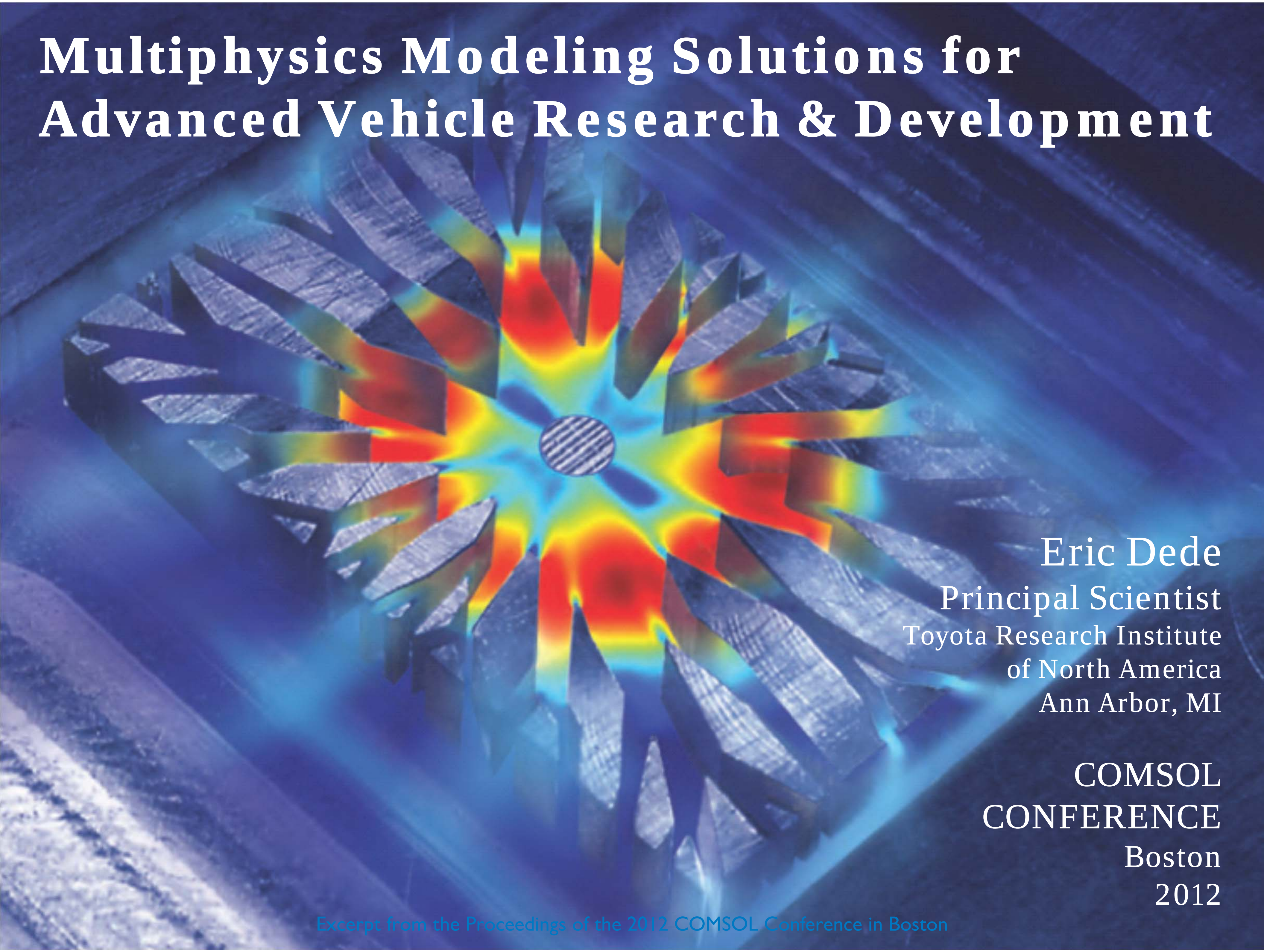
Multiphysics Modeling Solutions for Advanced Vehicle Research & Development



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COMSOL
CONFERENCE
Boston
2012

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  - Electronics Research Department
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    - Dr. Hideo Iizuka

- Korea Aerospace University
  - School of Aerospace and Mechanical Engineering
    - Assistant Professor Jaewook Lee

Toyota Technical Center – North American Operations

Overview of North American research

2020 Vision for Society – Sustainable Mobility

Toyota Research Institute of North America

- **Materials Research**
  Fundamental Material Design
- **Future Vehicle Research**
  Vehicle Control
- **Electronics Research**
  Hybrid Vehicle Power Electronics
  & Sensor Electronics

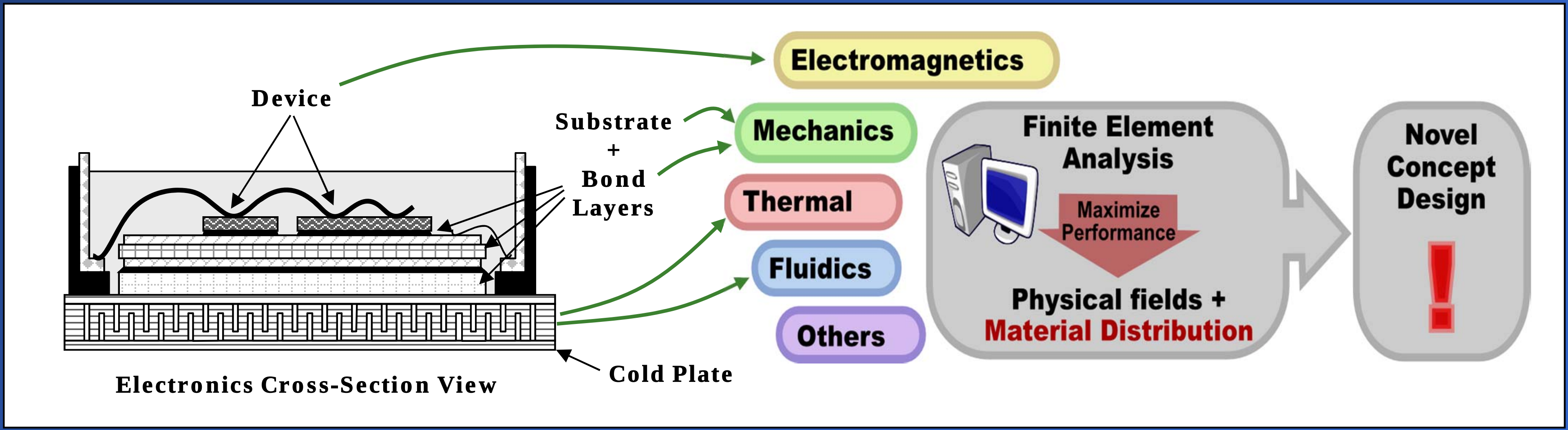
Research focused on the environment, safety, and human interaction

Thermal Management of Electronics Systems

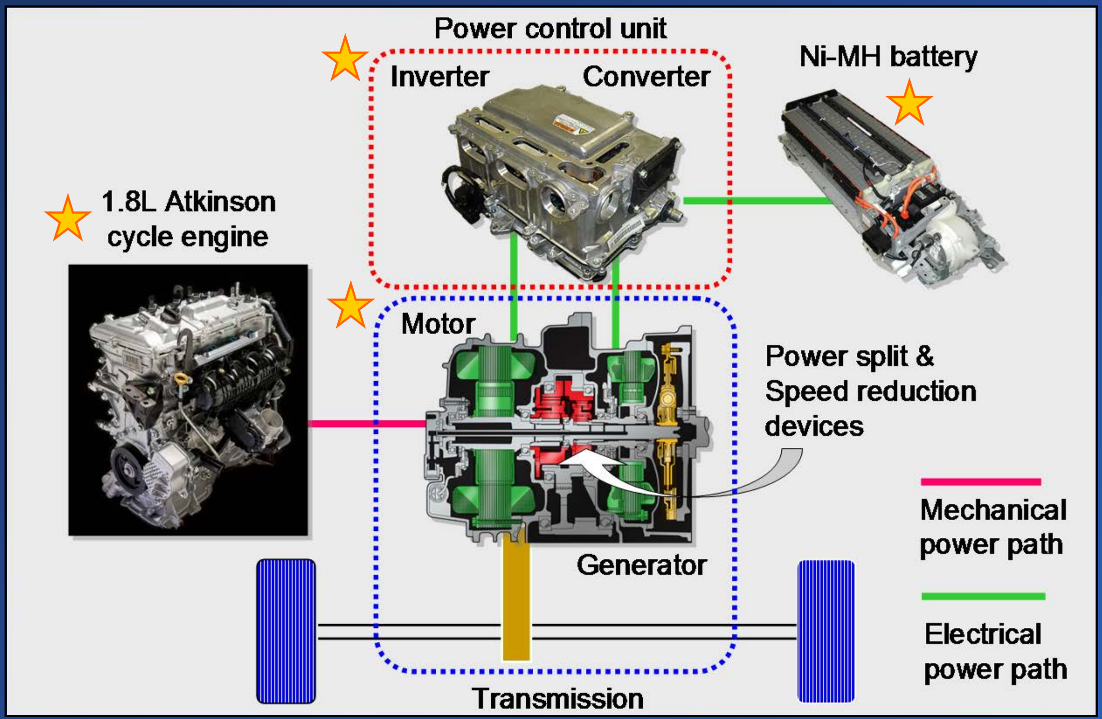
Application to cold plate design

Why multiphysics simulation?

Typical Hybrid Component

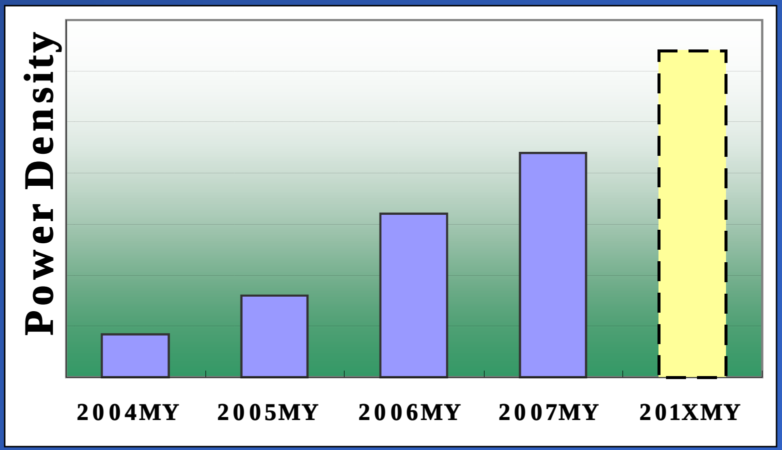


A focus on thermal energy management – key for advanced vehicle systems



★ = Thermal management location

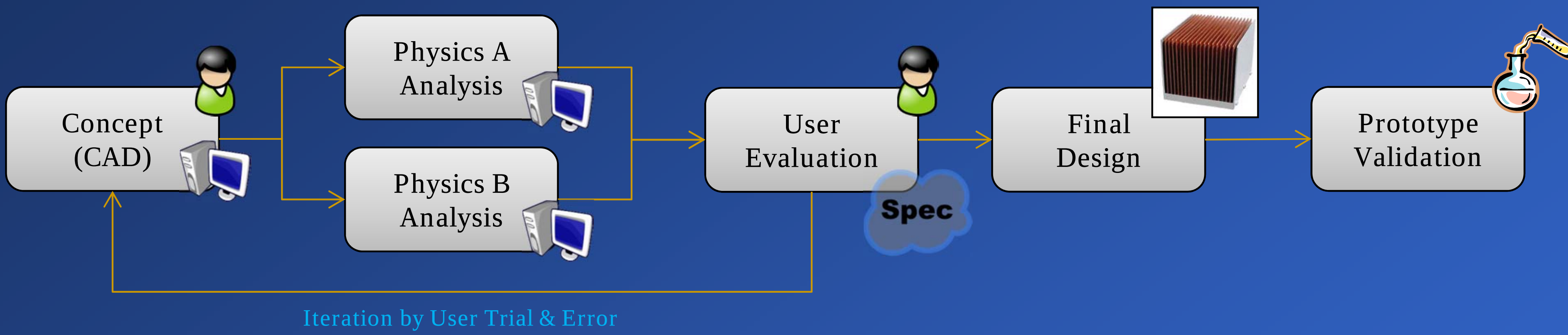
Example Drivetrain Schematic



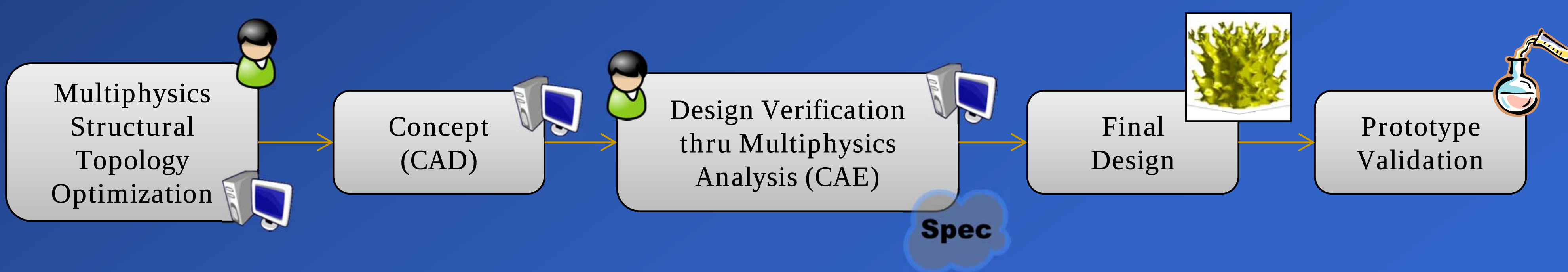
Trend in Electronics Power Density

Workflow process comparison

1. Traditional design approach:



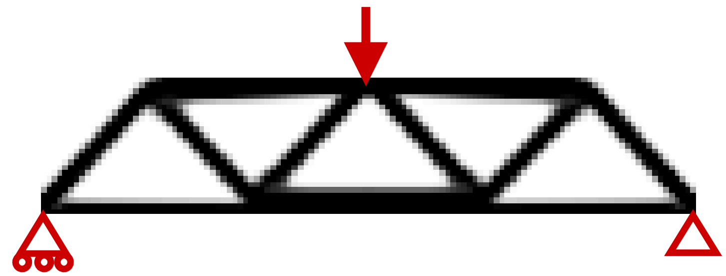
2. Inverse material layout design approach:



Topology optimization for concept development

Method to find an optimal geometry (e.g. size, shape, or number of holes)

E.g. Optimal Geometry for Stiffness

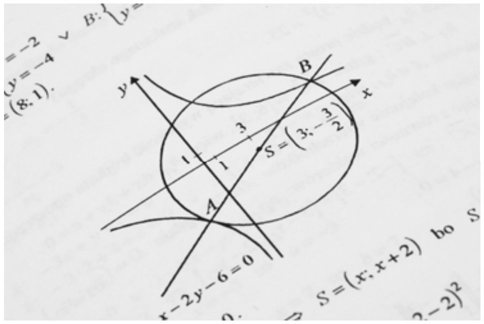


A mathematical approach using Finite Element Analysis (FEA)

Engineer's Intuition (experience) or Iteration

Vs.

Mathematical Method



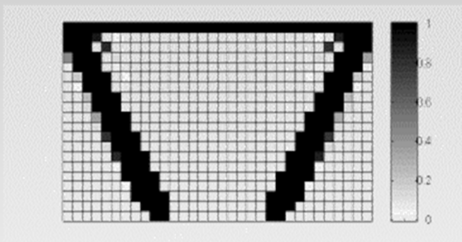
Topology optimization for concept development

Mathematical representation of geometry

Density, ρ, of each finite element

0: Void (Air/Material 1)

1: Solid (Steel/Material 2)



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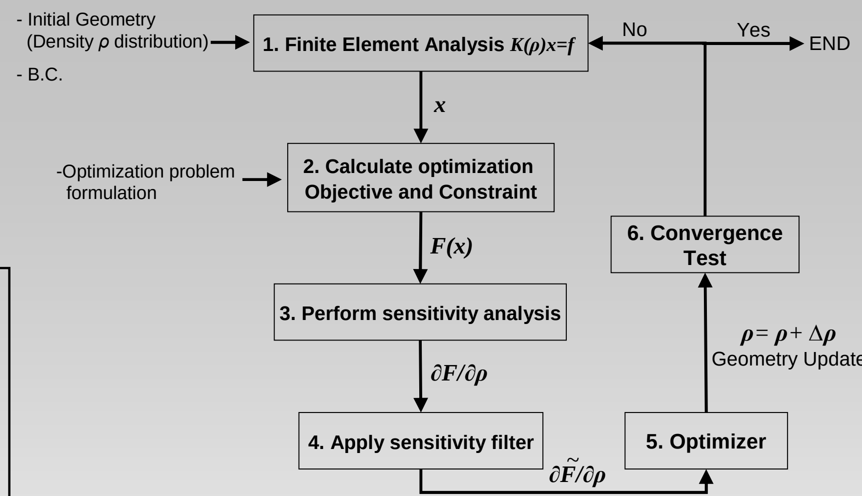
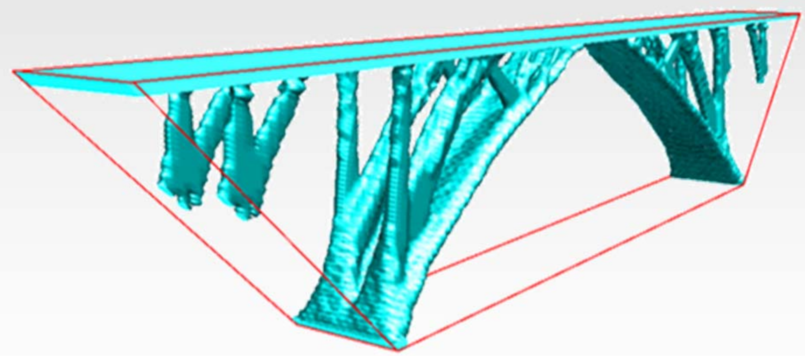
Material properties: function of density ρ

Ex.) ρ: 0 → E=0 (void), k=0.6 (water)

ρ: 1 → E=200 (steel), k=170 (aluminum)

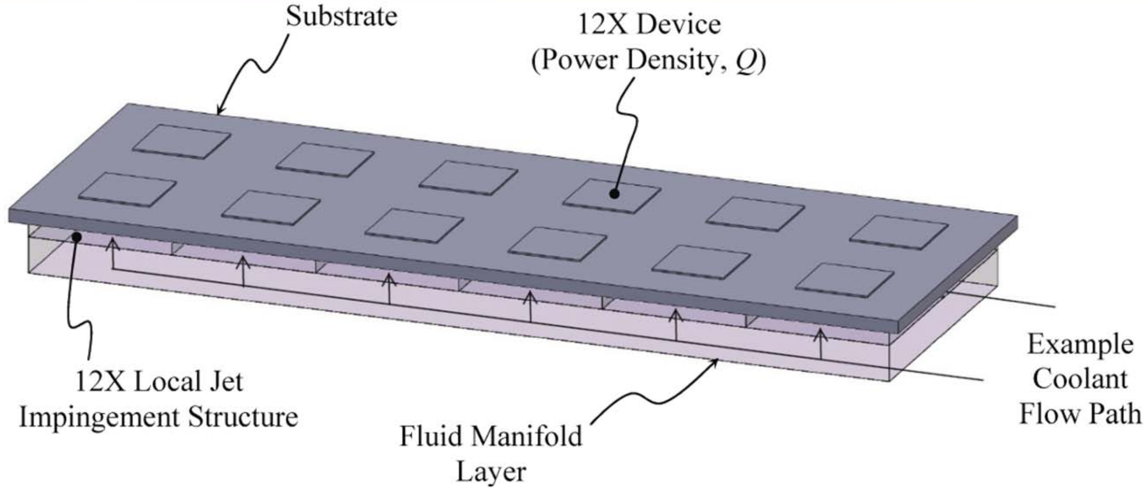




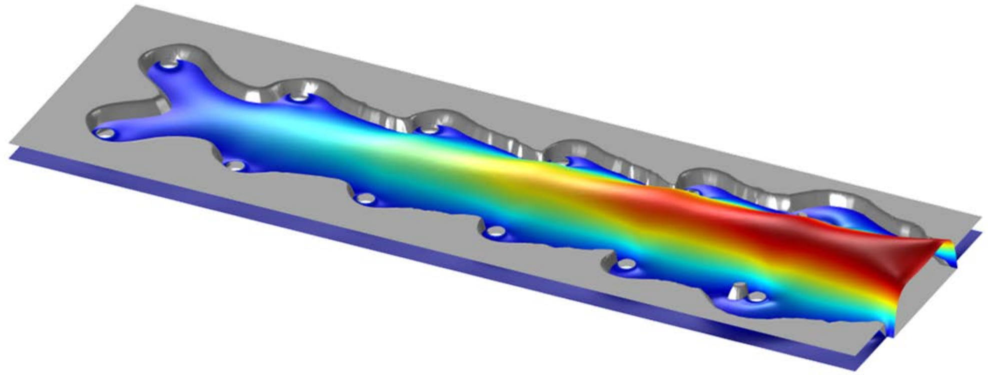
Geometry → Density, ρ, Distribution of Each Finite Element

Single-physics (fluid) topology optimization for concept development

- Electronics cold plate global manifold design



Obtained using
COMSOL
+
Matlab
custom
optimization
script

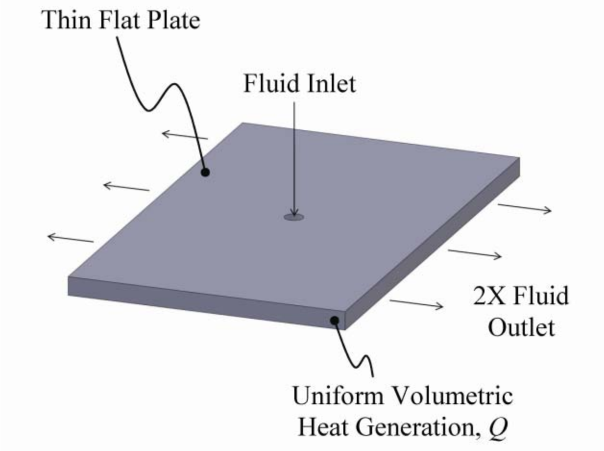


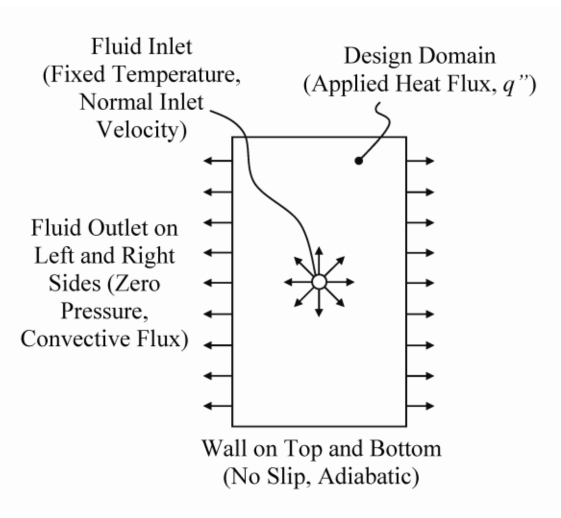
Optimal manifold topology with fluid velocity contours

E.M. Dede et al., Int. J. Vehicle Des., 2012

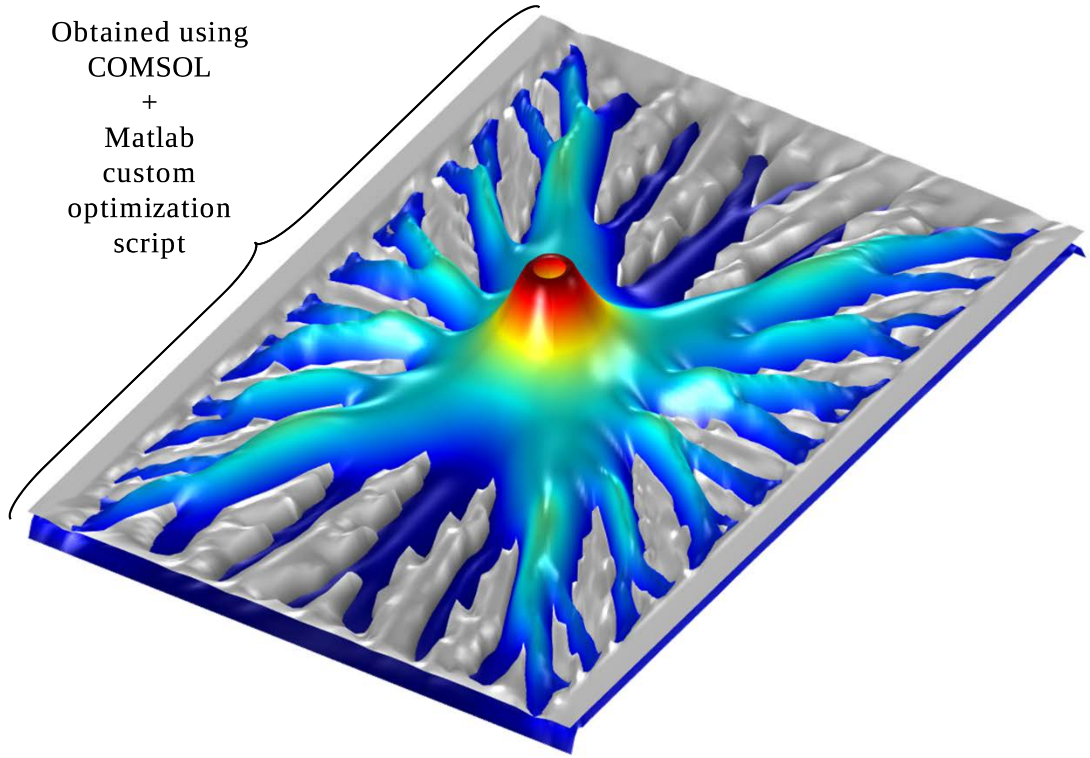
Multiphysics (thermal-fluid) topology optimization for concept development

- Electronics cold plate local cooling cell design





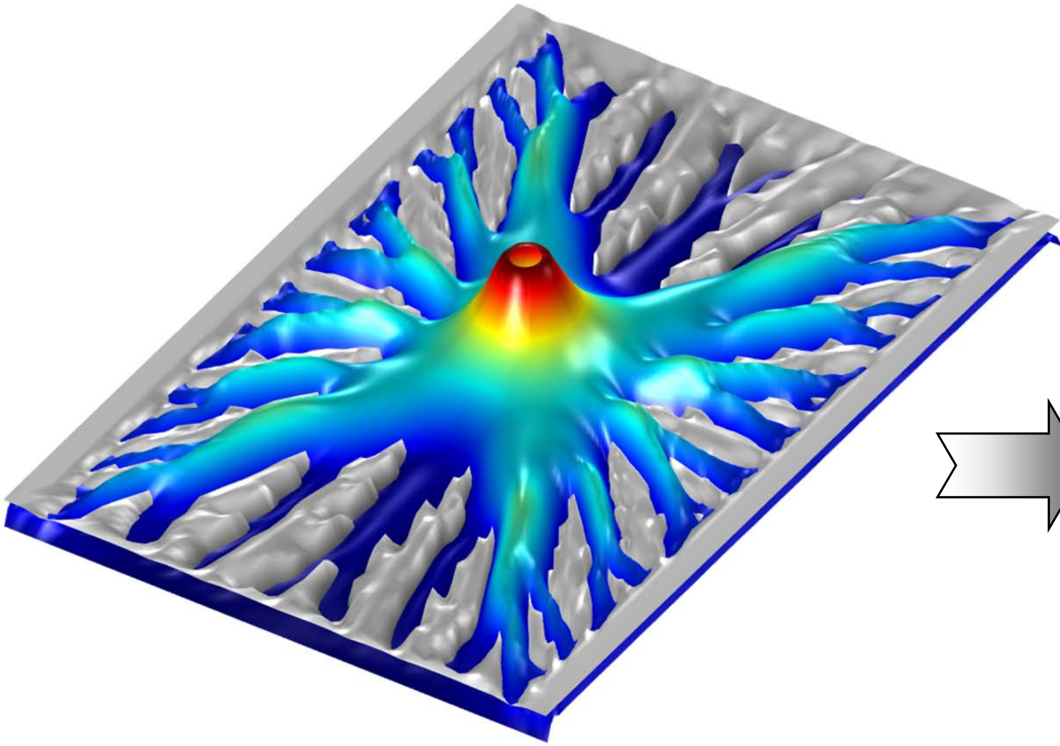
Obtained using COMSOL + Matlab custom optimization script



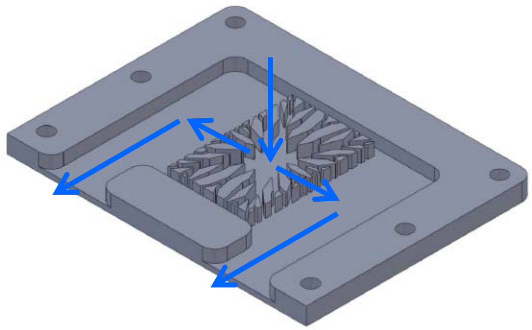
Optimal branching channel topology with normalized fluid velocity contours

E.M. Dede, InterPACK, 2011

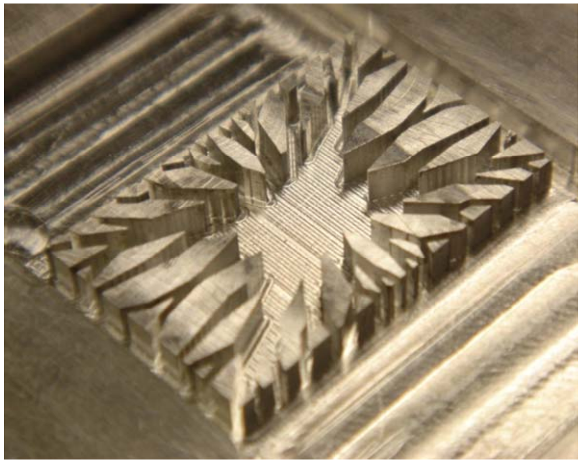
From optimization concept to advanced prototype development



Optimal branching channel topology with normalized fluid velocity contours



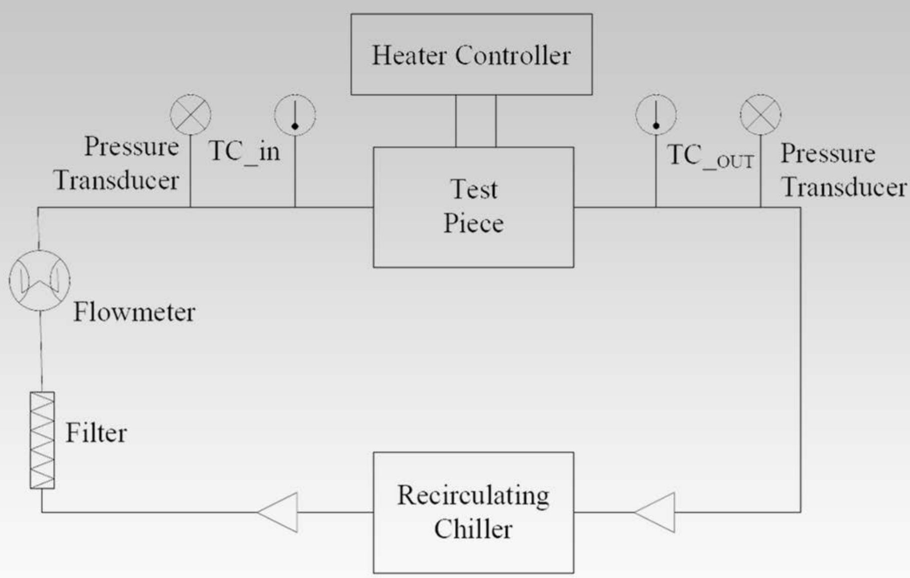
Synthesized CAD Model



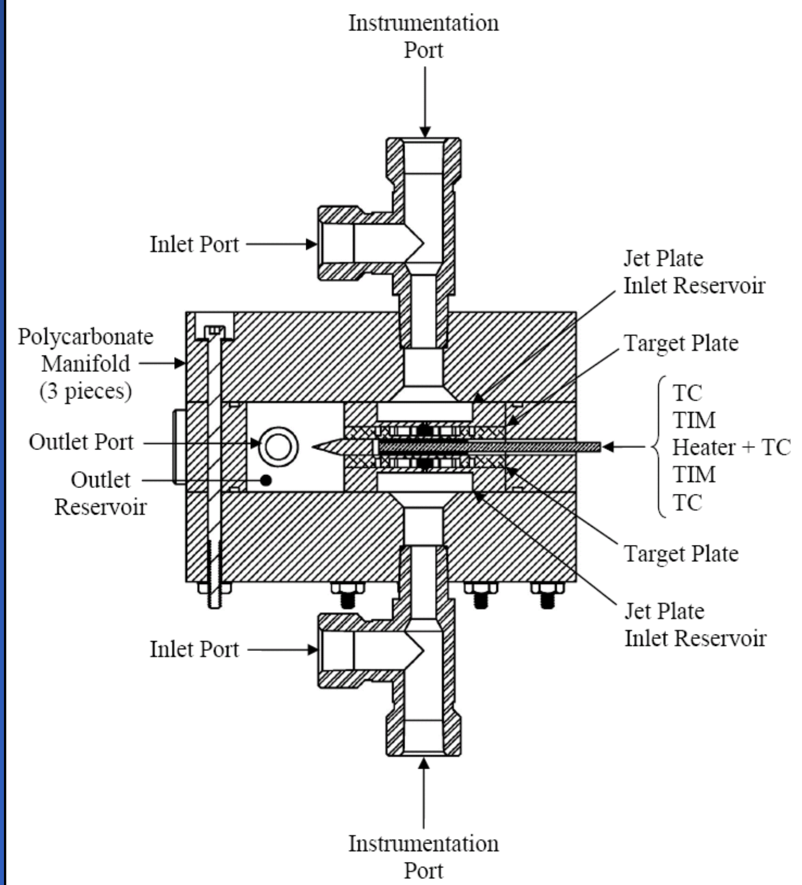
Cold Plate
Research Prototype

Concept validation via experimental tests using in-house test facility

- Single-phase thermal-fluid test bench



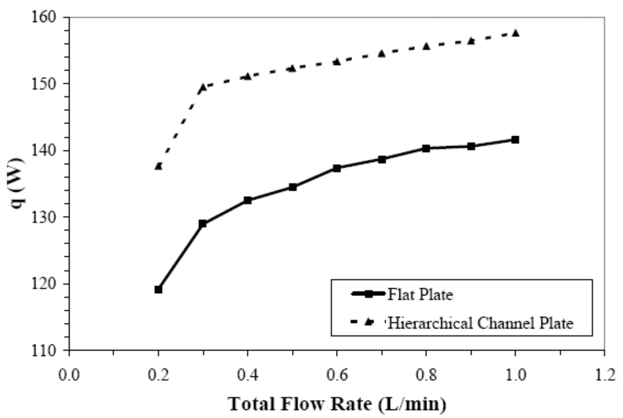
Schematic for Experimental Flow Loop



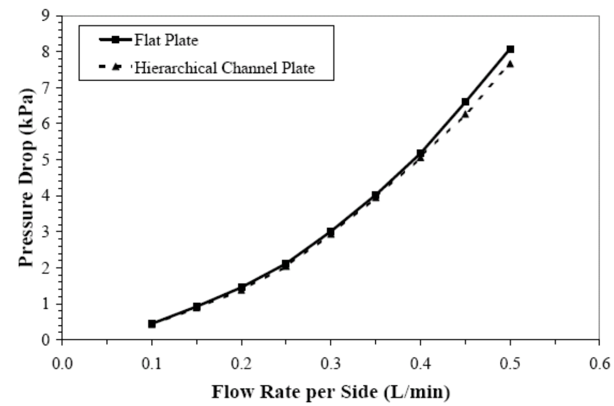
Side Cross-Section View of Test Piece

Concept validation via experimental tests using in-house test facility

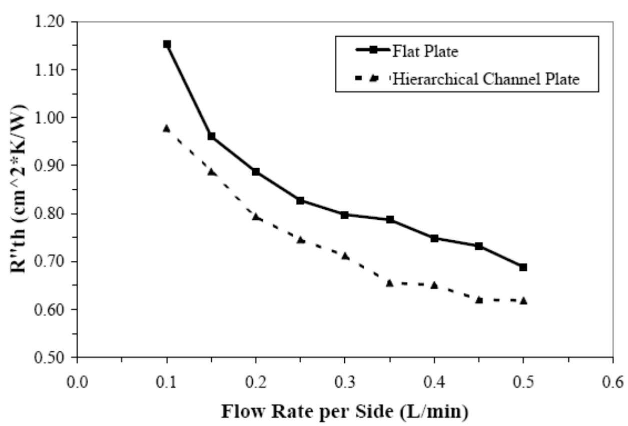
- Experimental and numerical results



Test Piece Total Power Dissipation

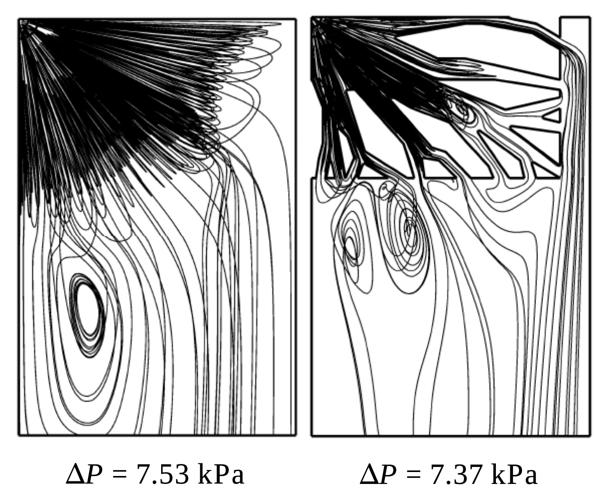


Cold Plate Pressure Drop



Cold Plate Unit Thermal Resistance

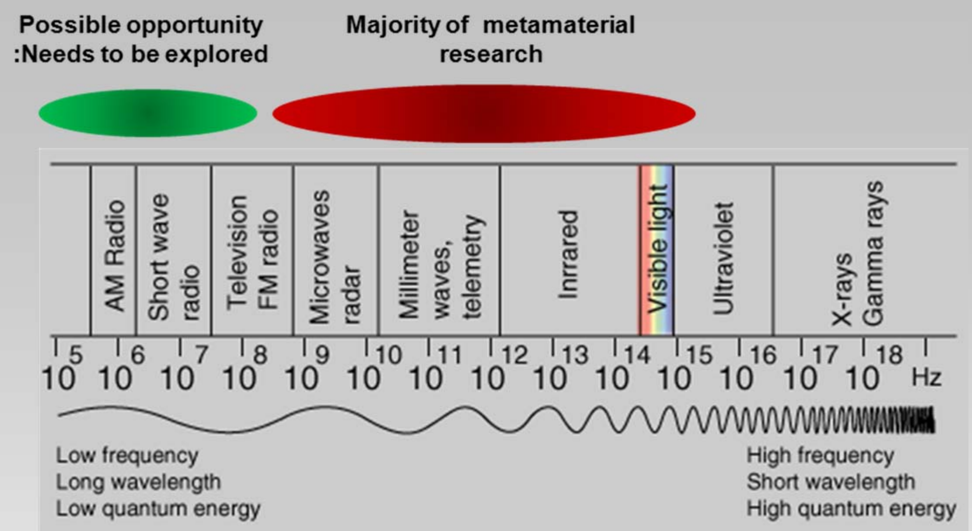
COMSOL Pressure Drop Verification Study at 0.5 L/min – Fluid Streamlines (Top View)



Magnetic Field Focusing & Force Enhancement

Application to electromechanical actuators

Need for efficient magnetic devices



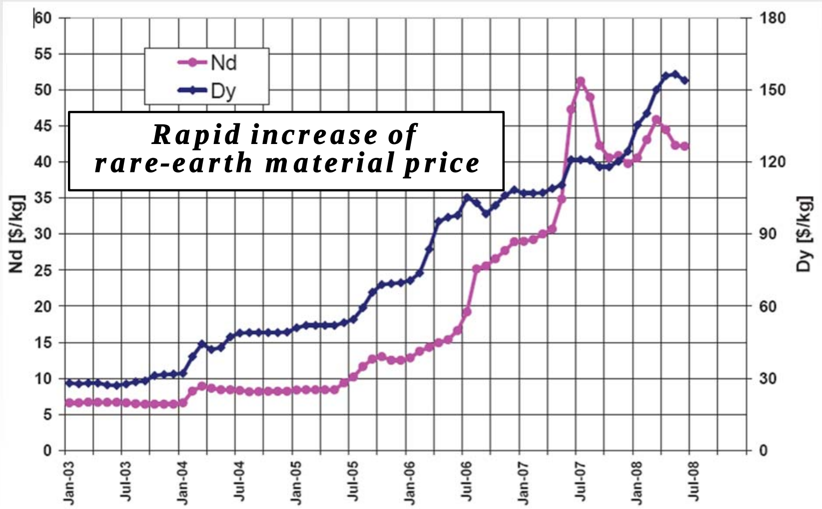
kHz Magnetic Motor and Actuators

Typical Device Frequency: 1-30 KHz

Motors

Actuators

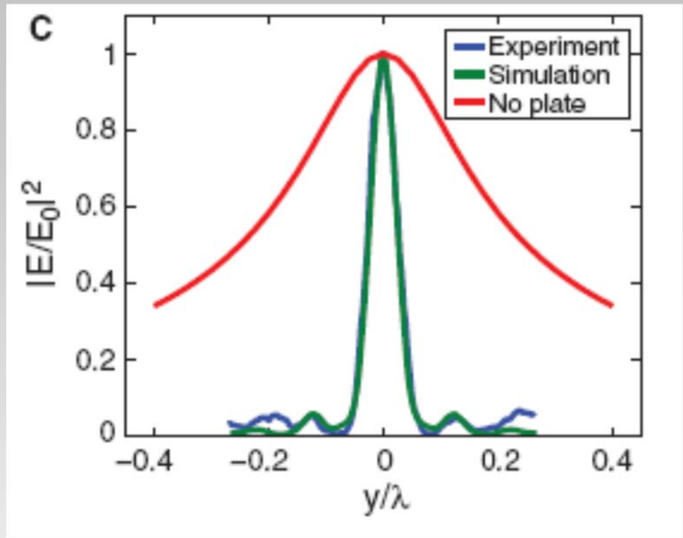
Thousands of magnetic devices utilize permanent magnets



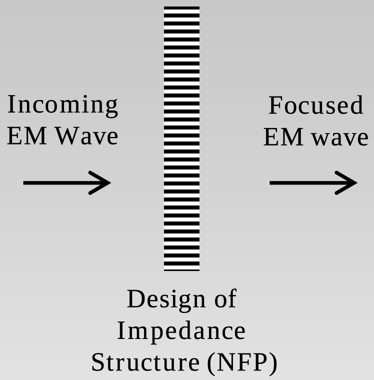
Electro-magnetic field focusing concept

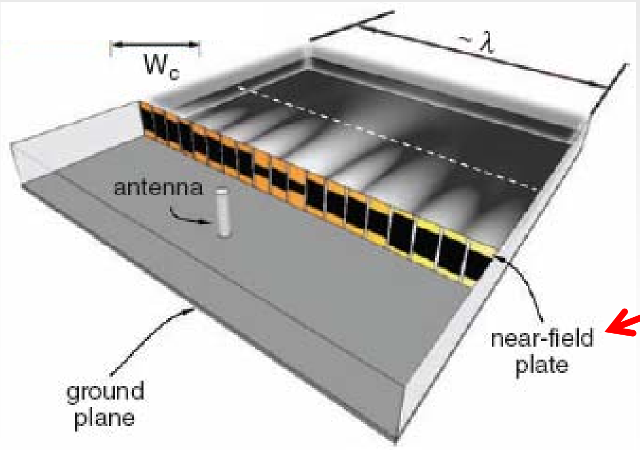
Focusing of **Electric Field** of 1 GHz frequency

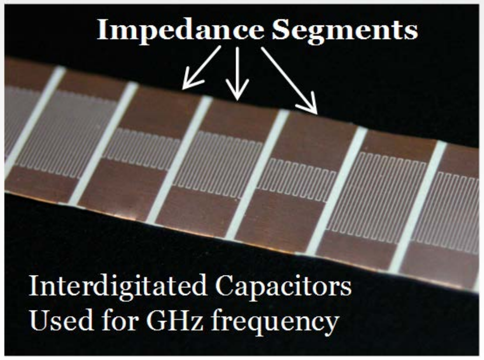
Demonstration of Field Focusing



Operation of Near Field Plate (NFP)





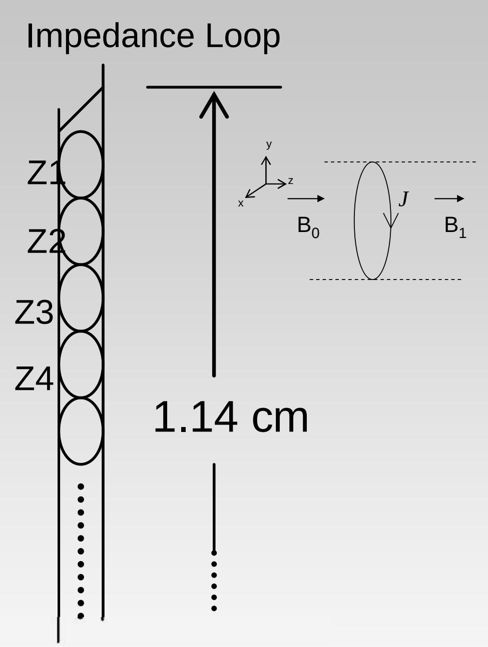


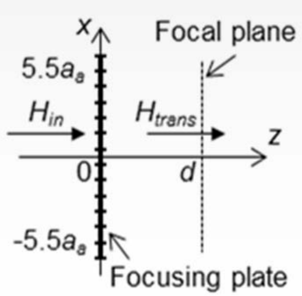
A. Grbic et al., Science, 2008

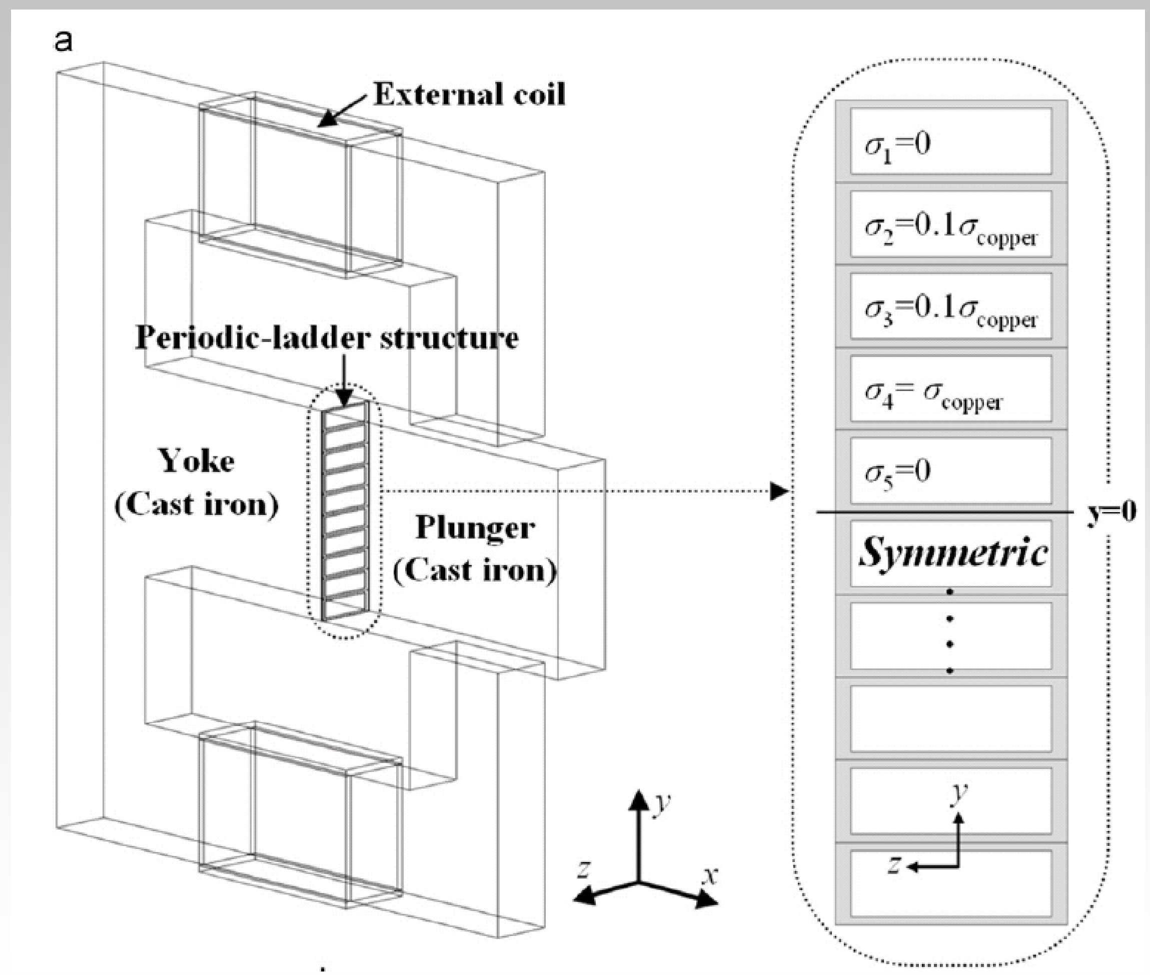
Extension to low frequency magnetic field design for motors / actuators

Focusing of **Magnetic Field** in kHz to MHz range

Device Concept



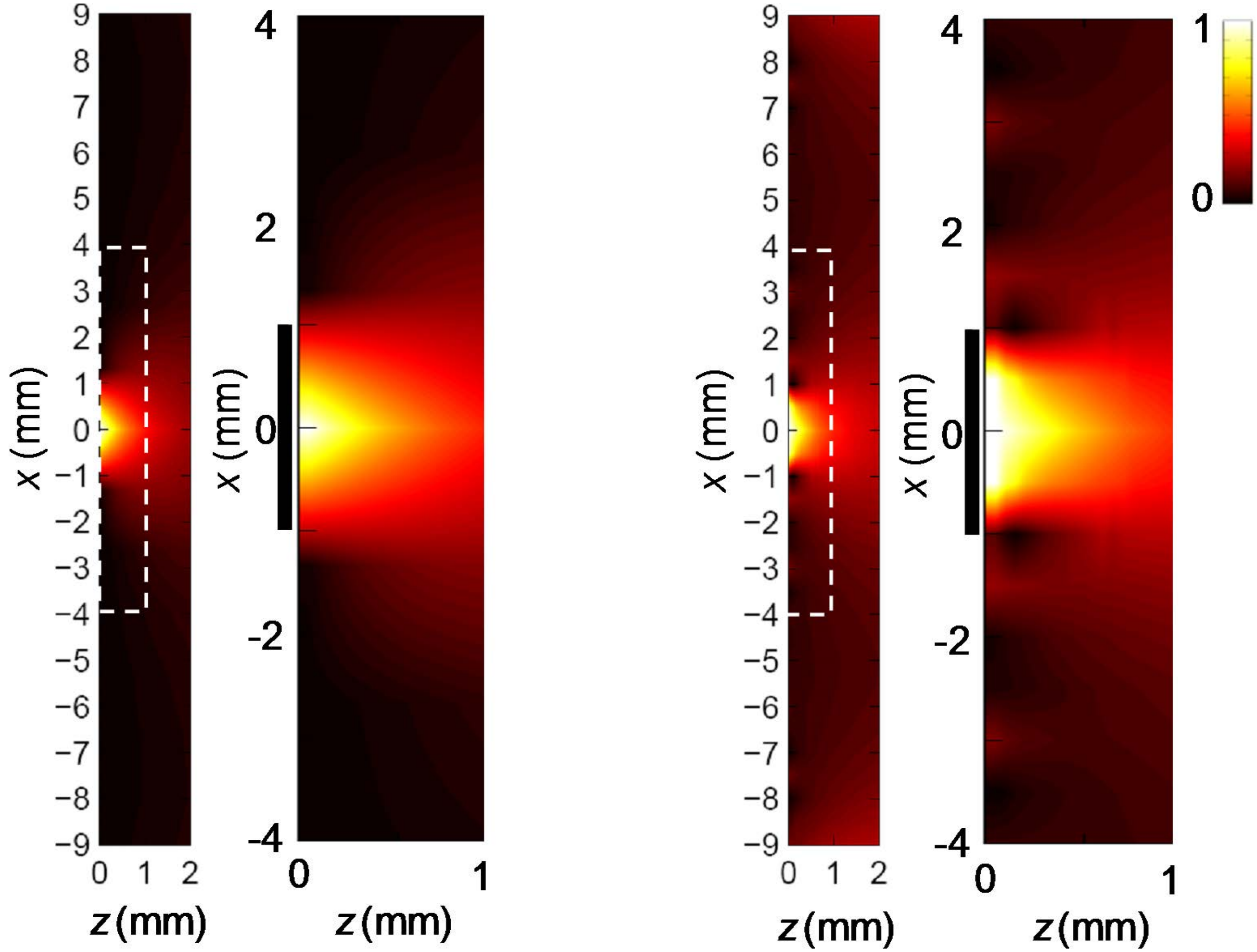




D. Banerjee et al., Appl. Phys. Lett., 2011 & J. Lee et al., Finite Elem. Anal. Des., 2012

Verification of magnetic field focusing

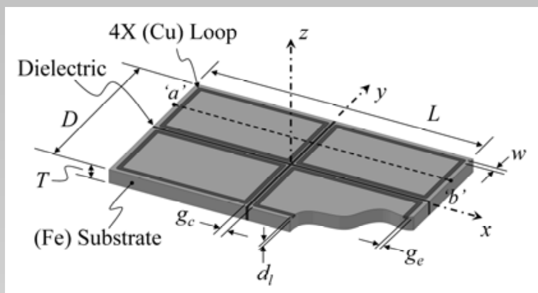
- Simulated field distribution for loop array with central gap



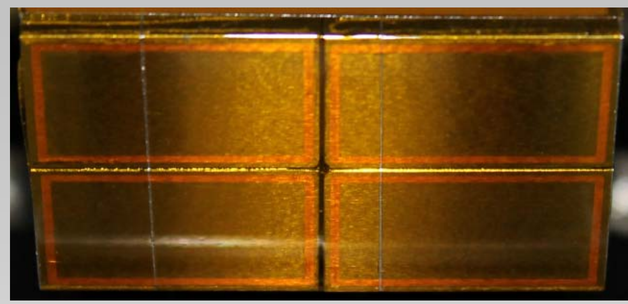
Analytical Solution
(2-D for simplified geometry)

COMSOL Solution
(3-D for complex geometry)

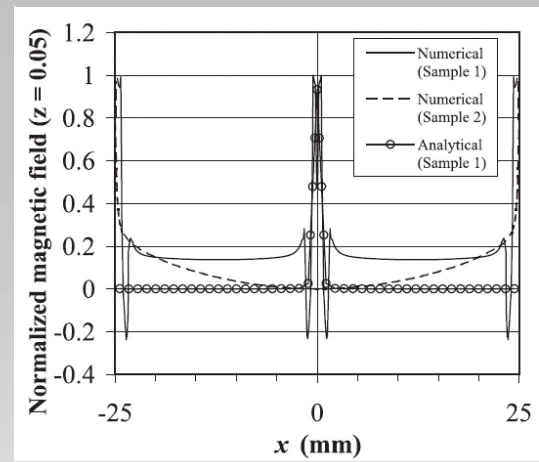
Validation of magnetic field focusing and force enhancement effect



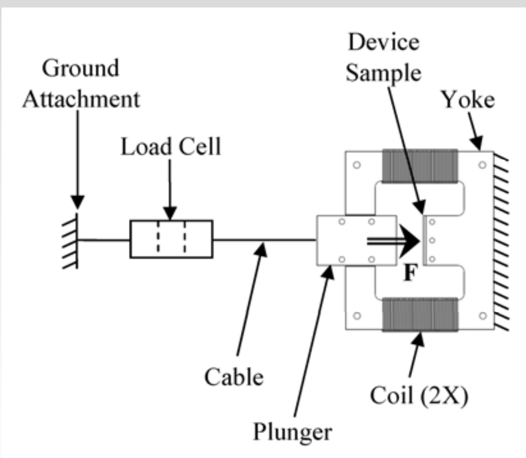
Material Sample Design



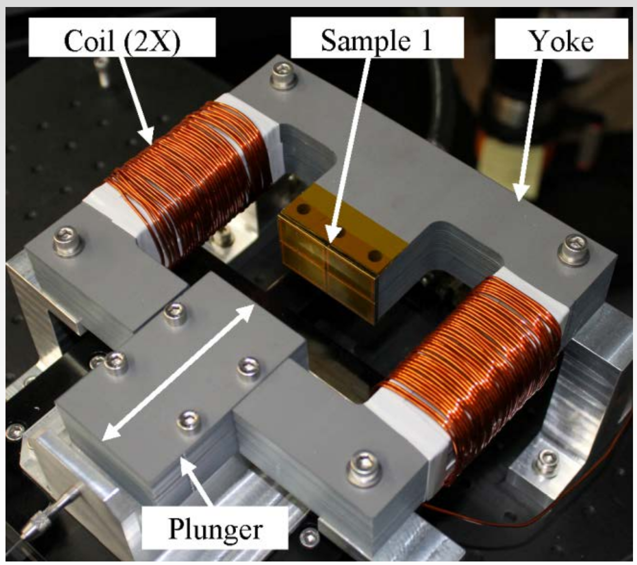
Material Prototype



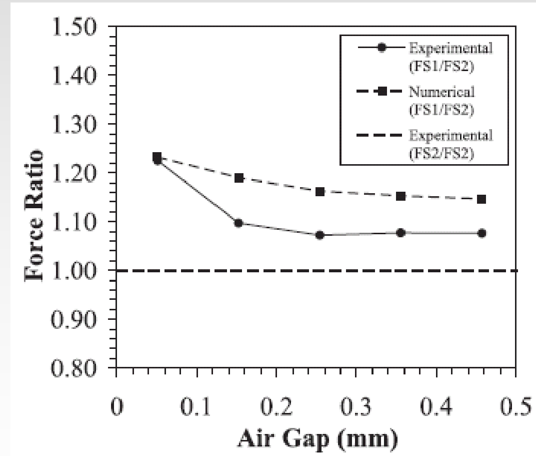
Magnetic Field Focusing Effect



Test Schematic



Experimental Facility



Force Enhancement Effect

E.M. Dede et al., Appl. Phys. Lett., 2012

Conclusions

- Multiphysics simulation is a key tool for advanced electromechanical system design
  - Coupling of several physics is common
- Material layout optimization technique built into workflow for streamlined design process
  - Informed initial concept vs. user trial & error approach
  - Often leads to unique (non-intuitive) solutions
- Integrated CAD to CAE tools crucial for verification and validation of optimized and as-built designs
  - Required for complex geometries