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Analysis of Microwave Radiation for Heating

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Outline

- General applications for microwave heating
- Problem setup for validation against analytical solution
- Simulation of geometry as waveguide
- Simulation of microwave heater
- Comparison with experimental data

Microwave Heating in COMSOL

- Heating of food in a commercial microwave oven
- Simulating non-lethal microwave weapon
- Extracting water from permafrost on the moon
- Heat source for hyperthermic oncology

Use of COMSOL Multiphysics

- Microwave heating in a waveguide
- Frequency-domain electromagnetic analysis
- Transient heat transfer analysis
- Interaction of oscillating electric field with gel produces dielectric heating (heat source)
- Transverse Electric (TE) wave

ANALYTICAL VALIDATION

Validation

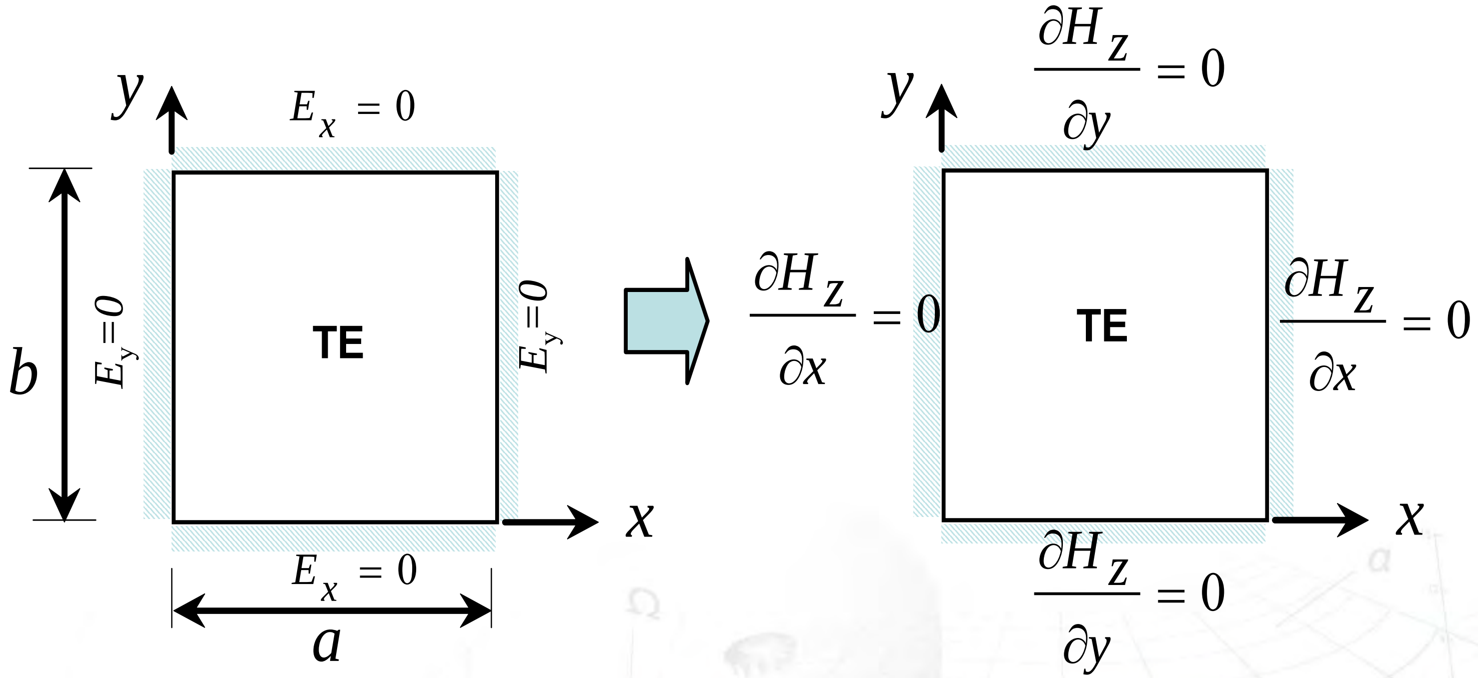
- General form for Transverse Electric wave propagation in z-direction

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \underbrace{\left(\gamma^2 + k^2\right)}_{k_c^2} H_z = 0$$

H_z is longitudinal magnetic field component

K_c is the cutoff wave number defined by specified boundary conditions

Validation – TE Rectangular Waveguide



Electric Conductor BCs

$$\begin{cases} E_x = \dfrac{-j\omega\mu}{\gamma^2 + k^2} \dfrac{\partial H_z}{\partial y} \\ E_y = \dfrac{j\omega\mu}{\gamma^2 + k^2} \dfrac{\partial H_z}{\partial x} \end{cases}$$

Validation – TE_{10} Mode

- Longitudinal magnetic field:

$$H_z = H_0 \cos\left(\frac{\pi x}{a}\right) e^{-j\beta_g z}$$

- Electric field:

$$\begin{cases} E_x = 0 \\ E_y = \dfrac{-j\omega\mu}{(\pi / a)} H_0 \sin\left(\dfrac{\pi x}{a}\right) e^{-j\beta_g z} \end{cases}$$

where,

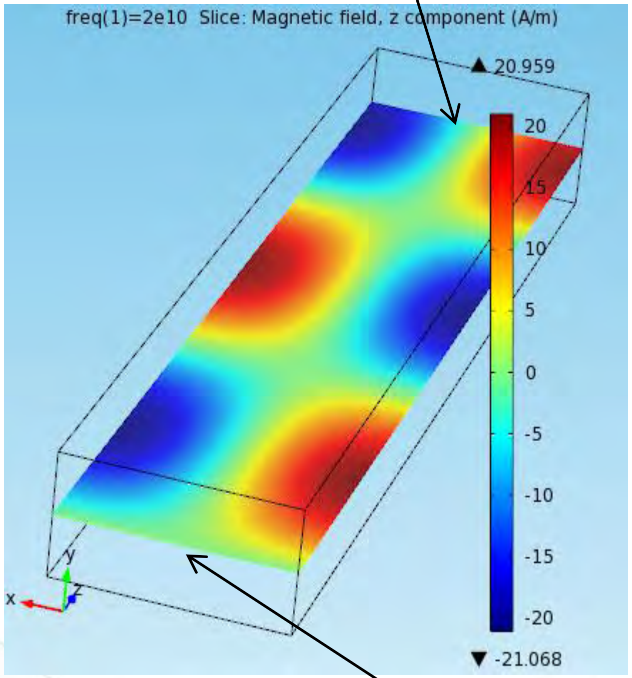
$\beta_g = \frac{2\pi}{c}\sqrt{f^2 - f_{c10}^2}$ - Guiding mode frequency

$f_{c10} = \frac{c}{2a}$ - Cutoff frequency

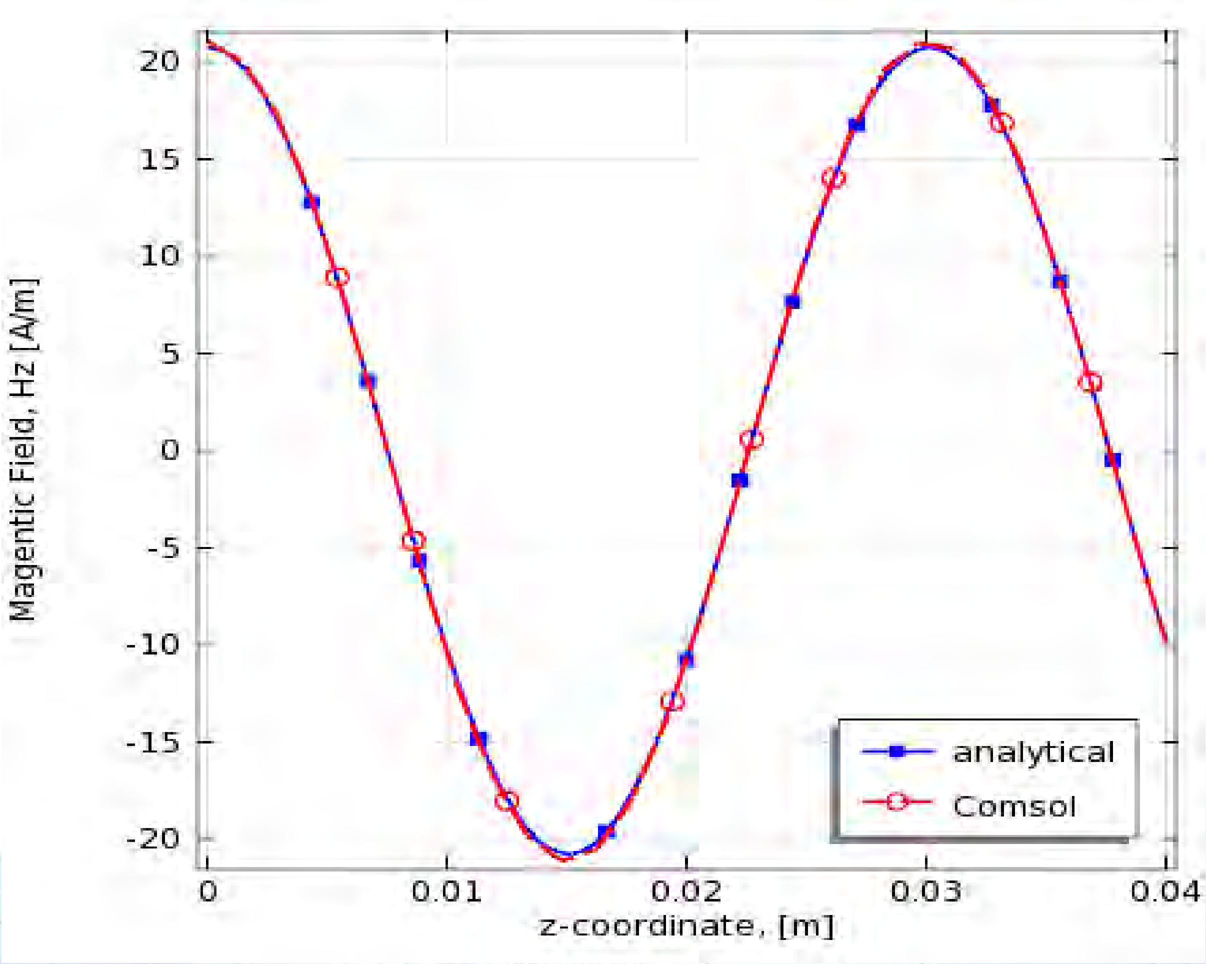
$c = 1/\sqrt{\mu\varepsilon}$ - Speed of light

Validation – TE_{10} Mode, H_z

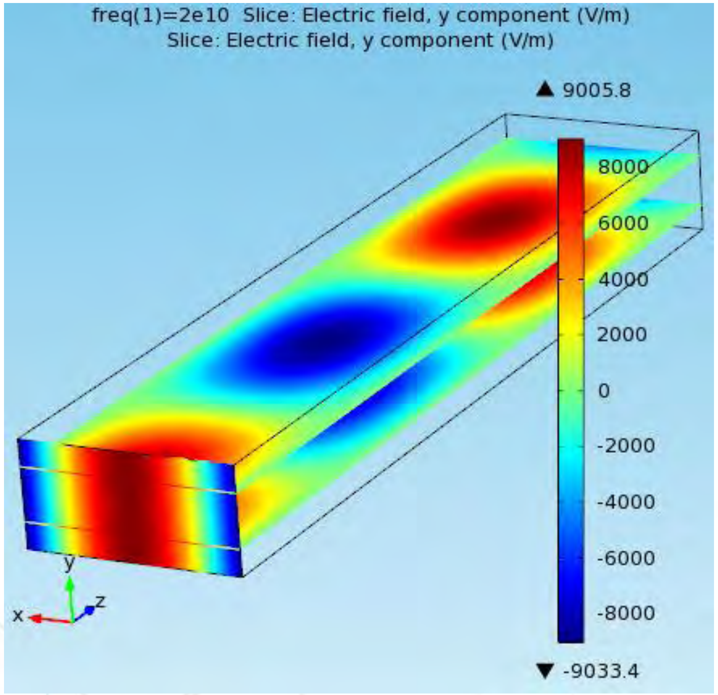
Open – Passive Port

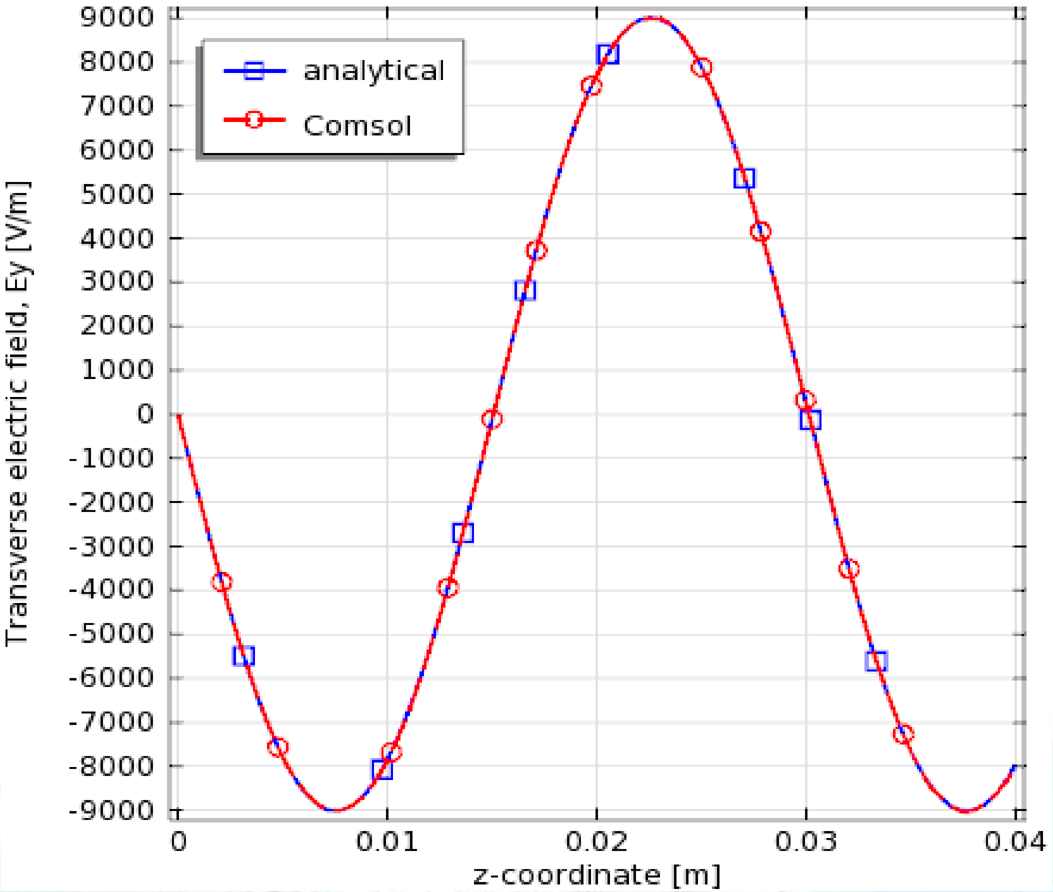


Excitation Port

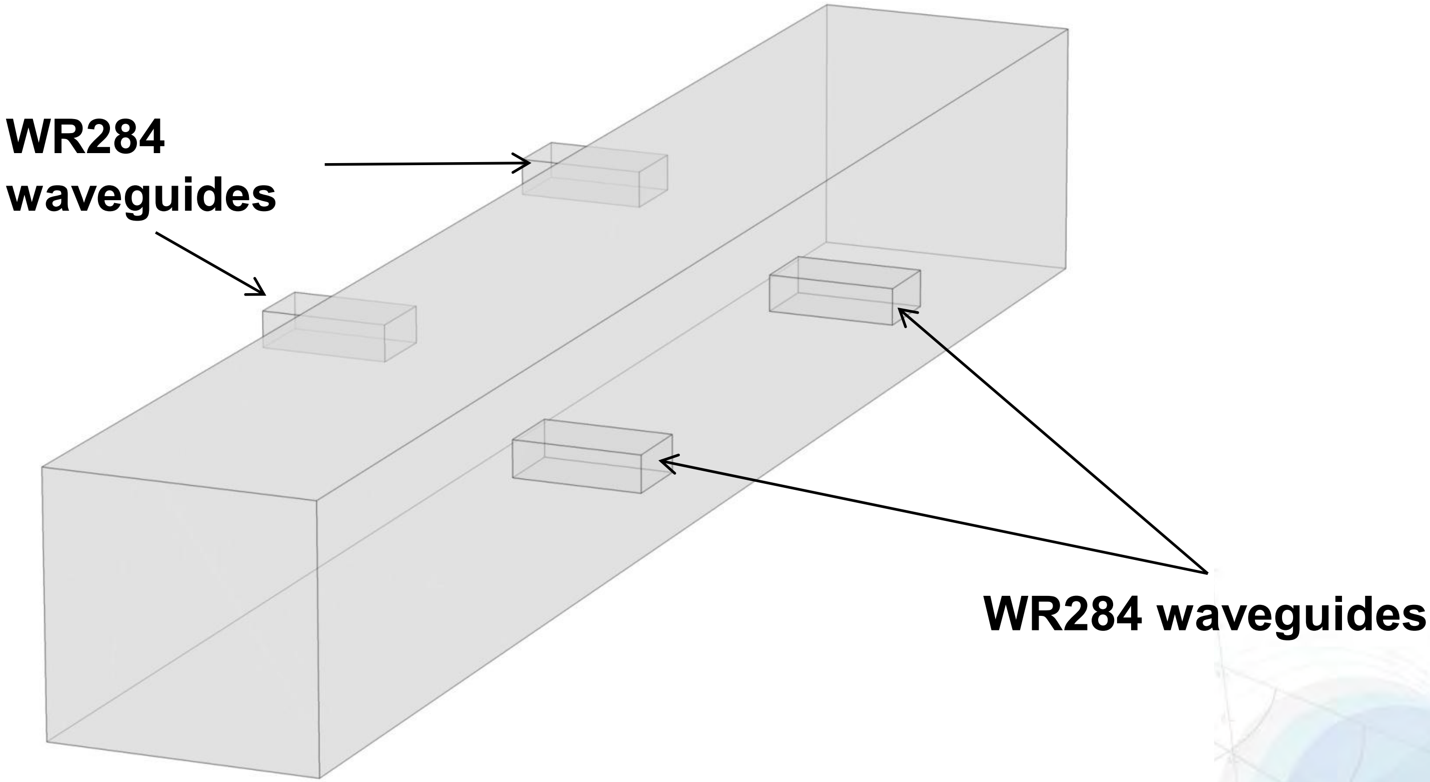


Validation – TE_{10} Mode, E_y



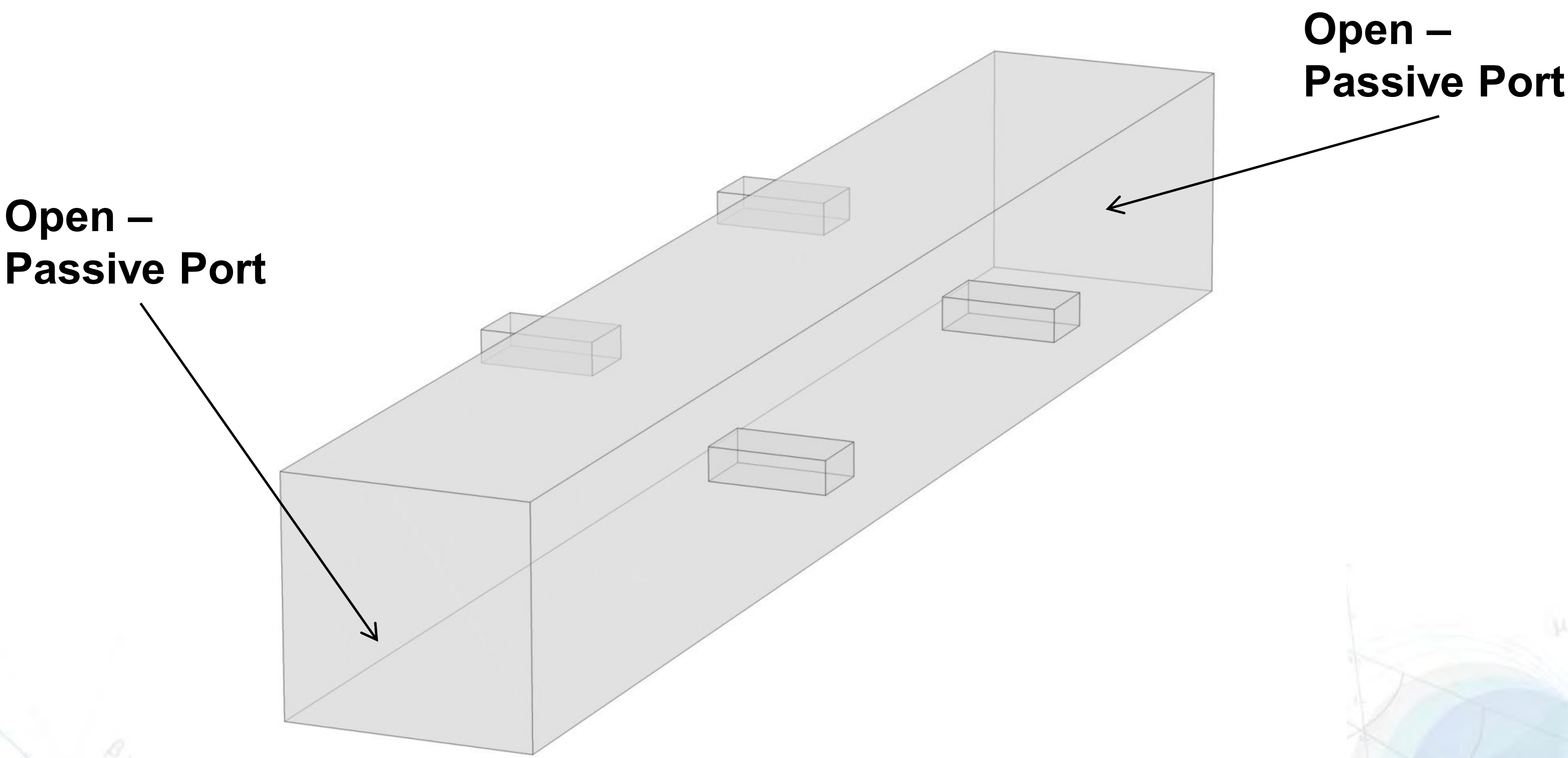


Microwave Heater



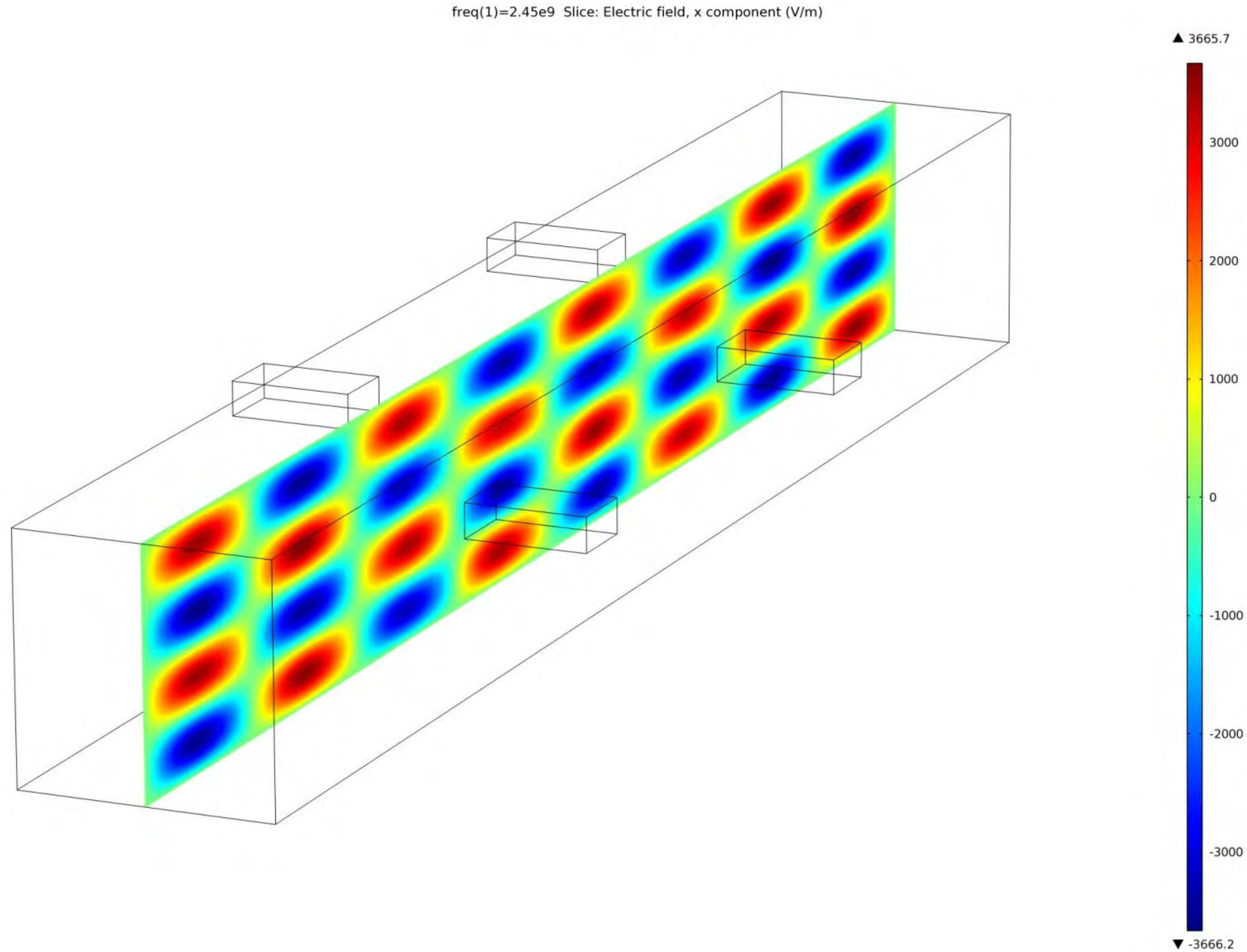
2.45 GHz

Microwave Heater

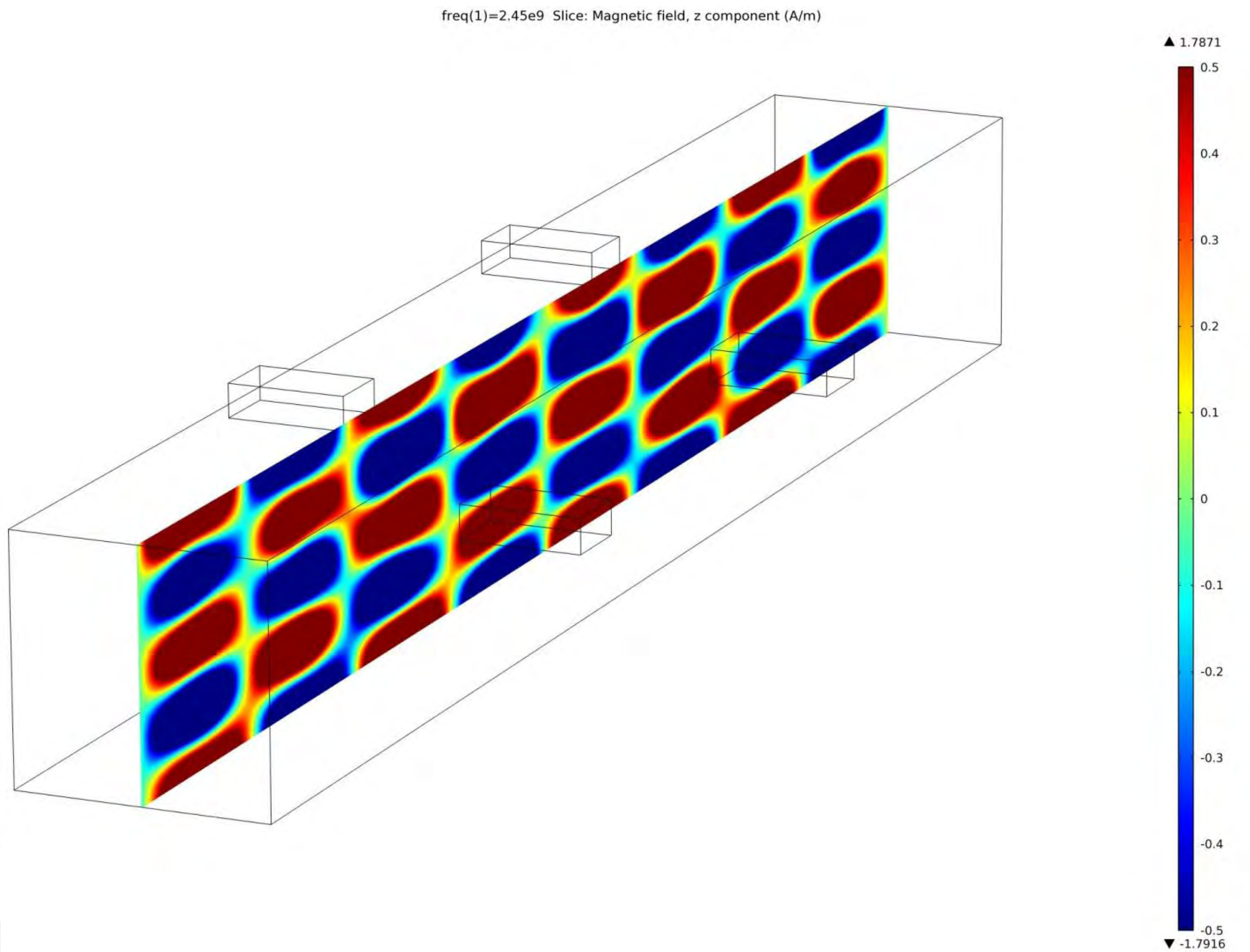


2.45 GHz

Electric Field, Ex (V/m)

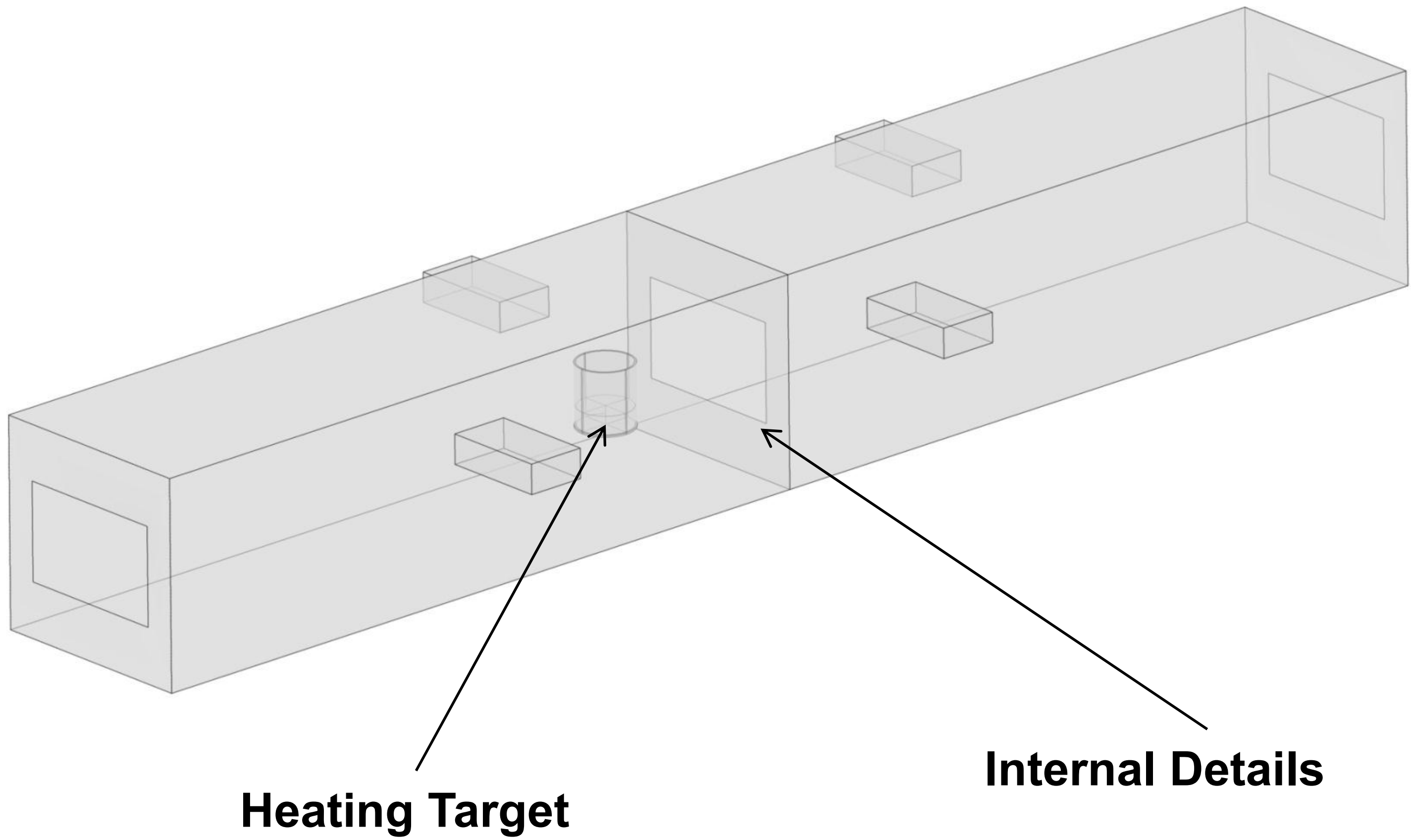


Magnetic Field, Hz (A/m)



GEOMETRIC DETAILS

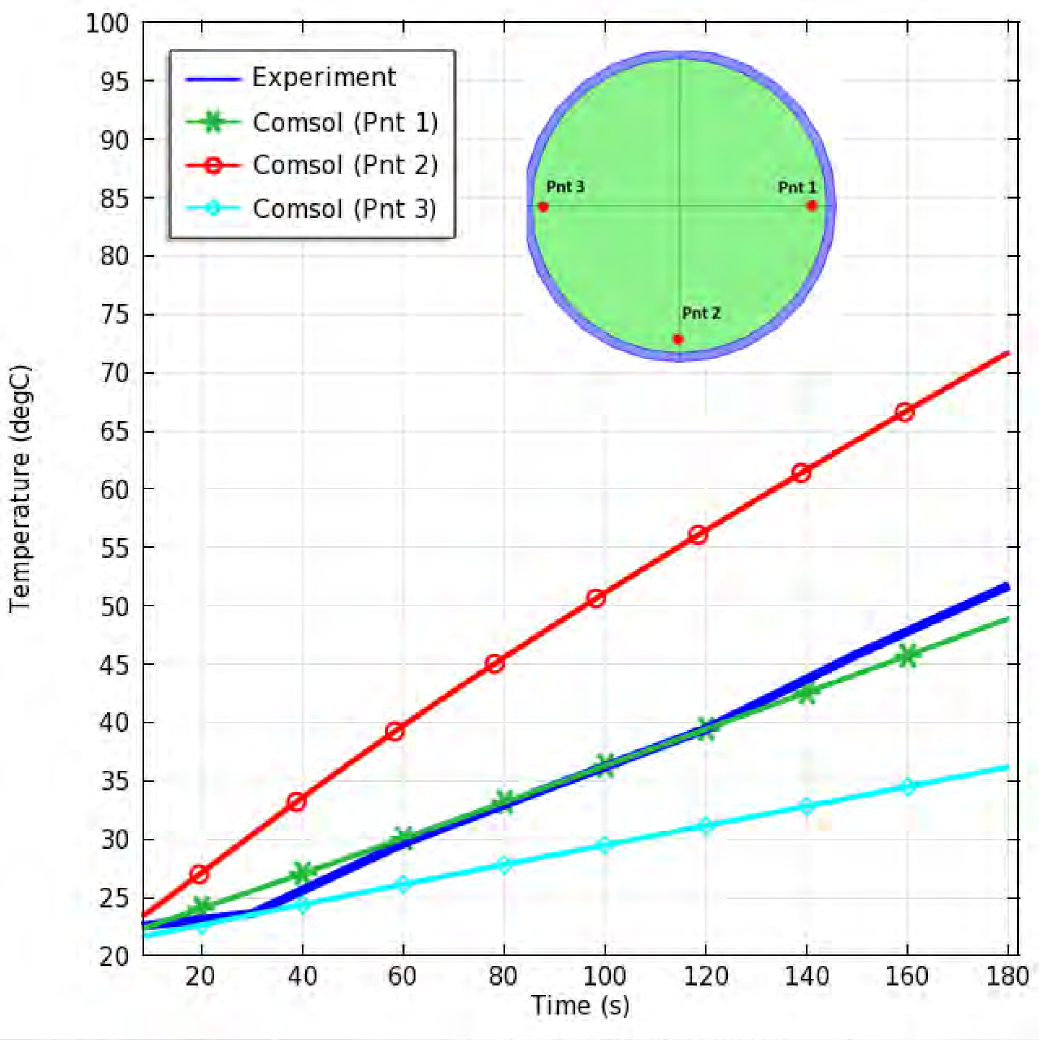
Microwave Heater



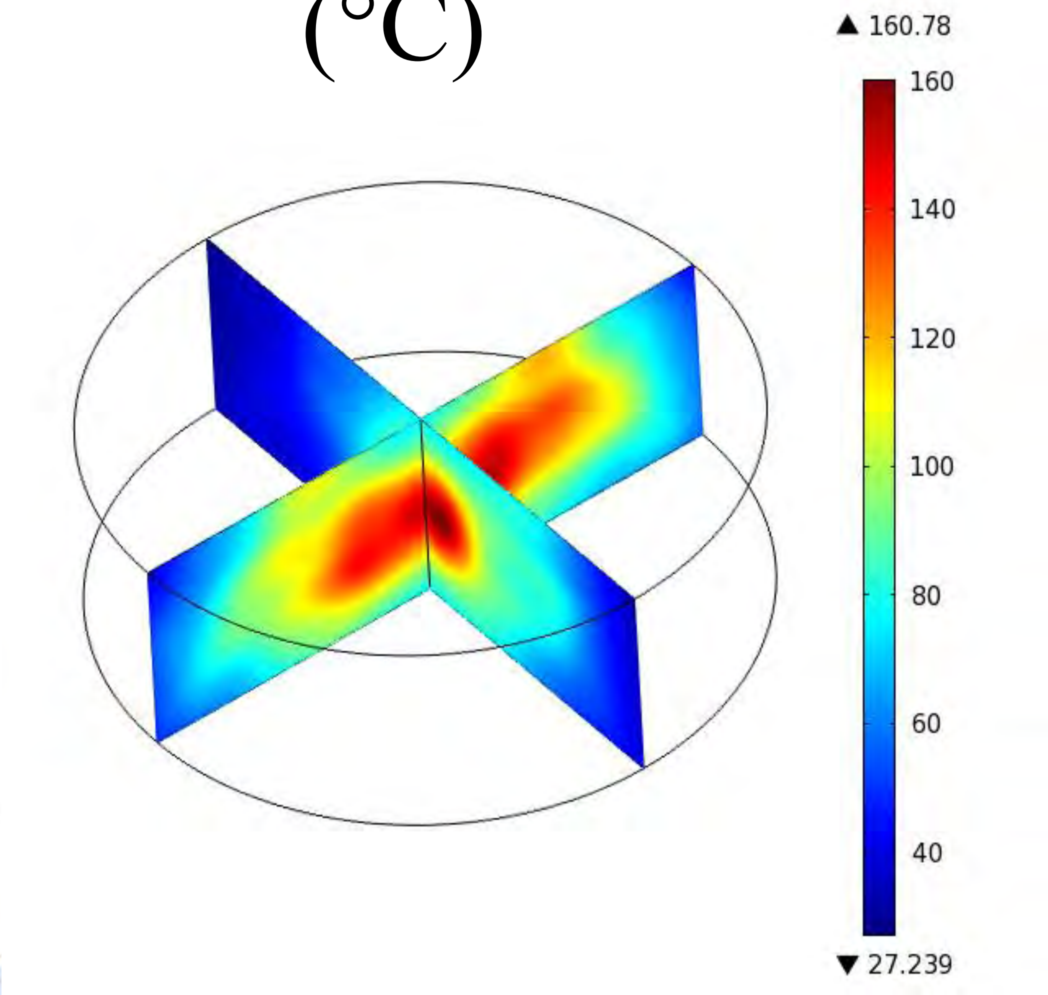
Heating Target

- Glass Container
- Gelled Saline – ASTM F2182
  - Conductivity = 0.5 S/m
  - Specific Heat = 4160 J/(kg K)
  - Relative Permittivity = 80
  - Density = 1000 kg/m^3
- Fiber optic thermocouple place 5 mm from glass wall

Experimental Verification



Heating Target – Temperature (°C)



Summary

- Procedure for developing microwave solutions presented
  - Validation against analytical solution
  - Simple model of multi-port waveguide
  - Add complexity
- Key aspects of waveguide modeling presented
  - Excitation ports
  - Passive ports
- Validation against experimental data
  - Good agreement with single point of measurement
  - High temperatures at center of target
  - Significant temperature gradients