Multiphysics Microwave Modeling in FEMLAB 2.2

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  - Short demo on building models in FEMLAB
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Why modeling ?

- Education
  - Modeling accelerates understanding by allowing interaction between equations and visualization of physical quantities
- Saves time and money
  - Modeling speeds up the prototyping process by focusing efforts on feasible designs
- Safety
  - Modeling spares equipment by predicting potentially risky experiments
- Fun!

FEMLAB Overview

- FEMLAB's Core Capabilities
  - Numerical solutions to physics models
  - Multiphysics—Couple related models
- FEMLAB Modules
  - Electromagnetics, Structural Mechanics, Chemical Engineering (including fluid dynamics)
- FEMLAB Compatibilities
  - Matlab, Simulink, Control Systems Toolbox

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The COMSOL Group

- Founded in 1986 by two Ph.D. students at the Royal Institute of Technology, Stockholm
- Developed several products within the Matlab family
- 95 employees in offices in Sweden, Finland, Norway, Denmark, USA, Germany, UK and France
- We want to provide user-friendly and powerful software for modeling in education, research, design, and development

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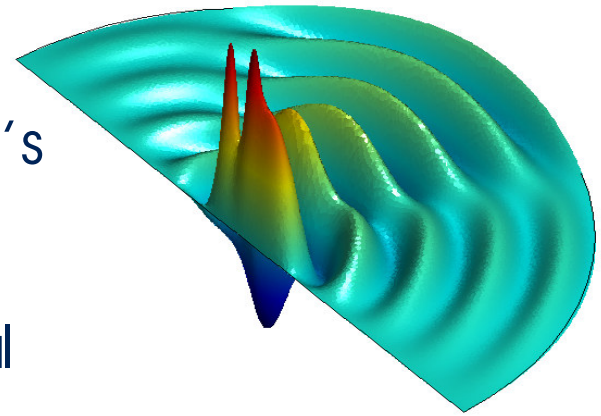
FEMLAB Awards and Milestones: 2001

- *NASA Tech Briefs* "Product of the Year" Silver Medalist (best software finish)
- Positive press in over 30 magazines worldwide including *IEEE Spectrum*
- Used in over 10 academic journal articles
- Leading edge technological developments
  - Generalized Element Library
  - Multidimensional Multiphysics (an industry first)
- Corporate infrastructure established in US, Germany, and UK

Microwave Power Engineering using FEMLAB

- FEMLAB solves the rudimentary mathematical problems associated with the laws of physics
- In particular, FEMLAB can solve for electromagnetic waves using Maxwell's equations
- FEMLAB is flexible enough to handle nonstandard phenomena and material properties as well as multiphysics coupling
- Up to three spatial dimensions plus time
- Extensive postprocessing capabilities and programming language enable the computation of related physical quantities



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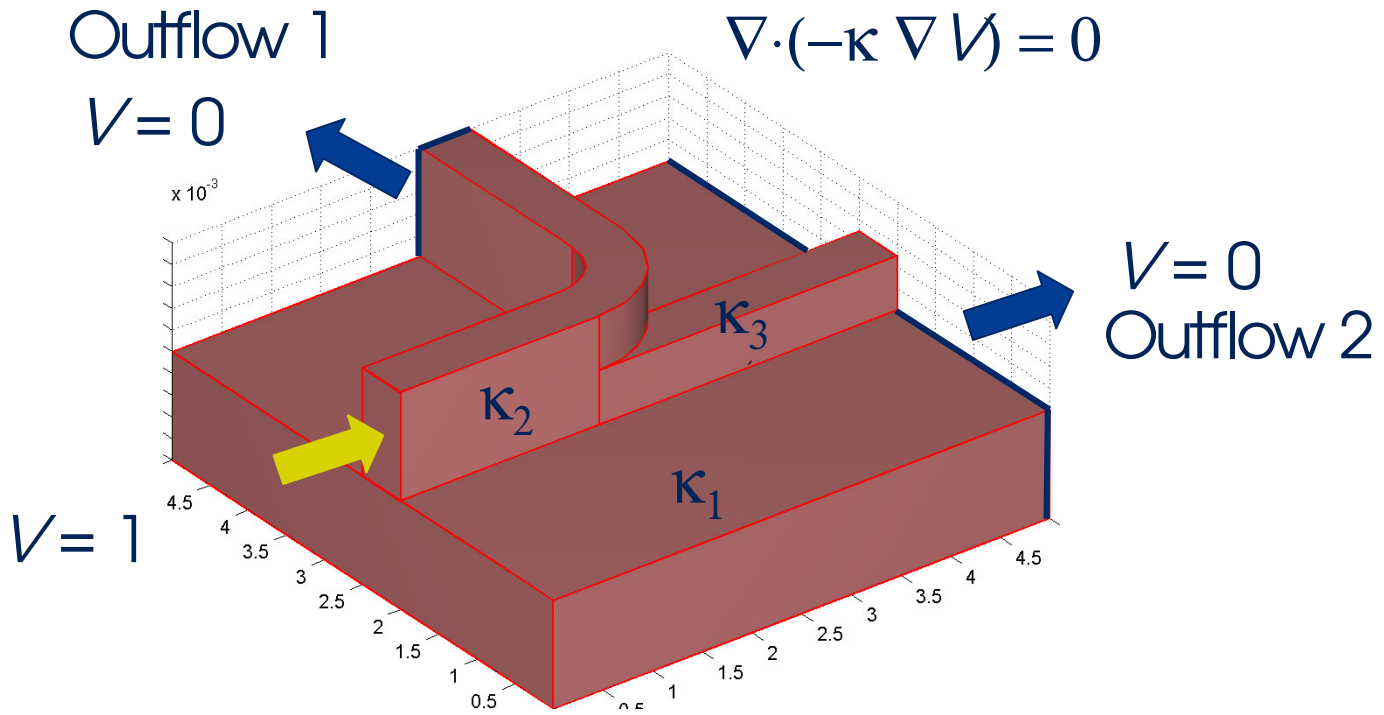
Our first FEMLAB model

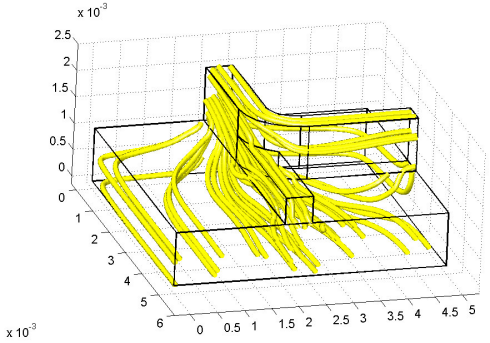
- Shows the main steps of the modeling process in FEMLAB
- Highlights
  - Models direct current conduction
  - 2D and 3D drawing tools
  - Several subdomains with different properties
  - Post processing including boundary integration
  - M-file features

Problem definition

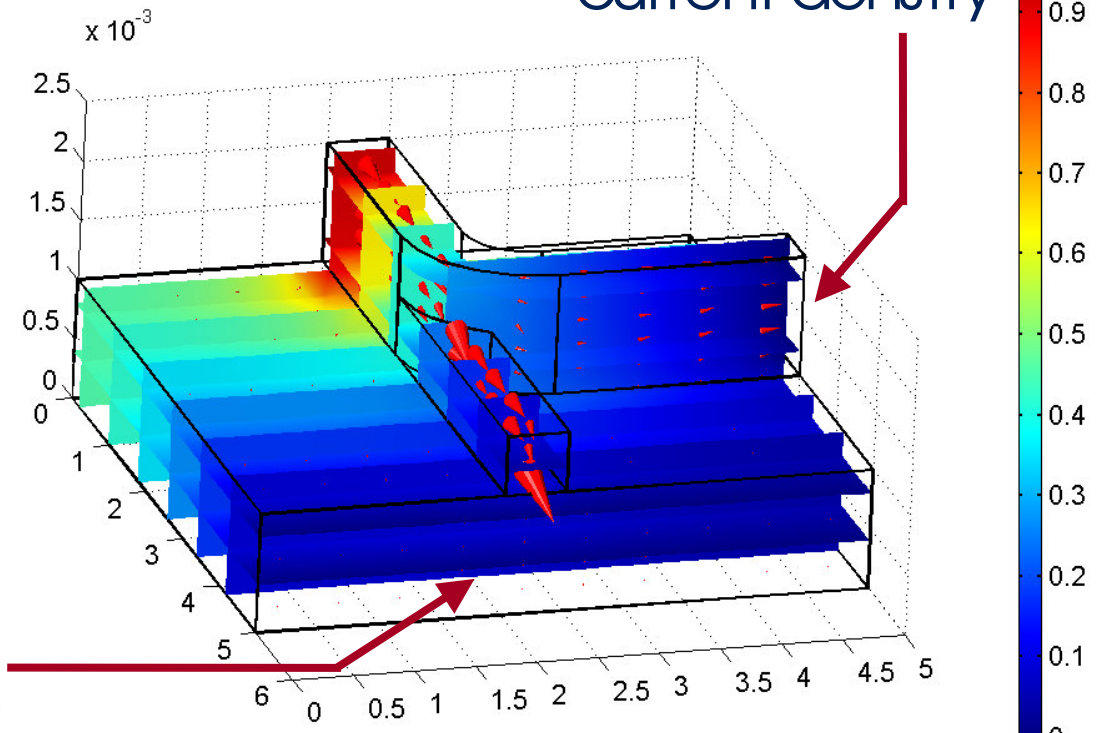


- How is the current distributed between outflows 1 and 2 ?

Results



Integrate current density



Integrate current density

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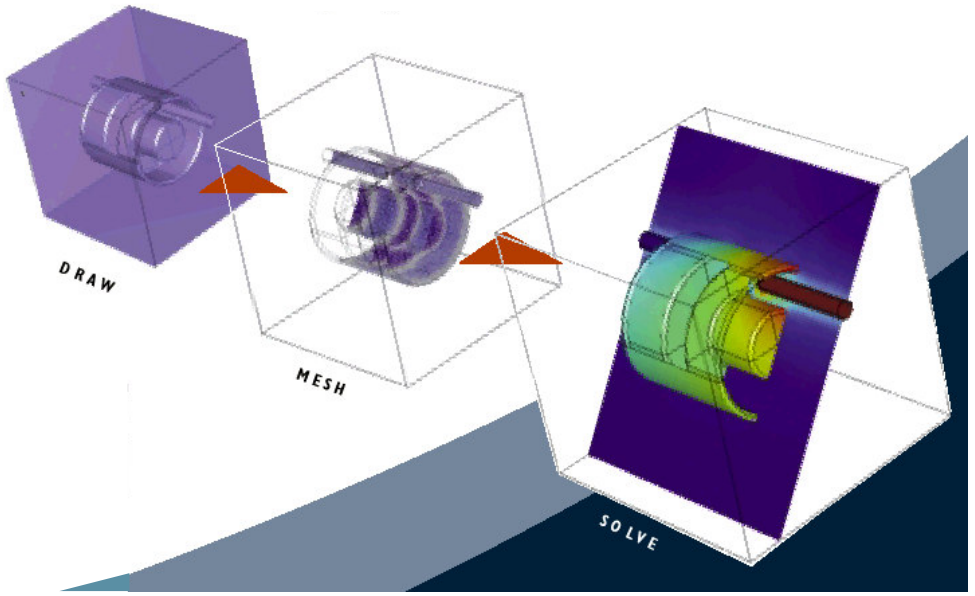
Summary of the modeling process

- Draw Mode
- Boundary Mode
- Subdomain Mode
- Mesh Mode
- Post Mode



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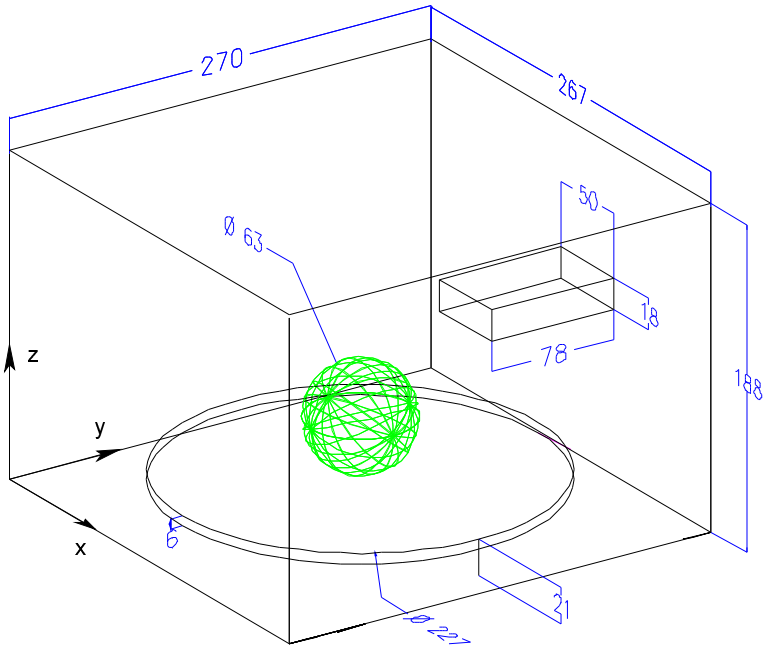
Benchmark Problem

- Problem definition: Microwave a potato!
- Excitation:
  - Sinusoidal signal (perfectly matching the waveguide)
  - Frequency 1.59 GHz
  - Average power 1 kW
- Relative permittivity of potato $\varepsilon = 65 - i20$



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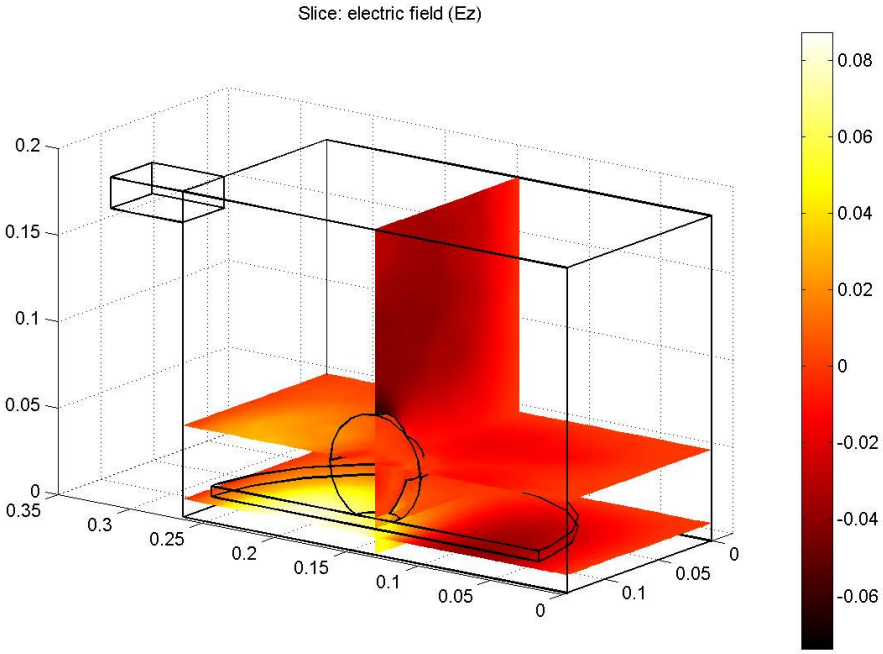
Results using FEMLAB and the Electromagnetics Module



- Computation includes all components of the electric field
- Visualization of the vertical component of the electric field
- Used symmetry to conserve computational resources

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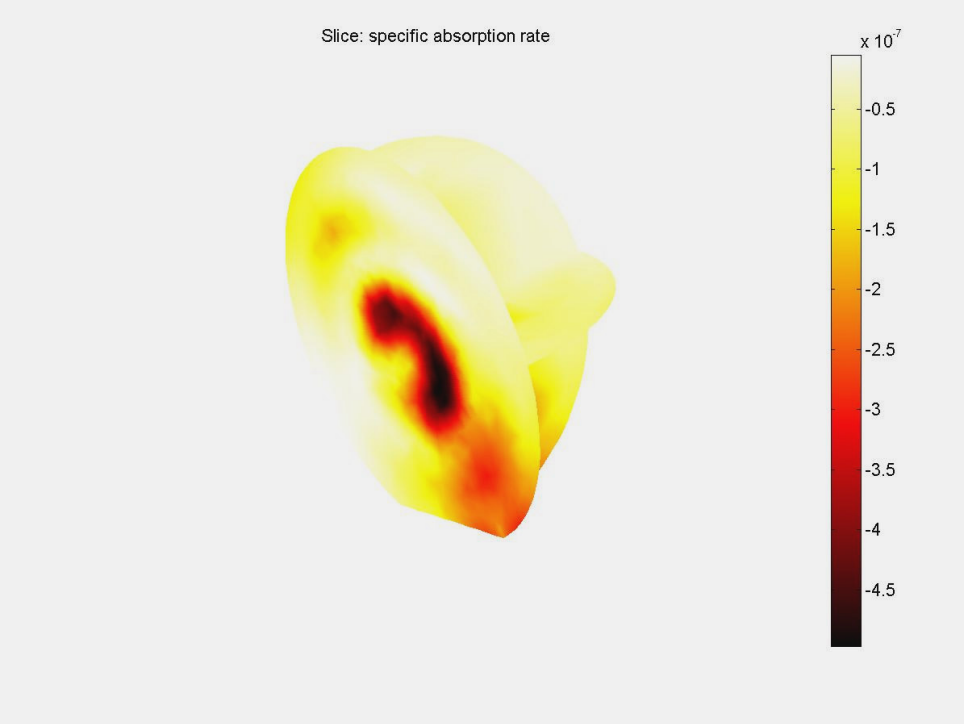
Results, continued

- Specific absorption rate as calculated from the electric field
- Post processed and visualized within FEMLAB environment
- Many other plot types are available



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Results, continued

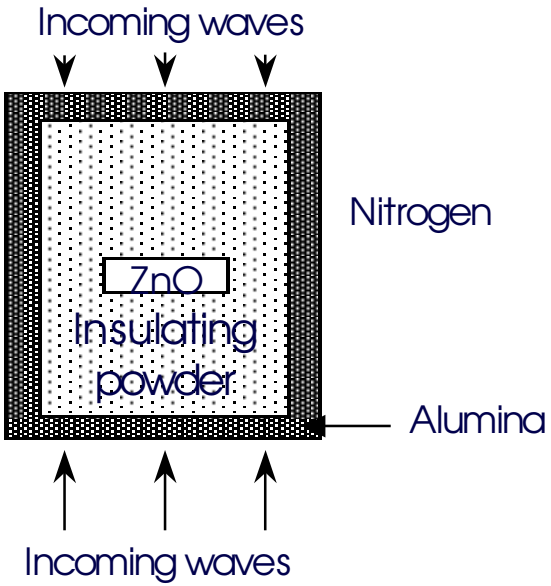
- FEMLAB's postprocessing includes subdomain and boundary integration
- As a result scattering parameters can be easily computed using the GUI
- Here, S_{11} parameter (reflection factor) has been calculated for the range 2.35-2.55 GHz

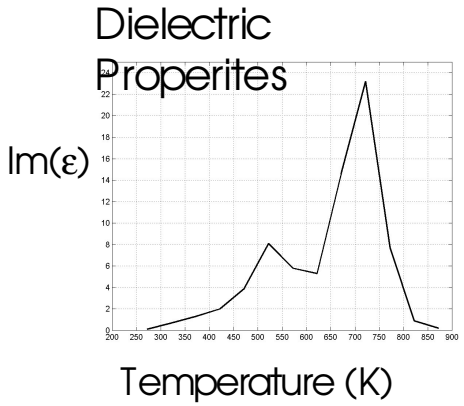
$$|S_{11}| = \sqrt{\frac{\text{Power reflected from input}}{\text{Power incident on input}}}$$

Microwave sintering of ceramic materials

- "Hot" area of research
- Advantages of Microwave Sintering
  - Uniform temperature distribution
  - Higher energy efficiency
  - Controllable heat rate
- Large variations in dielectric properties

Problem definition





- Zinc oxide is sintered within insulating powder
- Multiphysics application:
  - Transverse magnetic waves
  - Heat transfer
  - 2D Axisymmetric
- Two-way coupling:
  - Temperature depends directly on microwaves
  - Dielectric properties of material depend nonlinearly on temperature

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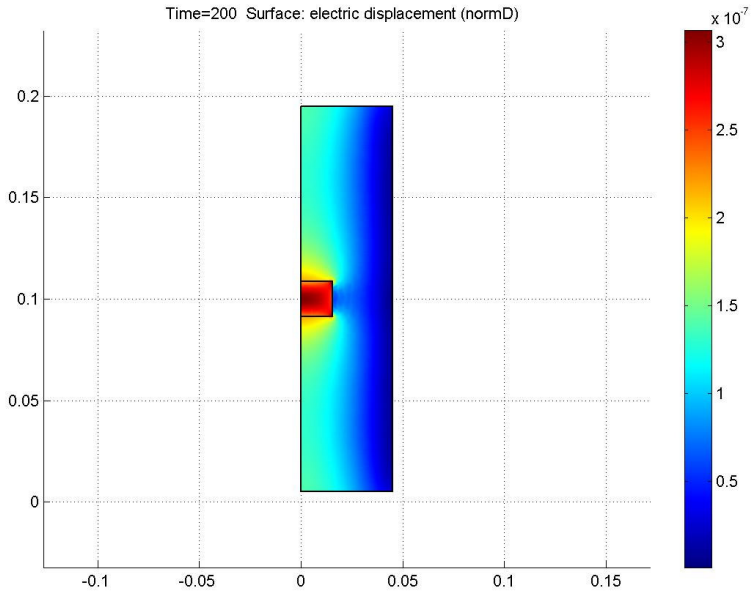
Results

- FEMLAB couples the time-dependent heating and the microwave simulation
- Interpolation (using Matlab functions) incorporates experimental data to define the permittivity of the material
- Post processing allows visualization of electric displacement, dielectric heating, and more



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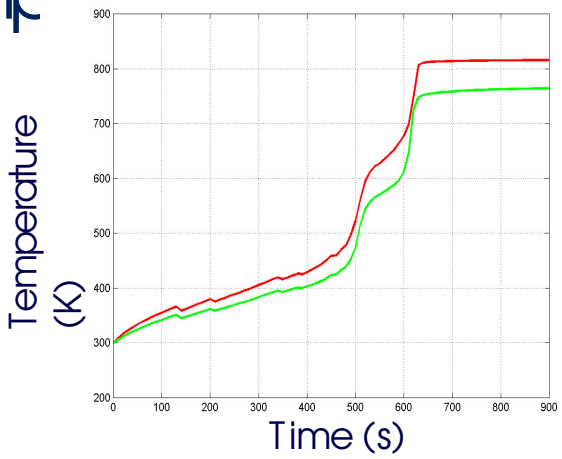
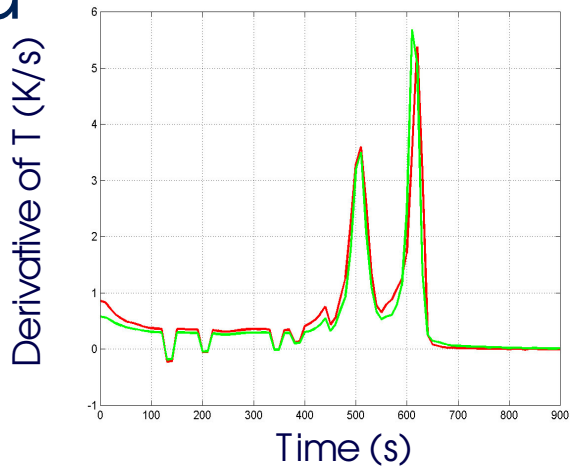
Results: Surface and core temperature and temperature change

- FEMLAB's post processing also features animation, cross-section, and time history plots
- Here temperature and the derivative of the temp[illegible]ed



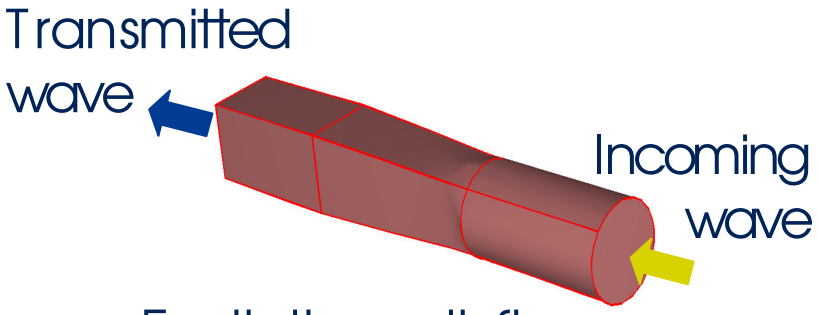


Study of waveguide geometry

- Waveguide geometry smoothly transitions from elliptical to rectangular
- Phenomena studied
  - Dependence of reflection coefficient on frequency
  - Mode of the traveling wave

Problem Definition

$$\nabla \times (\nabla \times \mathbf{E}) - k^2 \mathbf{E} = 0$$



Excitation satisfies

$$\mathbf{n} \times (\nabla \times \mathbf{E}) + ik\mathbf{E}_t = 2ik\mathbf{E}_{inc}$$

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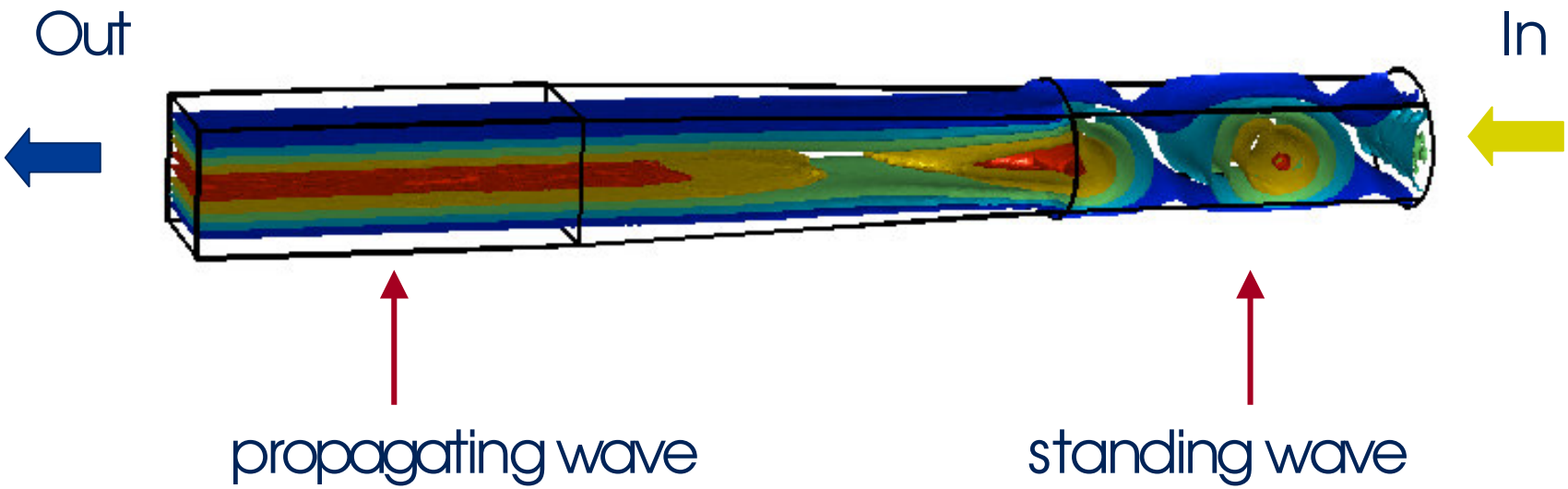
Results: Traveling wave mode



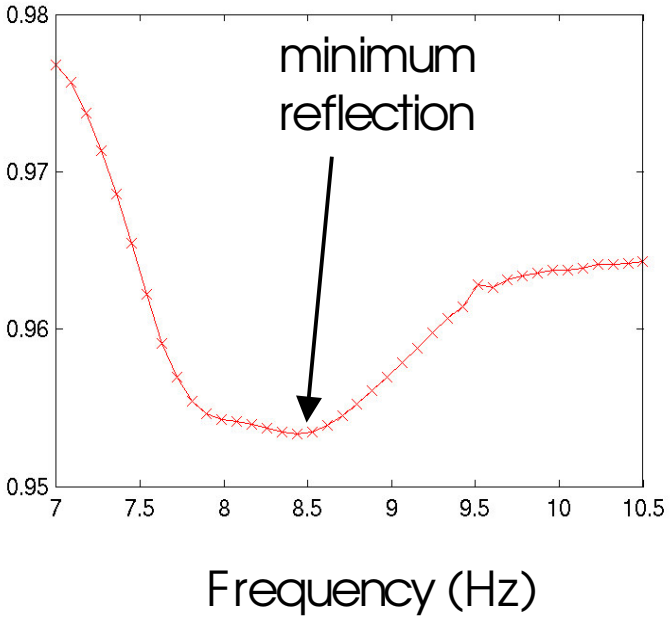
- The incoming TE11-mode is transformed to a TE10-wave

Results: S-parameters

- The S-parameter S_{21} (for open ends) is

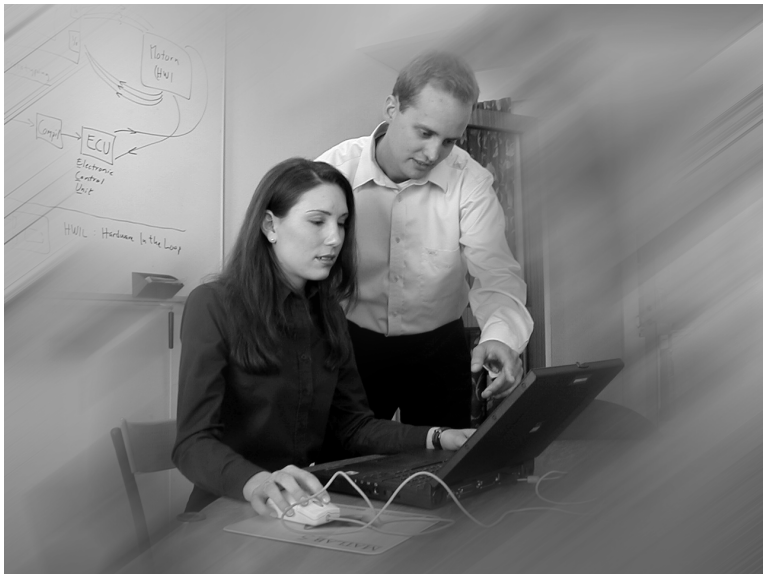
$$|S_{21}| = \sqrt{\frac{\int \text{Power flow through output}}{\int \text{Power flow through input}}}$$

- This can be computed as boundary integrals in the FEMLAB GUI
- Small reflections in the single mode range S21 > 0.95



Support & courses

- Experienced engineering staff
- Searchable FAQ database
- Extensive technical support: support@femlab.com
- Download minicourses, apply for on-site minicourses or attend to our courses
- Developer Zone



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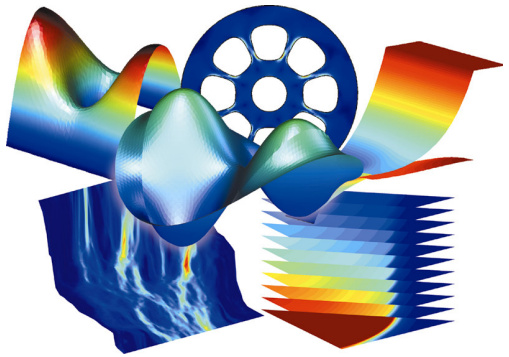
Next step

- Download white papers, articles product sheets etc.
- Apply for on-site seminars and hands-on seminars
- Run tutorials and models at www.femlab.com
- Purchase FEMLAB!



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Prices

- Modestly priced to increase user base
- Single user license for PC Windows platform for FEMLAB : $3995
- Single user license for PC Windows platform for the Electromagnetics Module: $1595
- Substantial academic discount available

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