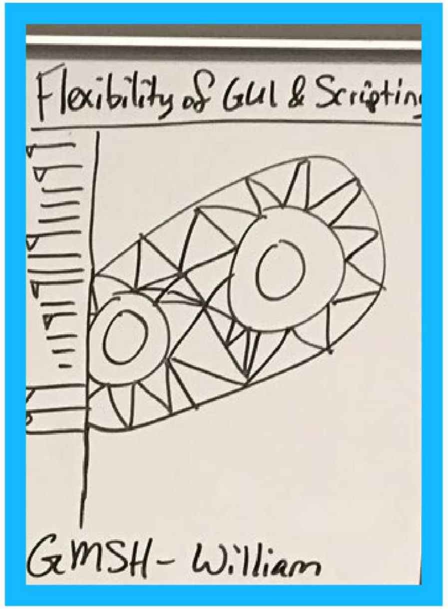
Interview EM experts



Lightning Demos Existing Solutions



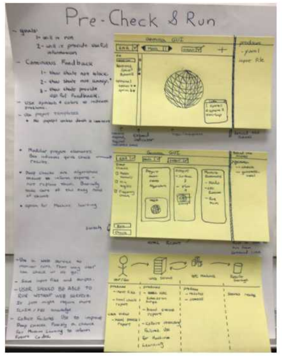




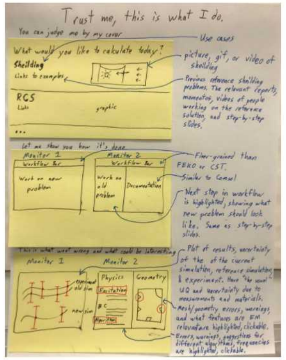
- "Automated meshes are nice… if you can trust them"
- "Get [Gemma] out to users as soon as you can. Iterate."
- "Do we want to give codes that provide an answer to someone who has no idea what they're doing? That seems dangerous to me."

Pre-Decision→ Present Concrete Solutions

Pre-Check & Run



Trust me, this is what I do

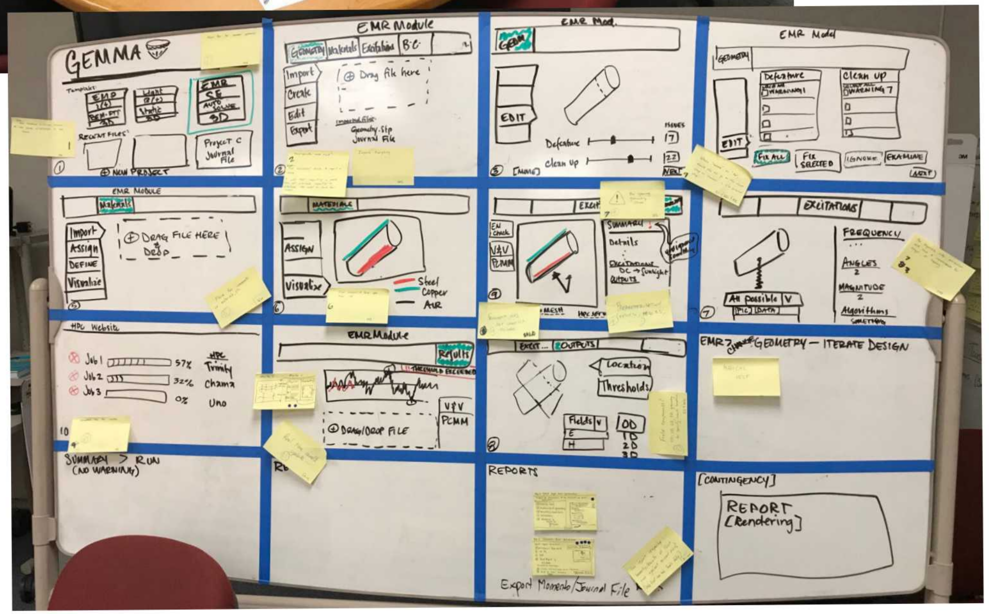


SPRINT

Google Venture Sprint—Build Gemma Prototype

- Fake It!
  - Build just enough to learn, but not more
  - Reactions are priceless
  - PowerPoint
  - Task for interview
  - Walk through demo

Gemma

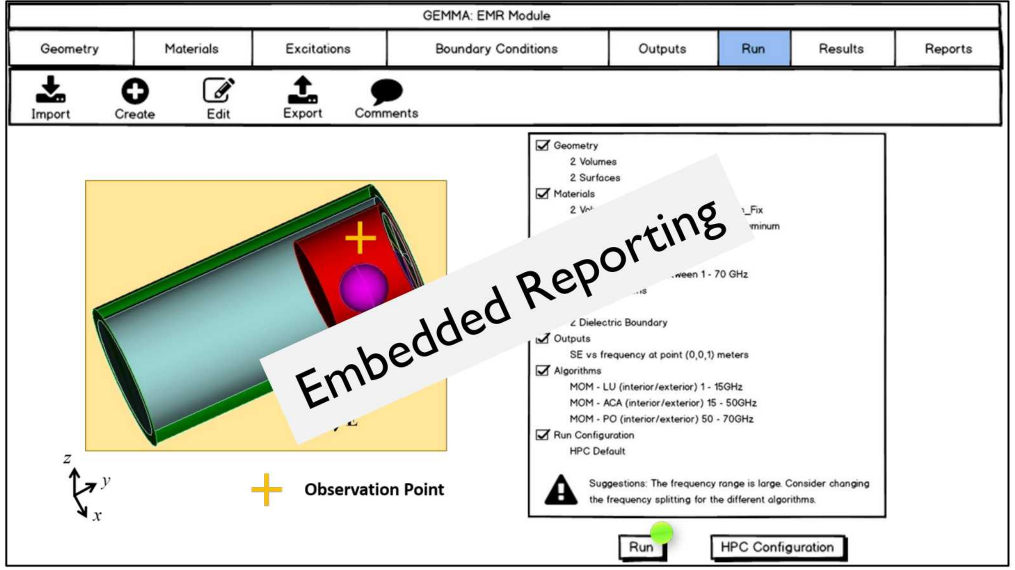


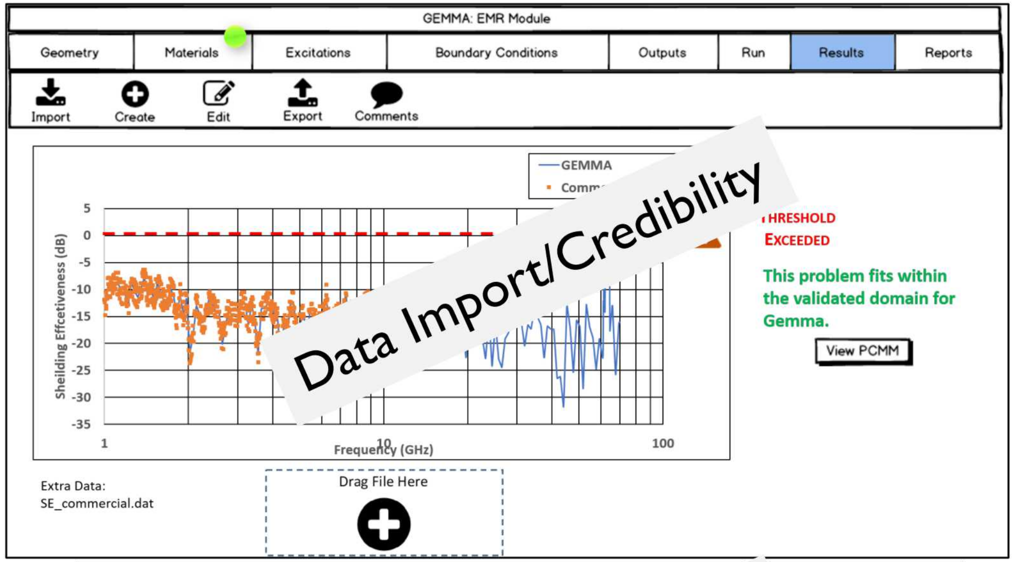
SPRINT

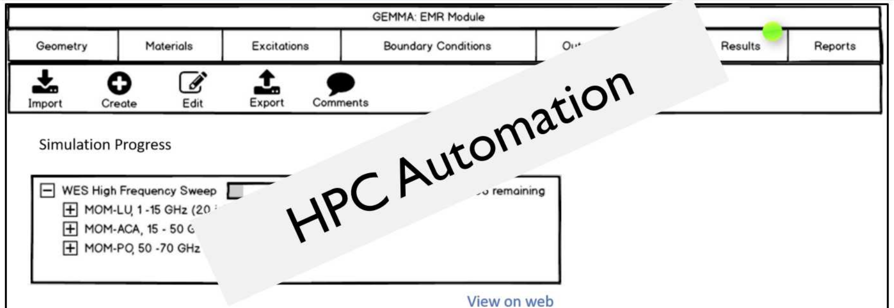
Google Venture Sprint: Results

- Key concepts we explored:
  - How much control do users want/need over algorithm choices?
  - Does 'defeaturing/clean-up' of solid model & mesh make sense?
  - Is credibility communicated?
  - Is a final simulation report valuable?

- User Findings:
  - A modern GUI is an absolute must have; should include a workflow
  - Reporting capability is a critical, high value component
  - Users really appreciated import feature for comparison to experimental or other simulation results
  - Users universally delighted by the pre-run summary and HPC automation

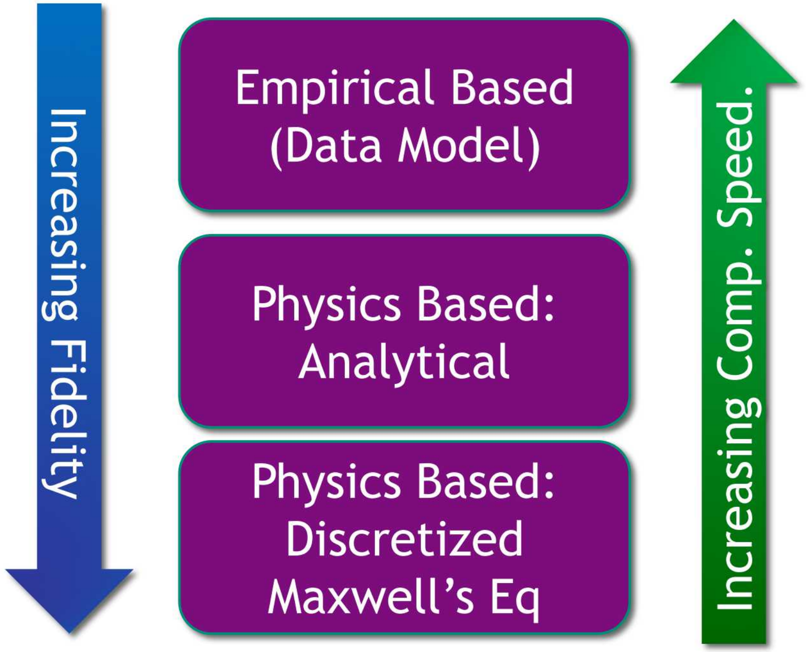




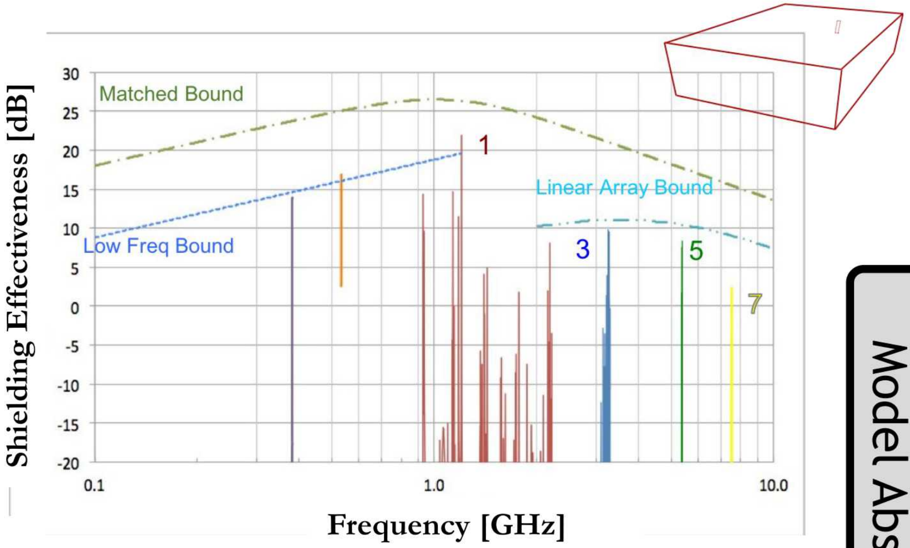


Embedded Layers of Abstraction

- Different application drivers have different requirements
  - Physics Fidelity
  - Geometric Fidelity
  - Computational Speed



Hierarchy of Model Abstraction

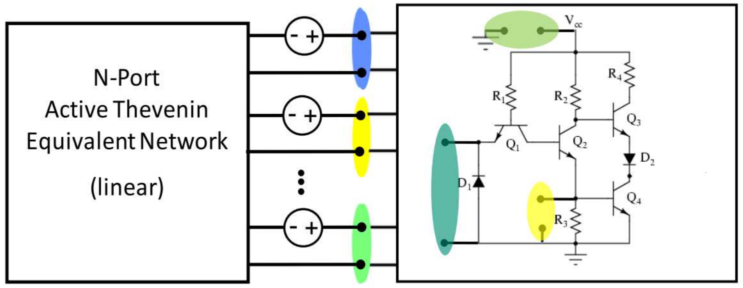


Analytic Methods For SE Response

Gemma

Equivalent Circuit

Emulates system response to EM

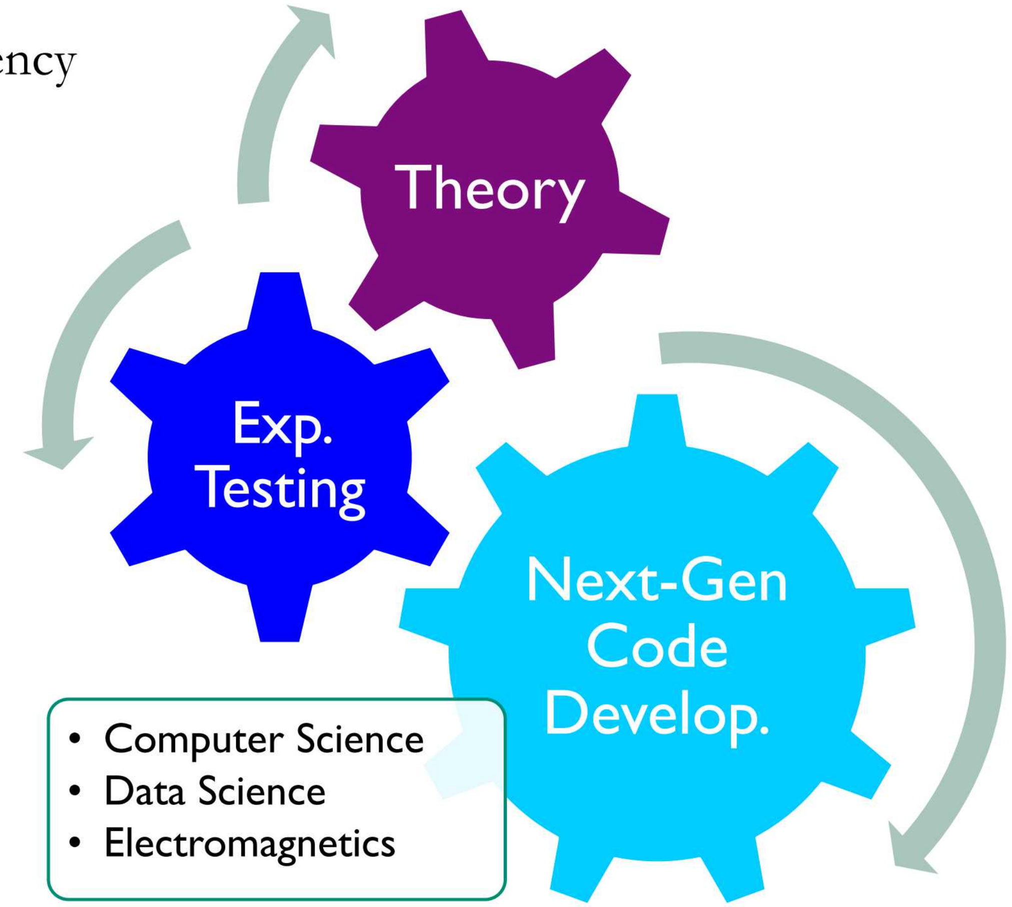


EM to circuit code coupling

Model Abstraction Examples

Key Take-Aways

- Next-generation code goals are to
  - Design/develop the code with improved workflow and efficiency
  - Provide an integrated code capability allowing for embedded data processing, experimental/simulation data archiving, integrated experimental/simulation data analysis
  - Provide timely and validated solutions to our NW customers
  - Design/develop the code so that it can provide value in the early design cycle



Gemma EMPIRE

Thank you