INL/CON-22-68724-Revision-0

Electromagnetics and Advanced Manufacturing Simulation Development within the MOOSE Ecosystem

August 2022

Changing the World's Energy Future

Casey T Icenhour, Stephanie A Pitts, Alexander D Lindsay

Idaho National Laboratory

INL/CON-22-68724-Revision-0

Electromagnetics and Advanced Manufacturing Simulation Development within the MOOSE Ecosystem

Casey T Icenhour, Stephanie A Pitts, Alexander D Lindsay

August 2022

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517, DE-AC07-05ID14517

Electromagnetics and Advanced Manufacturing Simulation Development within the MOOSE Ecosystem

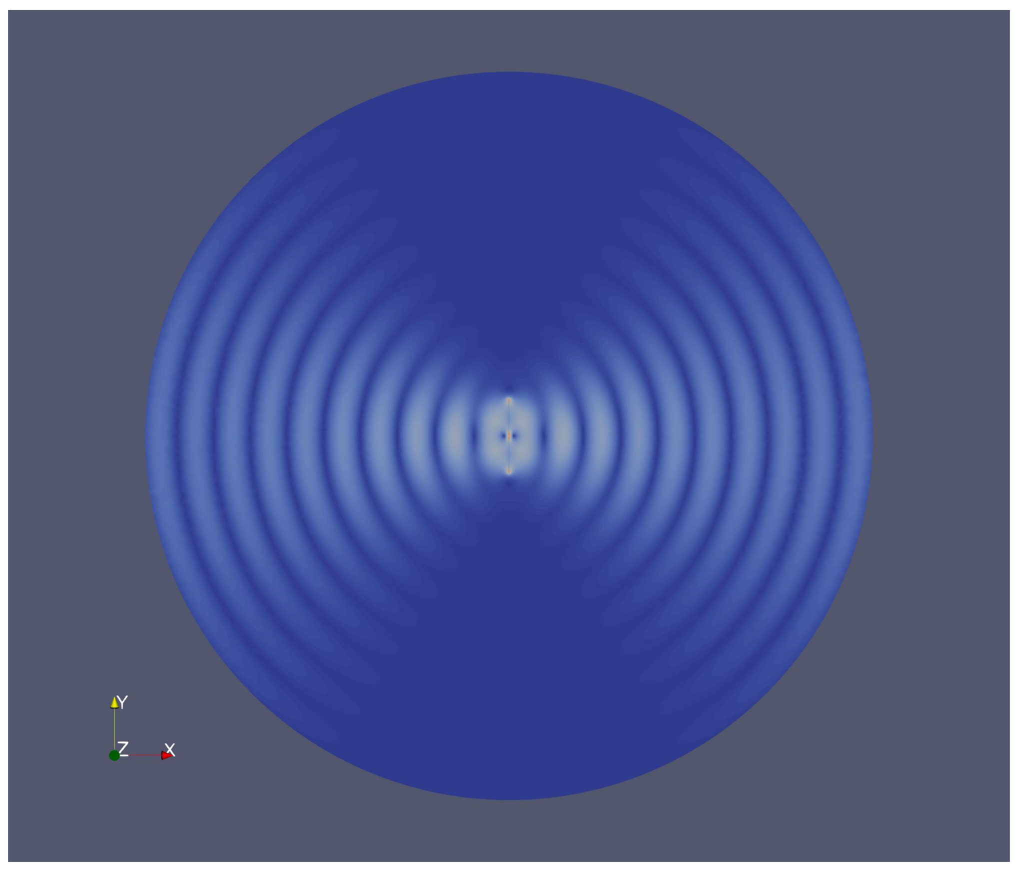
Casey Icenhour[1,2], Stephanie Pitts[1], Alexander Lindsay[1]

[1]Idaho National Laboratory, Idaho Falls, ID, USA

[2]North Carolina State University, Raleigh, NC, USA

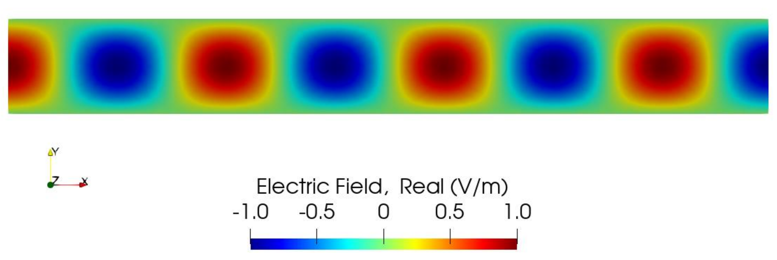
Introduction

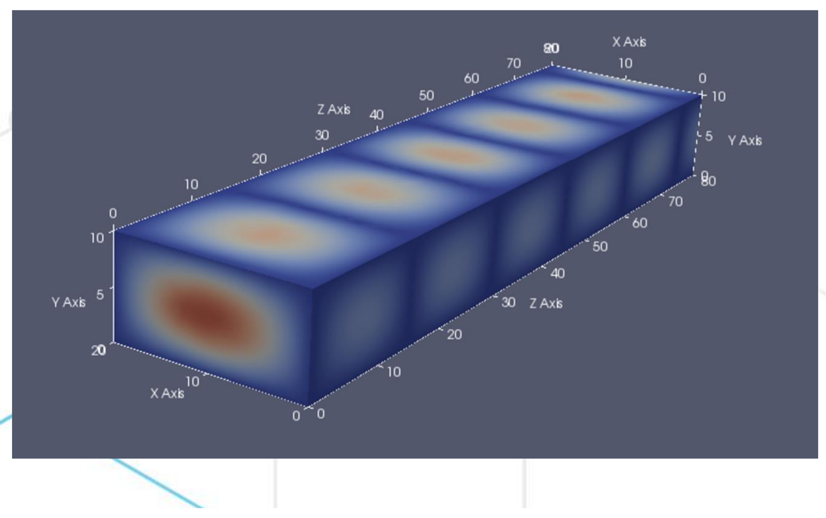
- MOOSE (Multiphysics Object Oriented Simulation Environment) is designed to solve highly non-linear, coupled systems of equations across many different physical domains utilizing the finite element method (FEM) and the finite volume method (FVM).
- MOOSE contains a central framework library of mathematical terms and libraries alongside a set of more specific physics modules that applications can use and inherit.
- The MOOSE electromagnetics module (EMM) was developed to provide a general simulation tool for modeling a wide range of problems encountered in computational electromagnetics.
- The EMM has since been used in conjunction with the MOOSE heat conduction module to model the engineering scale of the electric field assisted sintering (EFAS) process for novel material production.

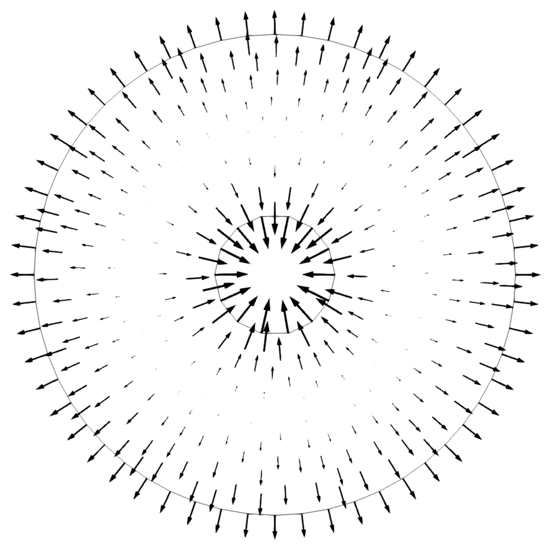


Electric field radiation pattern of half-wave dipole antenna in vacuum driven by a 1GHz signal, simulated using the MOOSE EMM.

The MOOSE Electromagnetics Module: A General Purpose Tool for Electrodynamics Simulation







(Top left) 2-D real electric field value (x-component) of a TM11 mode waveguide at 20MHz.

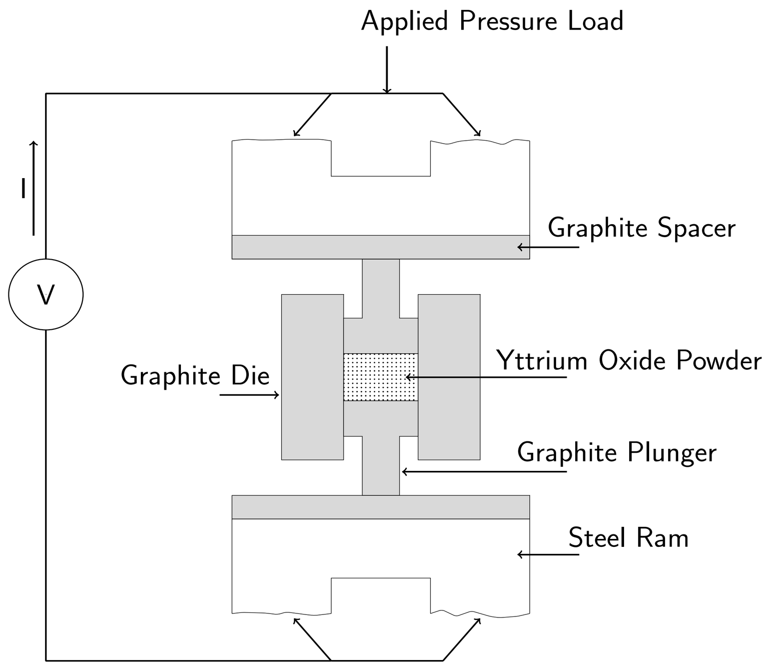
(Left) 3-D TM11 mode real electric field magnitude at 20MHz

(Top) TM01 mode electric field vector distribution in a coaxial waveguide

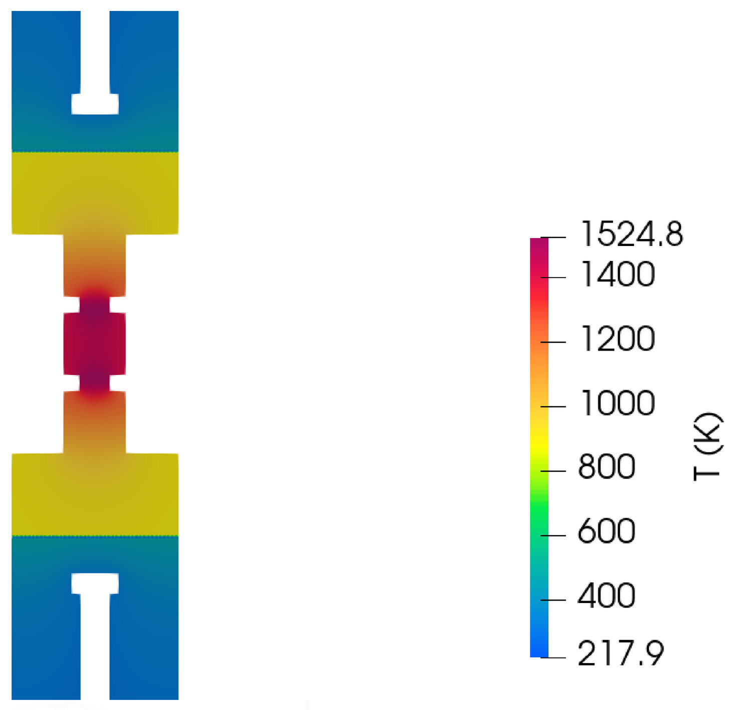
- The EMM solves Maxwell's equations for complex electric and magnetic fields in either steady-state (frequency domain) or transient modes.
- Originally developed for radio-frequency (RF) wave propagation and energy coupling for low-temperature plasma physics, the module was generalized for a wider range of applications and coupling to other MOOSE modules and codes.
- Electromagnetic material properties can be both real and complex/dissipative.
- The module uses the finite element method, with first-order Nédélec elements provided by the libMesh finite element library.
- Work is on-going to add H(div)-conforming elements (Whitney forms) as well as higher element orders.

Development of Electro-Thermal Simulation Capability for Advanced Manufacturing

- Electric field-assisted sintering (EFAS) techniques reduce energy usage and fabricate parts that might be difficult or impossible to create using traditional manufacturing techniques.
- DC voltage and constant mechanical pressure are applied through stainless steel rams and graphite tooling to a powder to be sintered.
- Tightly-coupled electrostatic and heat conduction models were developed (and utilized from MOOSE) and serve as a basis for future coupling to microstructural simulations of the sintered power for predictive modeling of sintered material properties and performance.
- These models included basic electro-thermal contact representing the resistance to both heat and electrical conduction throughout the various components of the EFAS experimental apparatus.
- This modeling capability is now part of the application MALAMUTE (MOOSE Application Library for Advanced Manufacturing Utilities).



Schematic of EFAS technique rams, tooling, and powder (in this case, yttrium oxide).



Coupled electro-thermal modeling of a representative EFAS process at 3.8 kN pressure, 980 A applied current after 10 minutes using MALAMUTE.

Capabilities developed in this work will be used in future projects to create simulations for novel materials development and manufacturing for extreme environments.

Acknowledgements Work supported through the INL Laboratory Directed Research & Development (LDRD) Program and the DOE Office of Nuclear Energy under DOE Idaho Operations Office Contract DE-AC07-05ID14517. This research also made use of INL computing resources supported by the Office of Nuclear Energy and the DOE Nuclear Science User Facilities.

MOOSE MALAMUTE

https://mooseframework.inl.gov

NC STATE UNIVERSITY

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy

INL Idaho National Laboratory