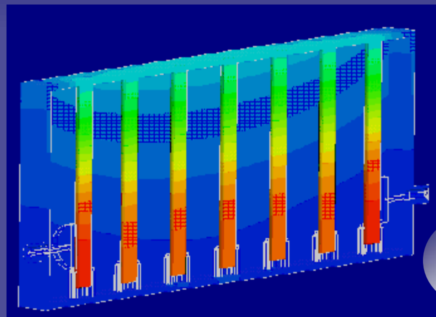
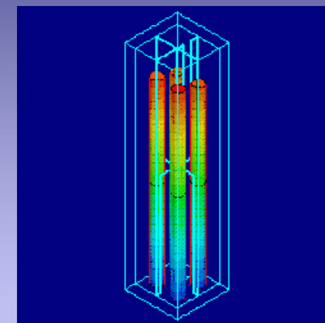
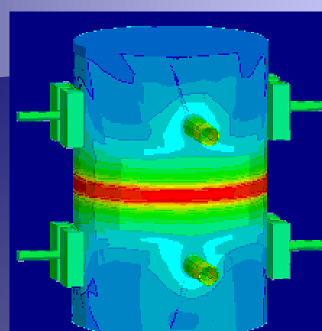
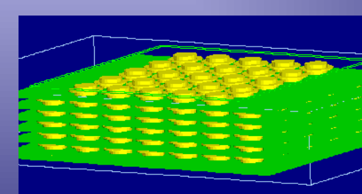
ANSOFT





HFSS & ePhysics Features for the Simulation of Microwave Power Applications



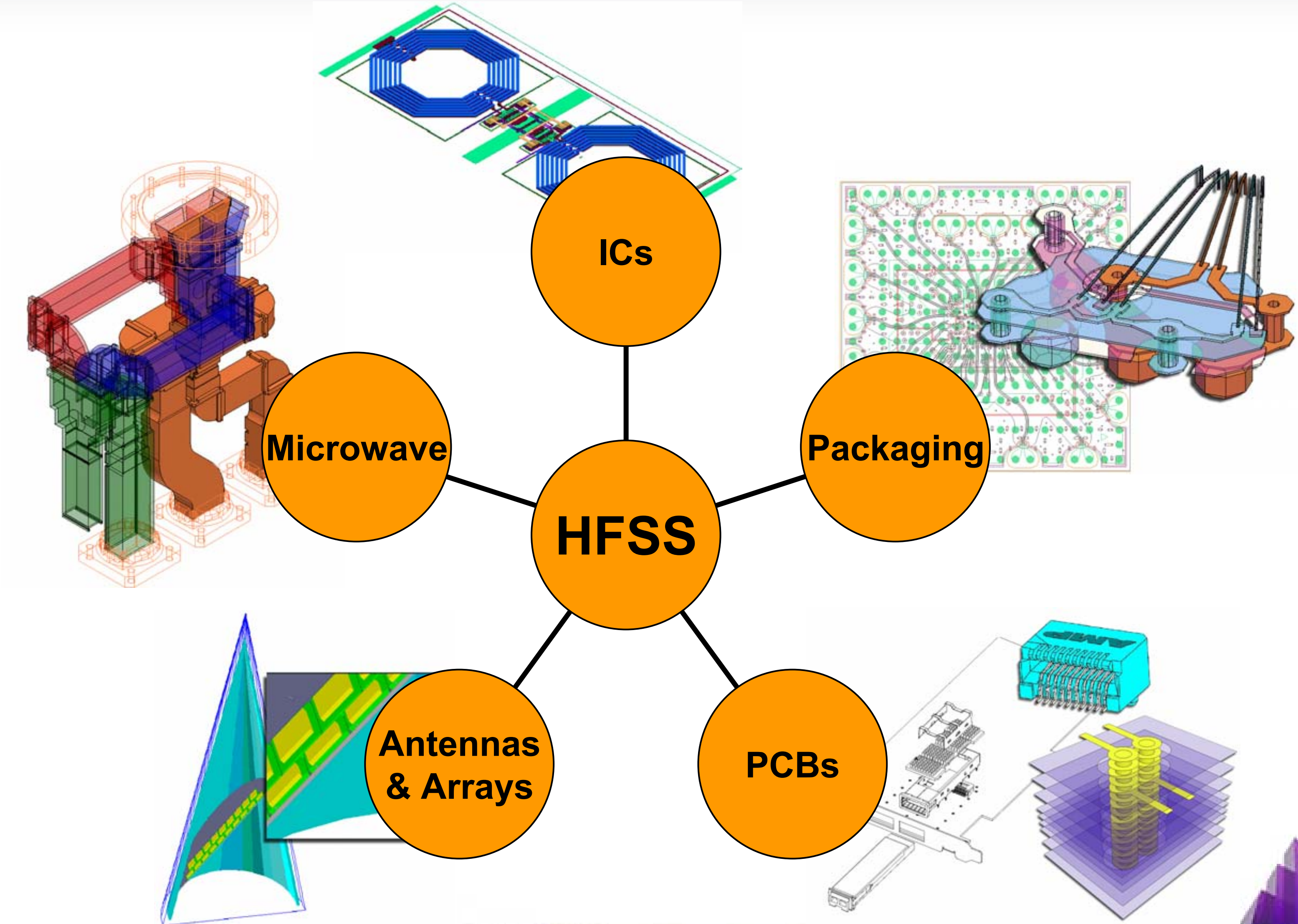


Bogdan C. Ionescu

Brad Brim

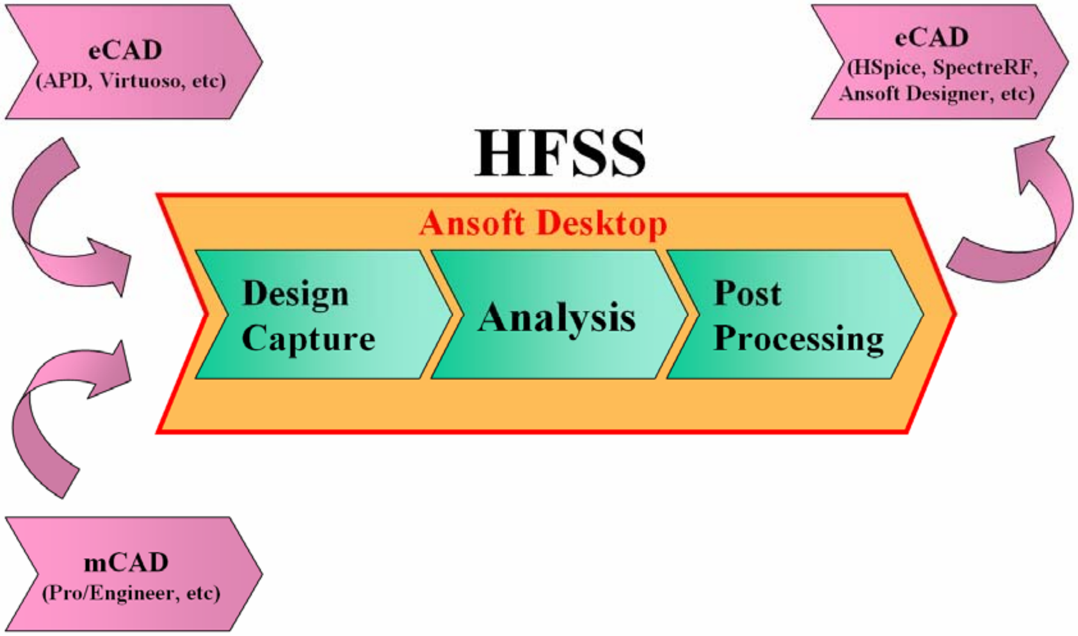
Ansoft Corporation

HFSS Applications

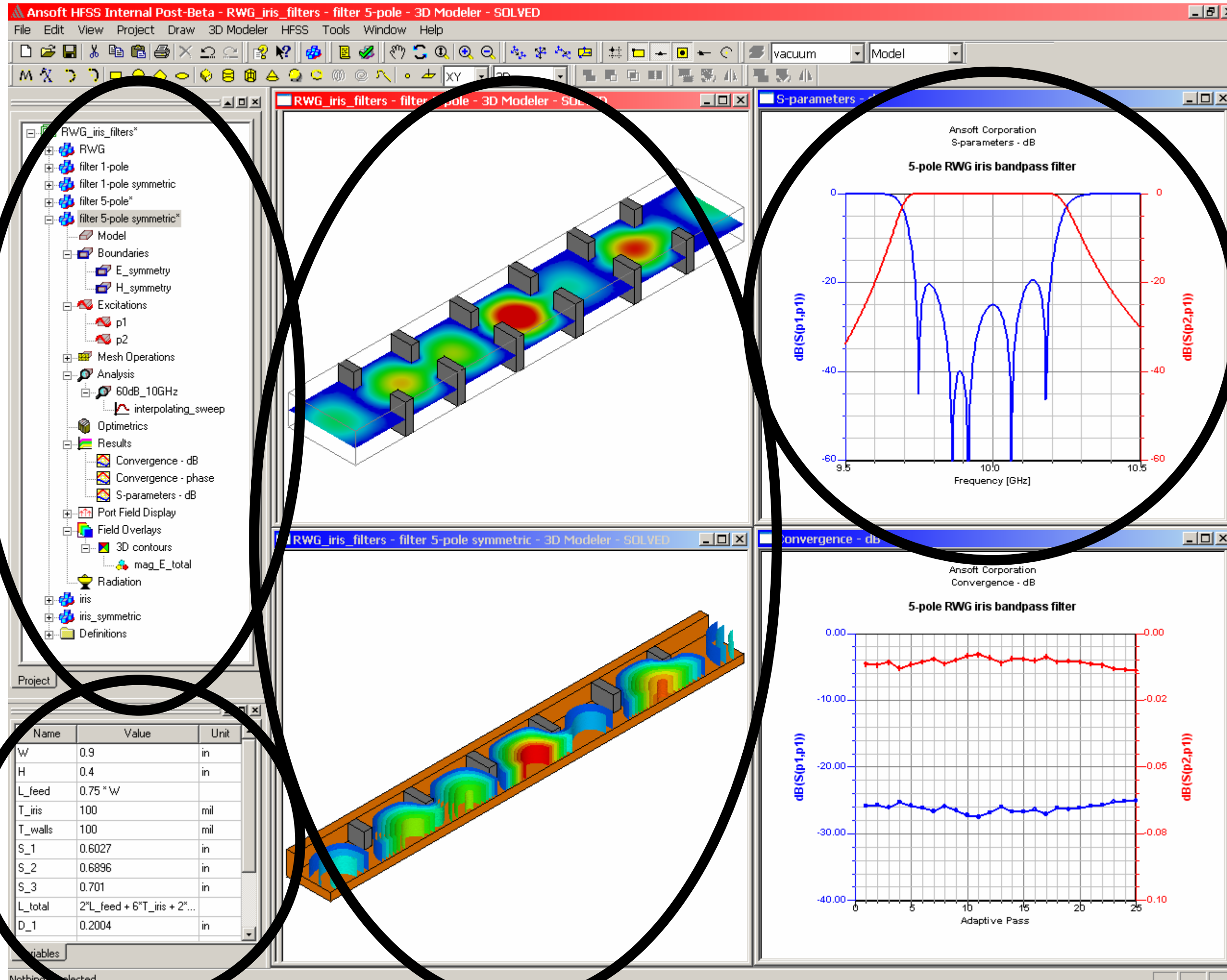


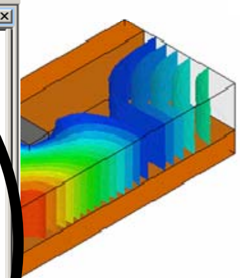
The Ansoft Desktop

- HFSS is a "design environment" enabling an automated 3D EM-based design flow
  - design flow management with a familiar use model
  - parametric design database creation and editing
  - parametric data management and access

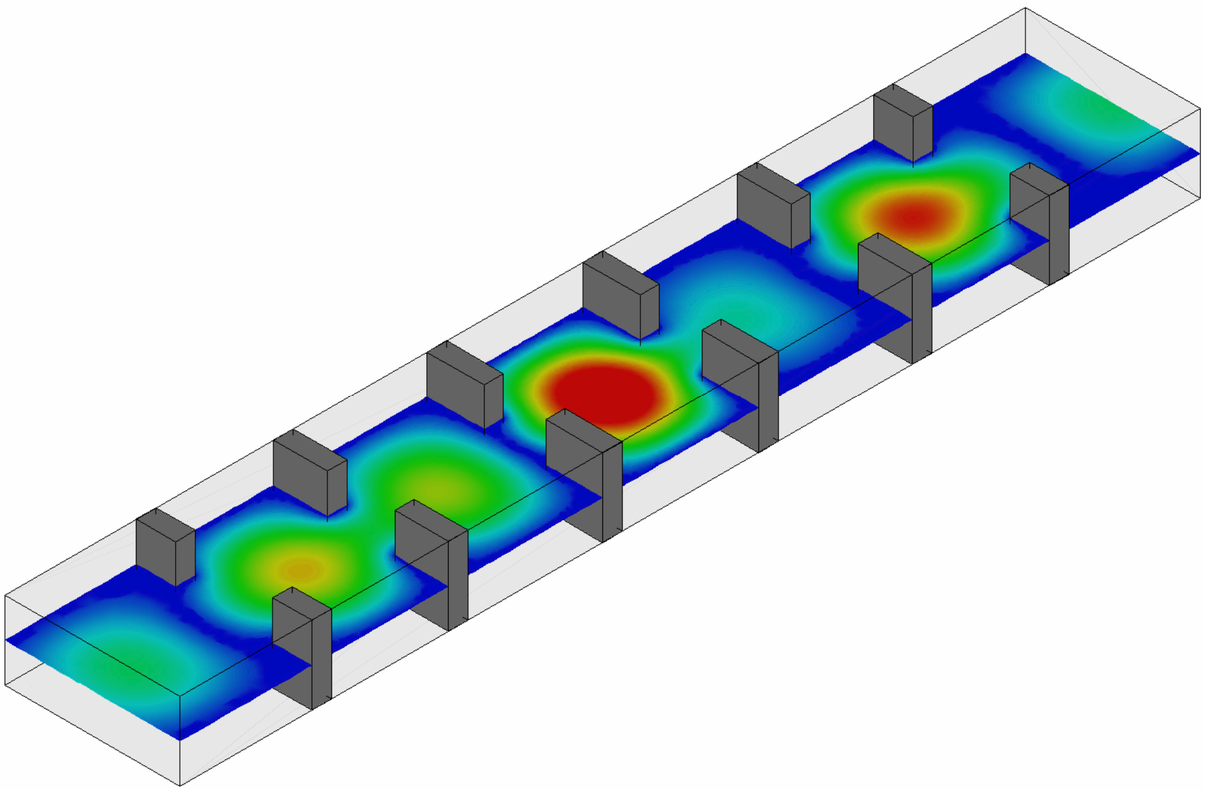


An HFSS Design Example



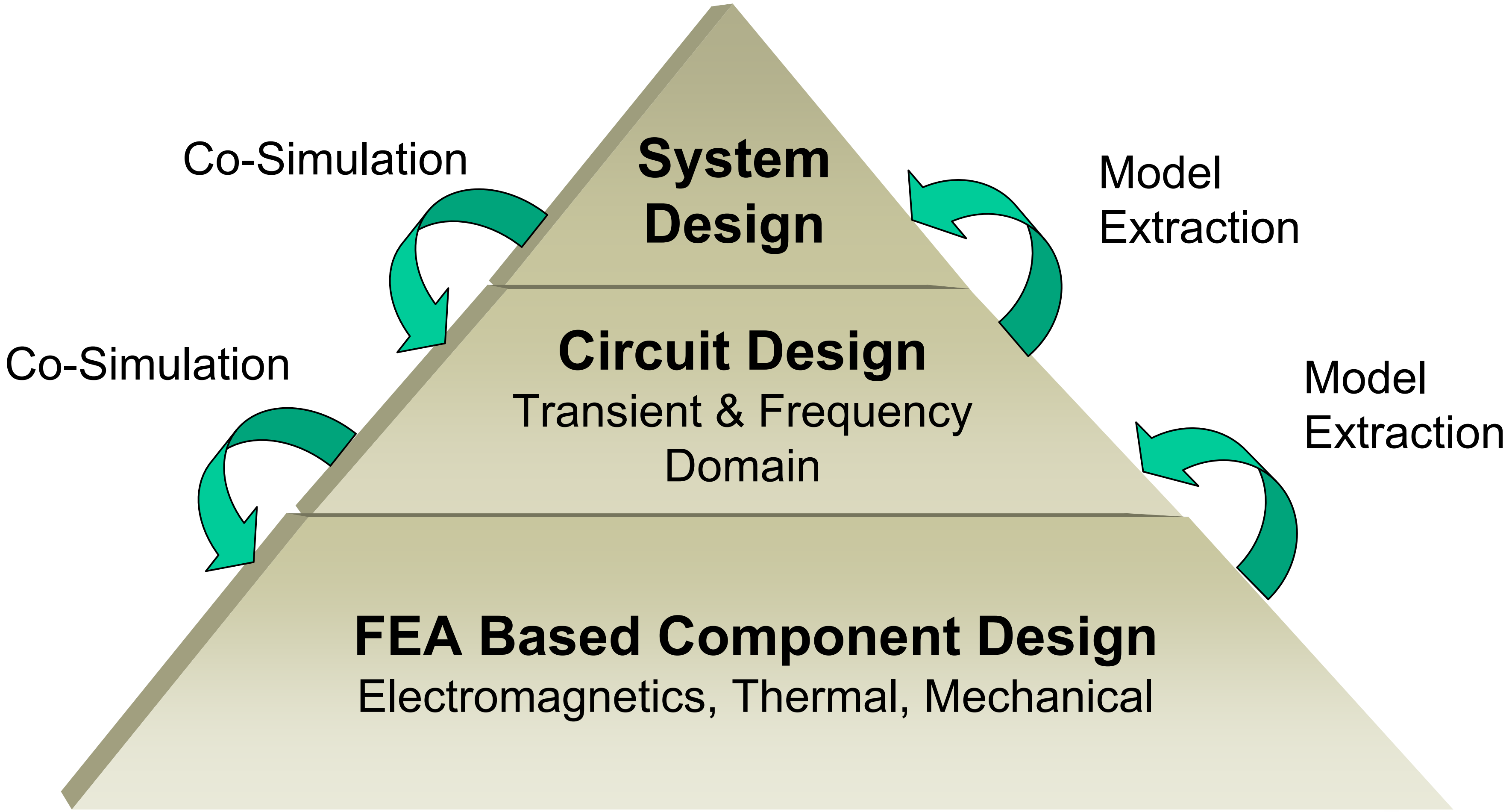


High Power HF Components



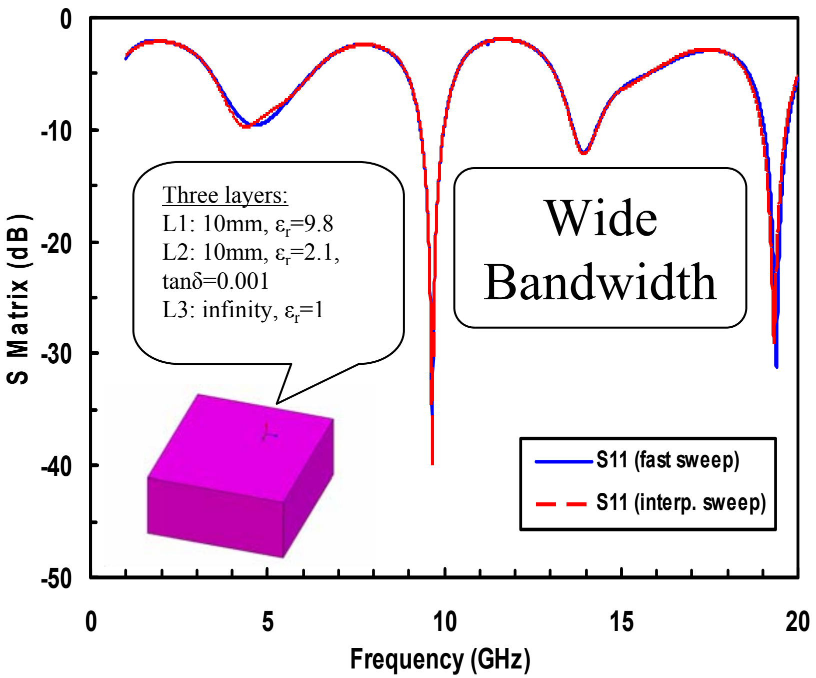
Pass band iris filter

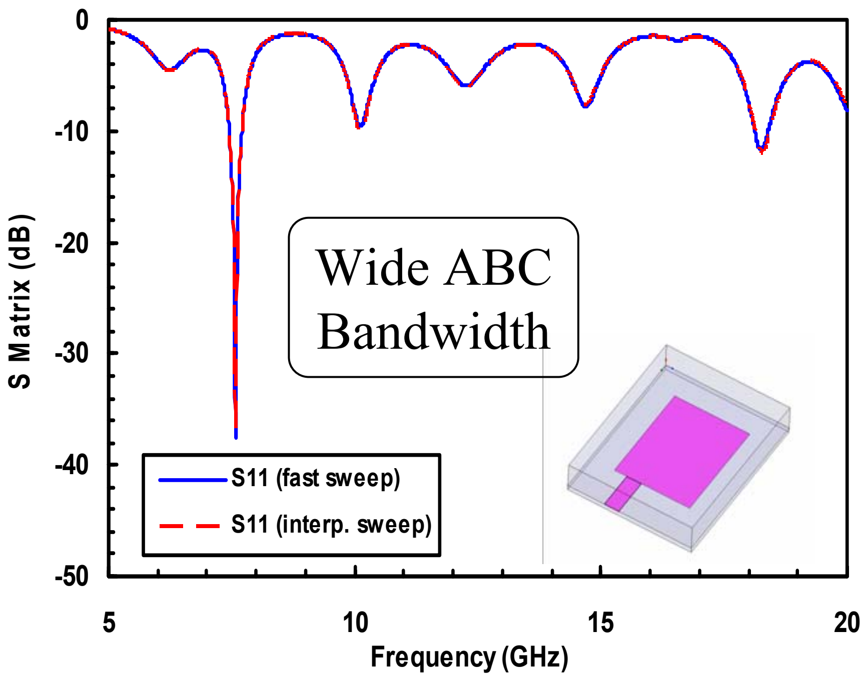
Trend: Eliminate Boundaries



Model Order Reduction

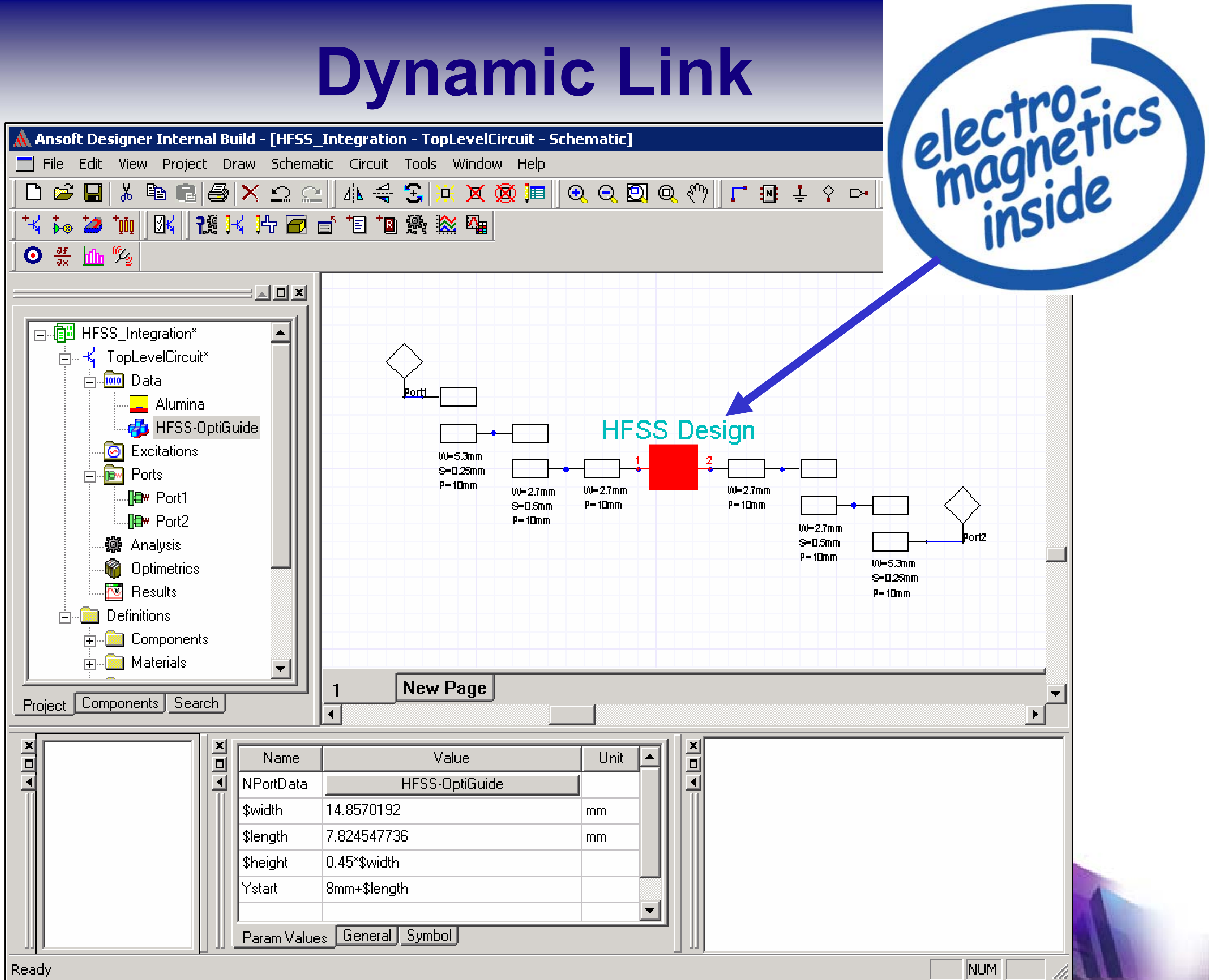
- Fast Frequency Sweep



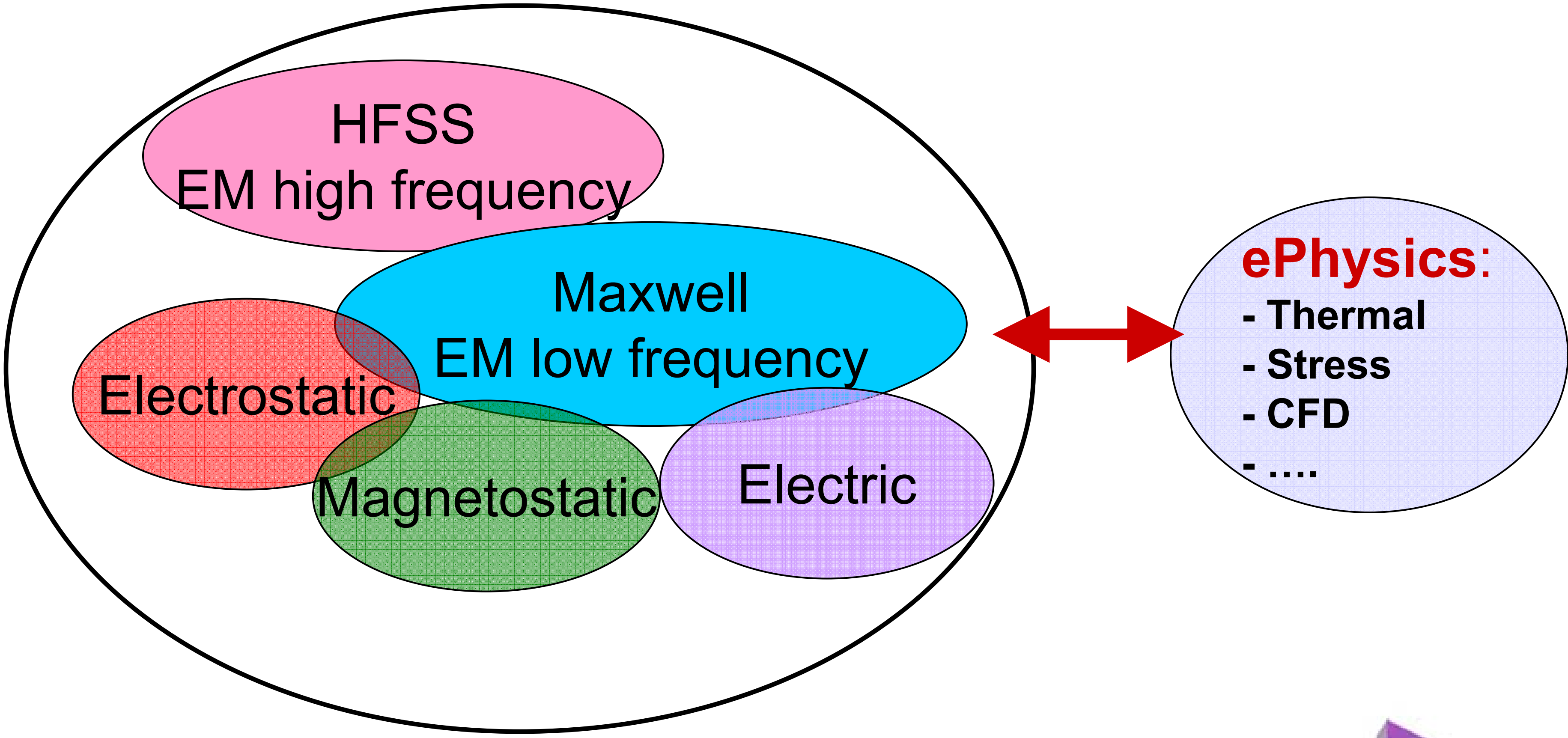


B. Anderson, J. E. Bracken, J. B. Manges, G. Peng and Z. J. Cendes, "Full-Wave analysis in SPICE via Model-Order Reduction", *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 9, pp. 2314-2320, September 2004.

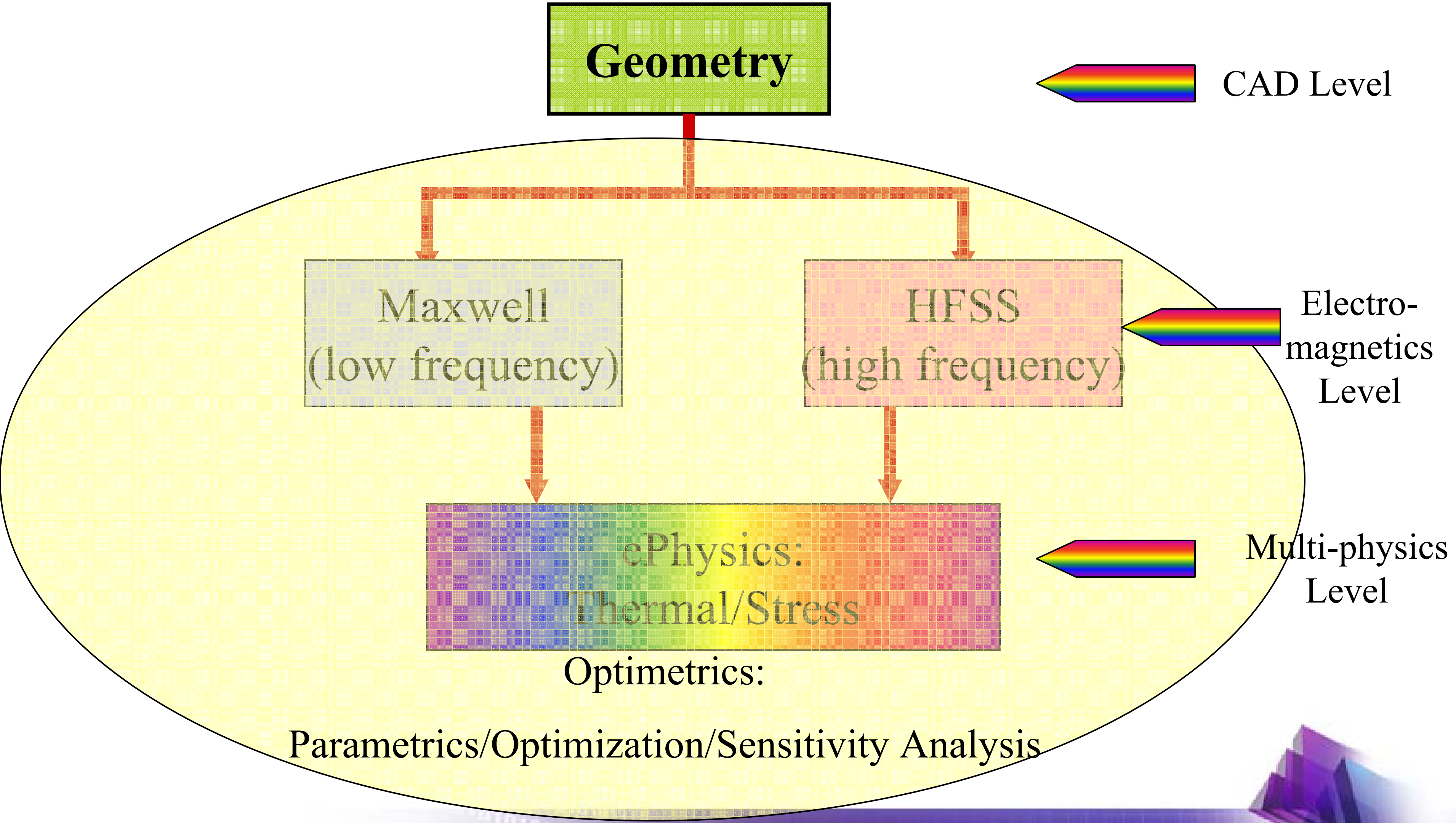
Dynamic Link



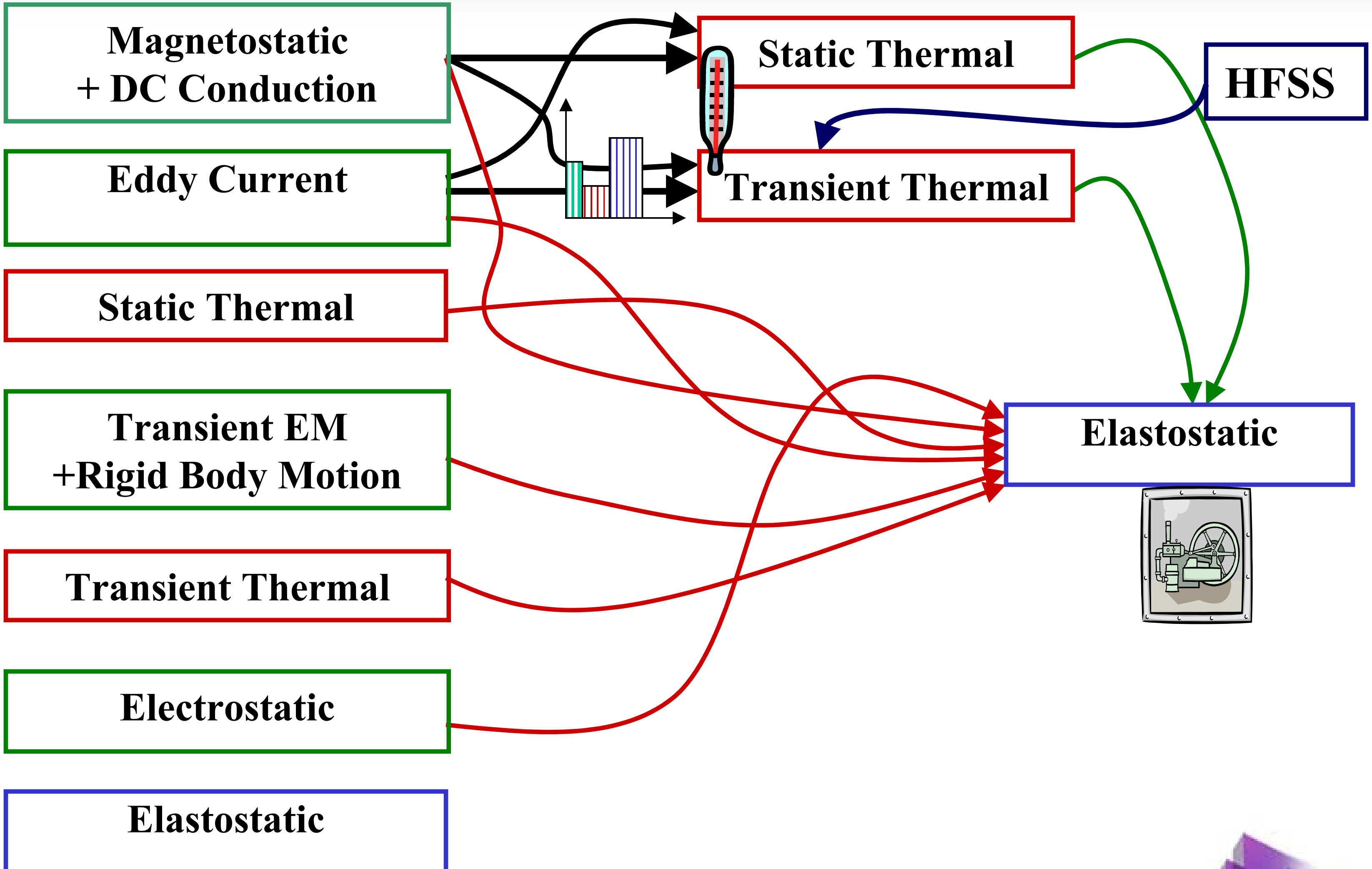
ePhysics for Electromagnetic Applications



Higher Level Analysis



ePhysics ™ Functional Links



Thermal Transient Solution

IN:

1 **Geometry (. sm3 from HFSS, use File/Open rather than File/Import)**

Material properties (thermal conductivity, specific heat, mass density)

Sources (volumetric power loss density, superficial power loss density, other non-electromagnetic sources) 2,3

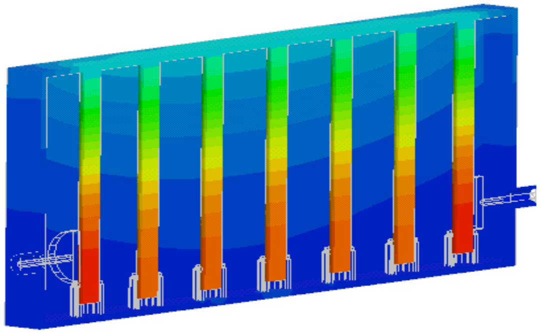
Boundary conditions (prescribed temperature, convection, radiation)

Solver setup (time step, HFSS mesh, thermal mesh mapping) 4

From HFSS

From ePhysics

ALL mesh files are necessary!



OUT:

Temperature distribution (scalar)
Heat Flow (vector)
Executive parameters (average temp., hot spot temp., cold spot temp., locations)
Post processing macro results

Static Stress Solution (coupled with thermal transient)

IN:

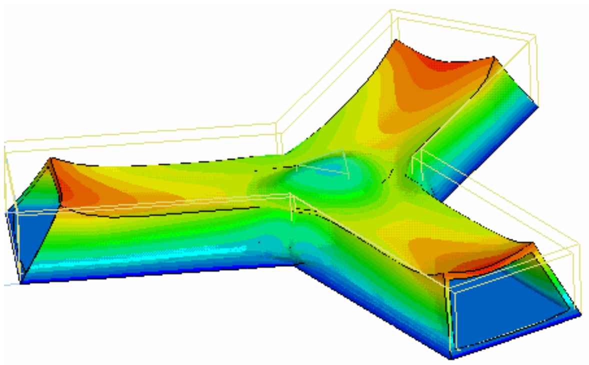
Geometry (already there, with origin in . sm3 from HFSS)

Material properties (Young's modulus, Poisson's ratio, coefficient of thermal expansion)

Sources (temperature distribution, other non-thermal sources)

Boundary conditions (displacement)

Solver setup (mesh, mapping)



OUT: (at user-selected time steps)

Displacement (vector)
Traction (vector)
Von Mises stress (vector)
Executive parameters (max von Mises stress, max principal stress, etc.)

3D Thermal Transient

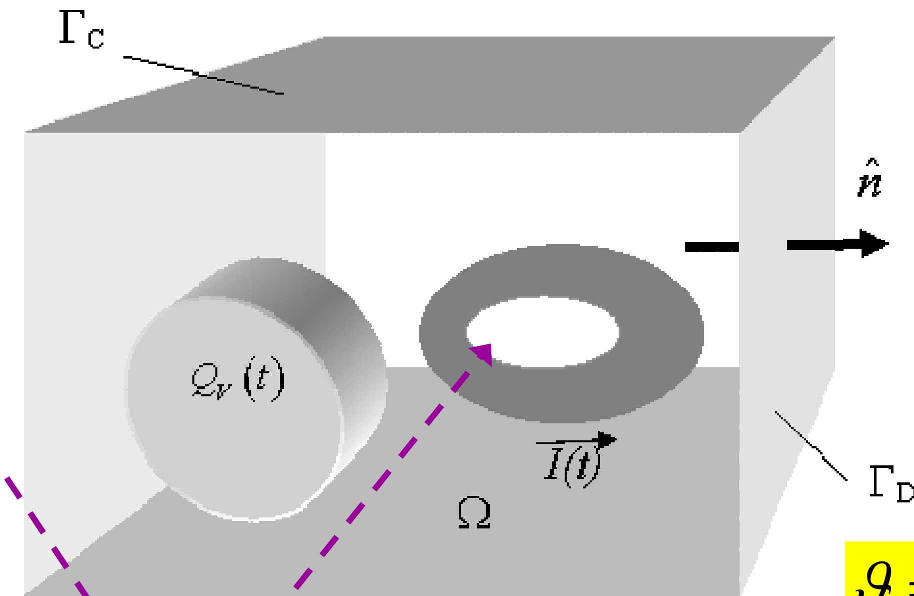
$$\vec{q}\cdot\hat{n} = q_C(\vartheta) = h(\vartheta)(\vartheta - \vartheta_r)$$

$$\rho c \partial_t \vartheta = -\nabla\cdot\vec{q} + Q_v(t,\vec{x})$$

$$\vec{q} = -\mathbf{k}\nabla\vartheta$$

initial condition

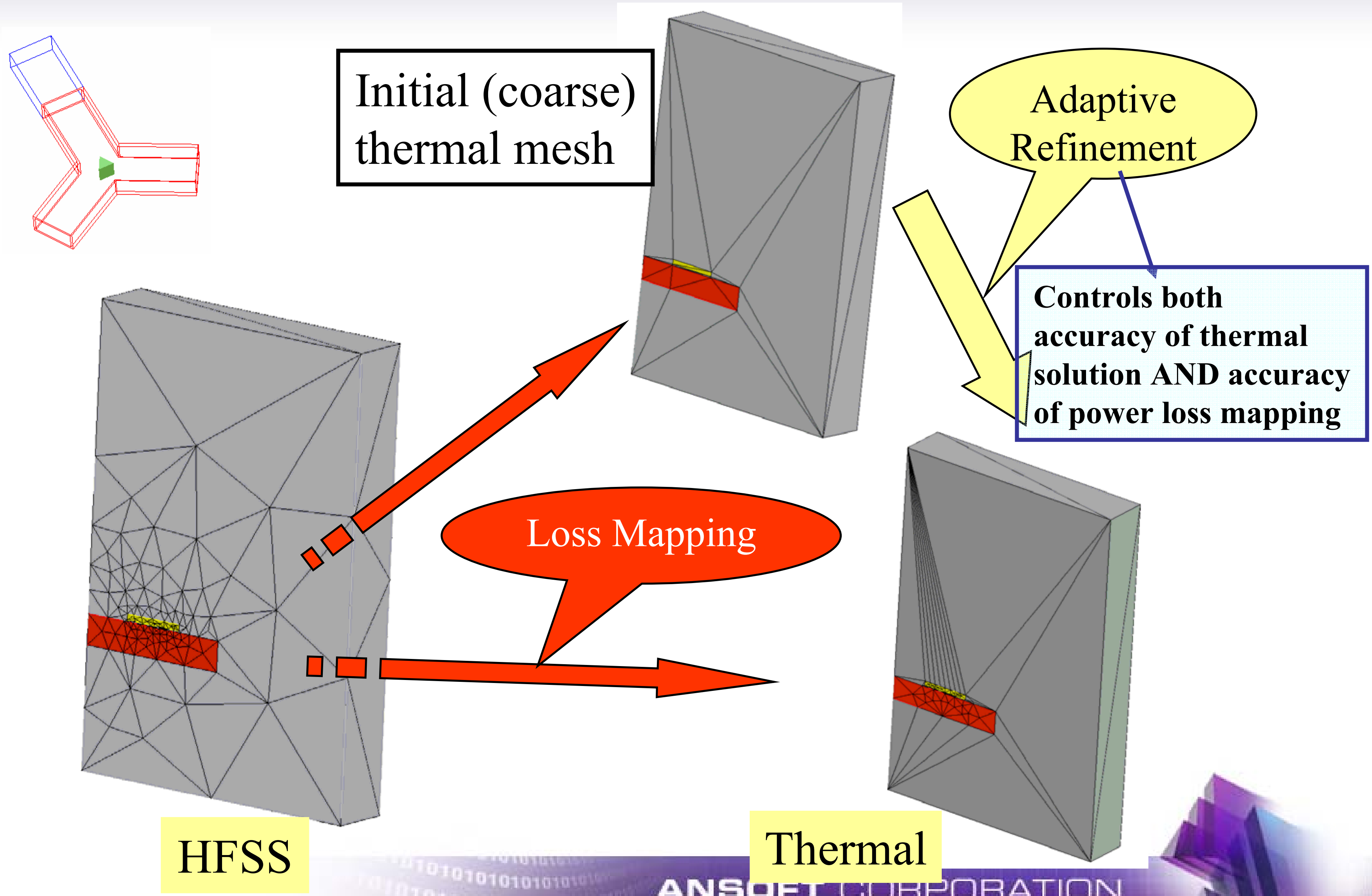
$$\vartheta(0,\vec{x}) = \vartheta_0(\vec{x})$$



$$\vartheta = \vartheta_D$$

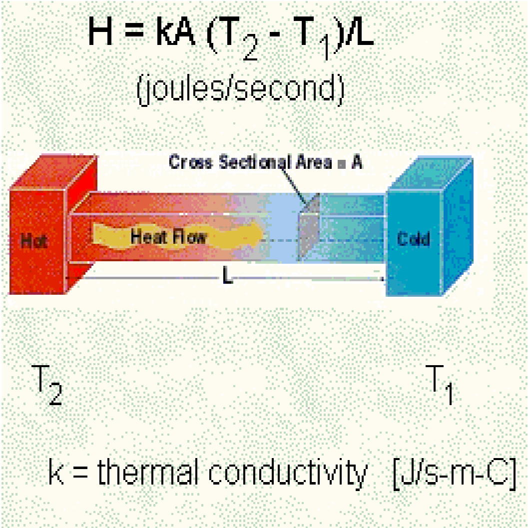
$$Q_v = \vec{E}\cdot\vec{J}$$

Solution Process HFSS - Thermal

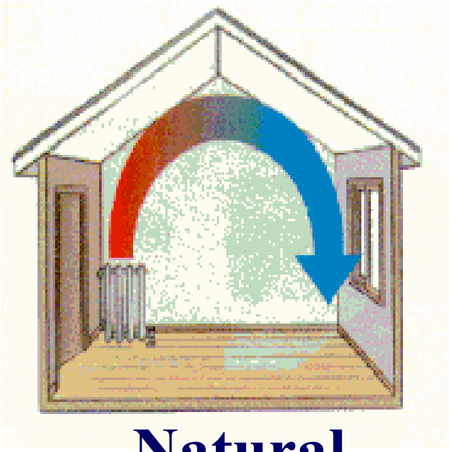


Heat Transfer Mechanisms

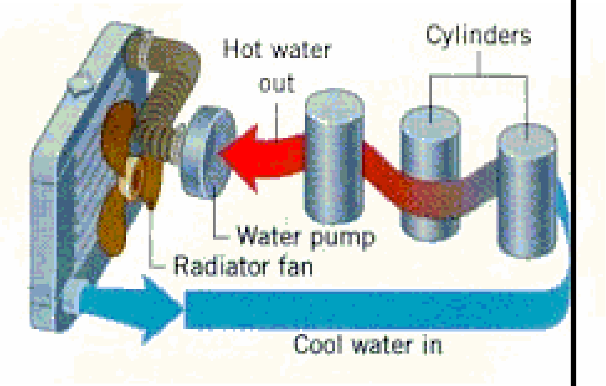
Conduction



Convection

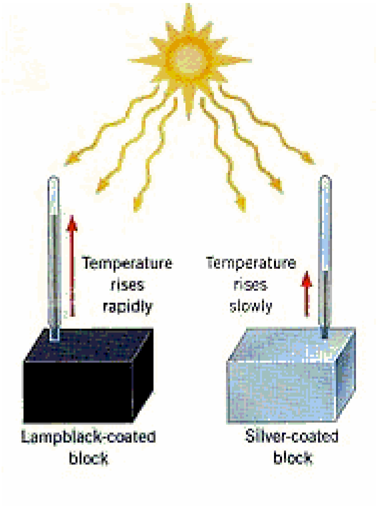


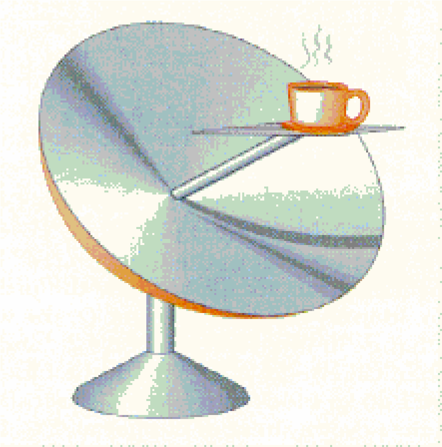
Natural



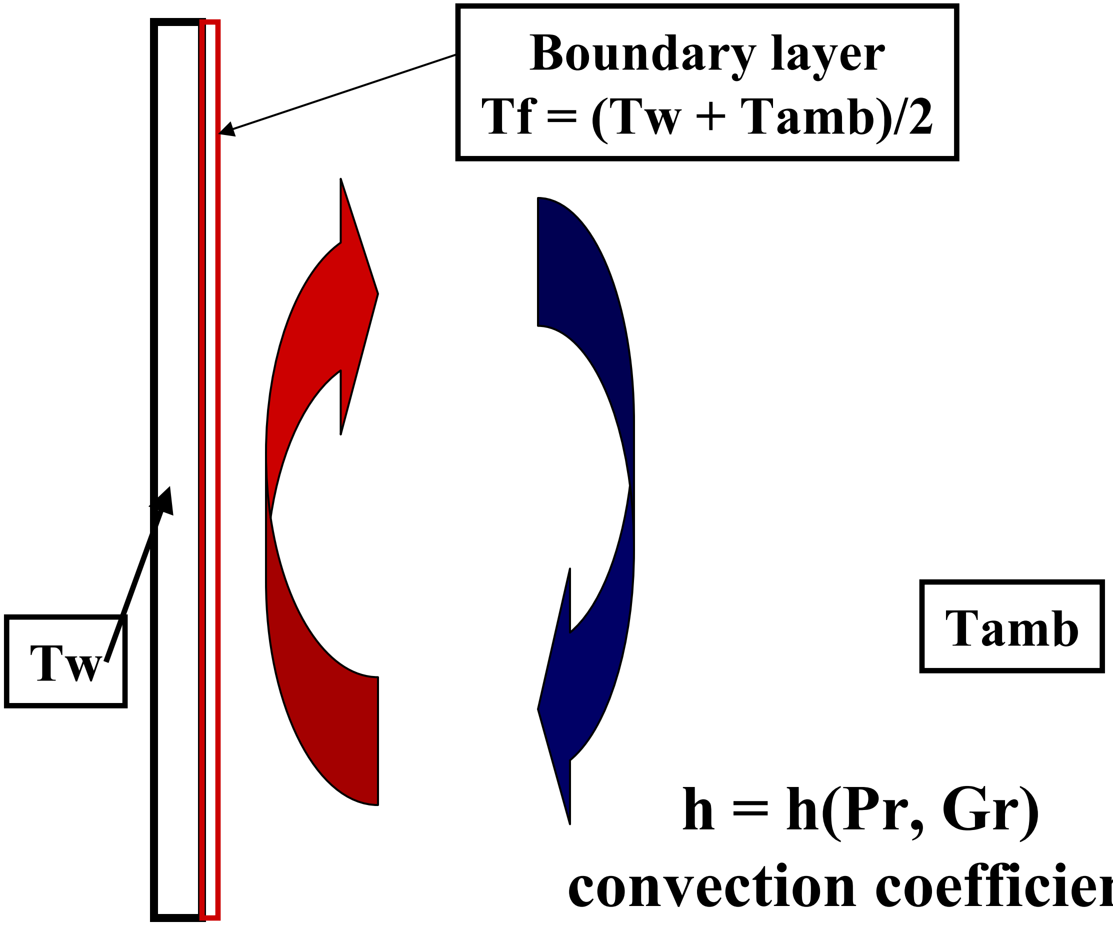
Forced

Radiation



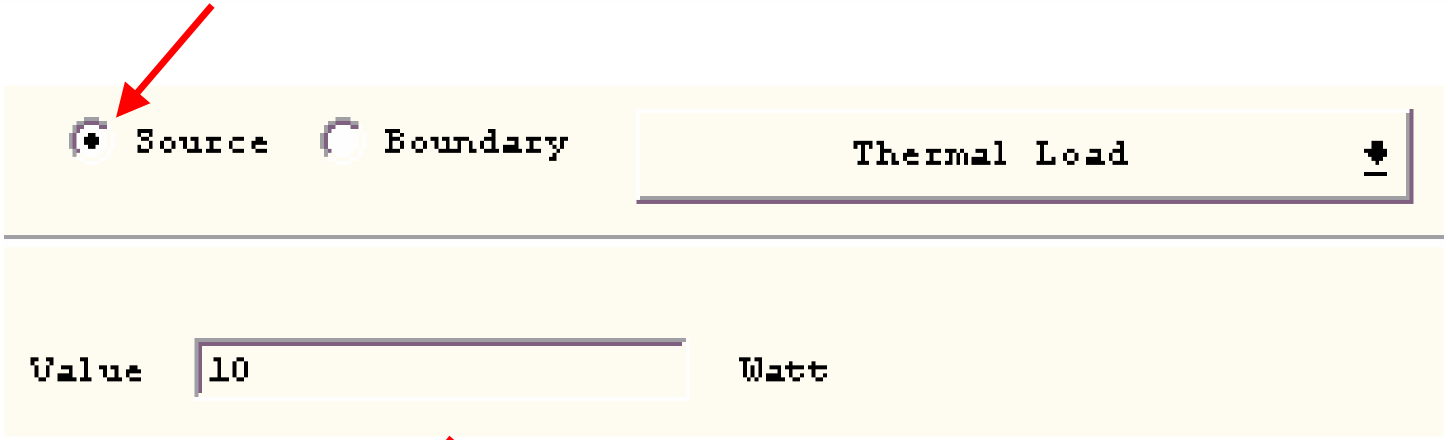


Convection Mechanism on a Vertical Wall

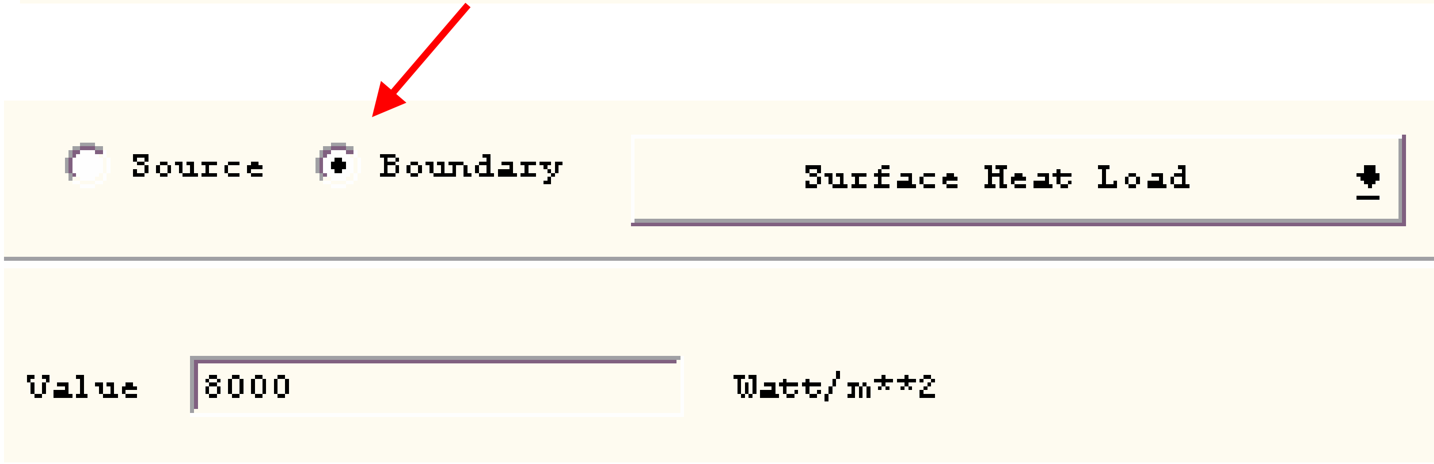


h = h(Pr, Gr)
convection coefficient depends on the temperature of the wall

Frequently Used Thermal Sources



On solids



On surfaces, surface can be between objects

Frequently Used Thermal Boundary Conditions

- Source ◉ Boundary — **Temperature**

  Value: 50 Celsius

- Source ◉ Boundary — **Heat Transfer**

  Thermal Flux Density = H*(TEMP-TEMP_A)

  Heat transfer coef. (H): 10 Watt/Celsius-m**2

  Ambient temperature (TEMP_A): 25 Celsius

- Source ◉ Boundary — **Convection _Radiation**

  q = C*(TEMP-TEMP_A)*|TEMP-TEMP_A|**FEXP + F*B*(TEMP**4-TEMP_R**4)

  Convection coefficient (C): 12 W/C**ALPHA/m**2

  Ambient temperature (TEMP_A): 35 Celsius

  Exponent (FEXP): 0

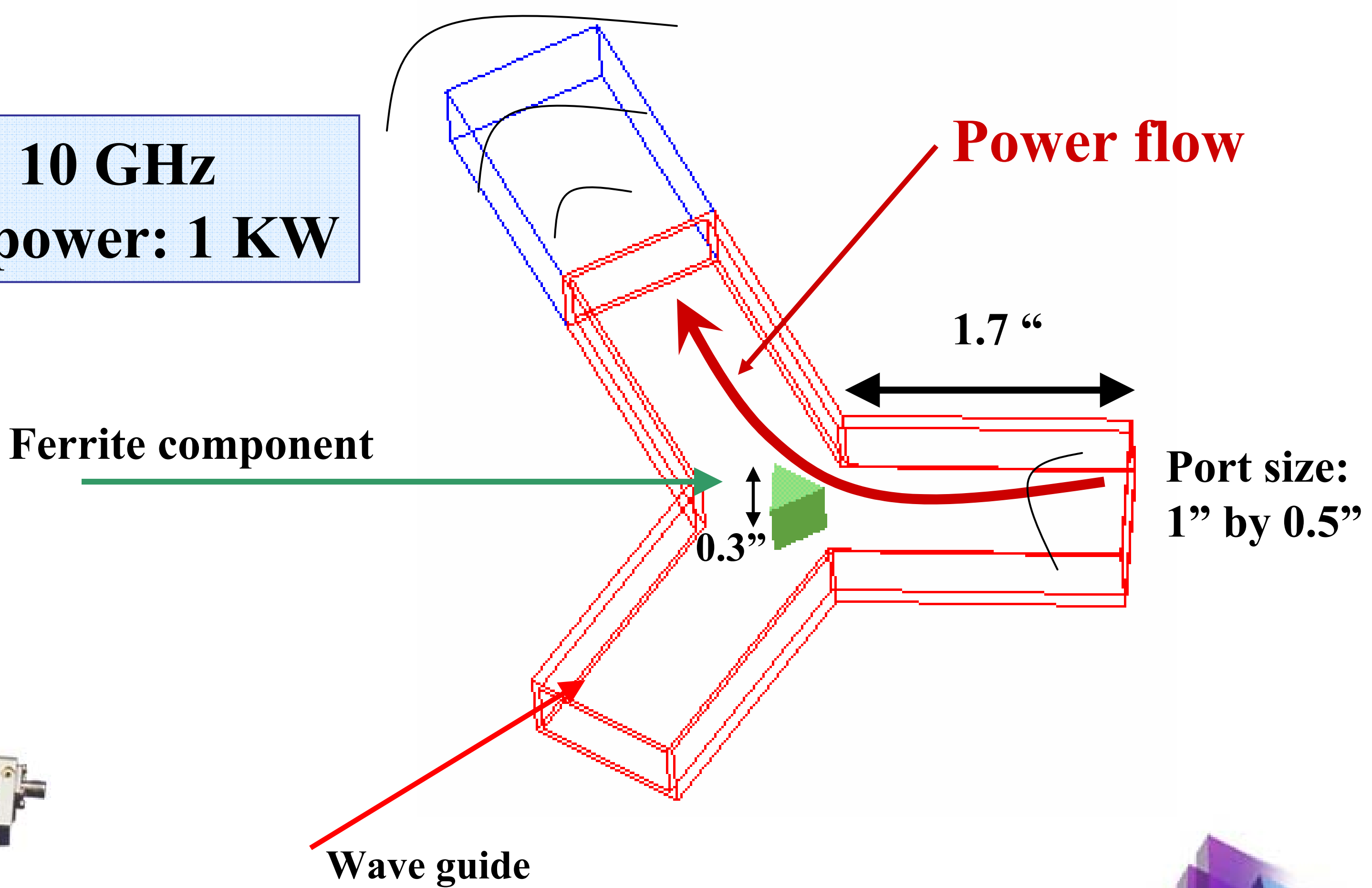
  Radiation emissivity (F): 0.9

  Radiation ref. temp. (TEMP_R): 35 Celsius

Can be functional!
(temperature – dependent)
Can include radiation if needed!

Ferrite Circulator Application
-geometry-

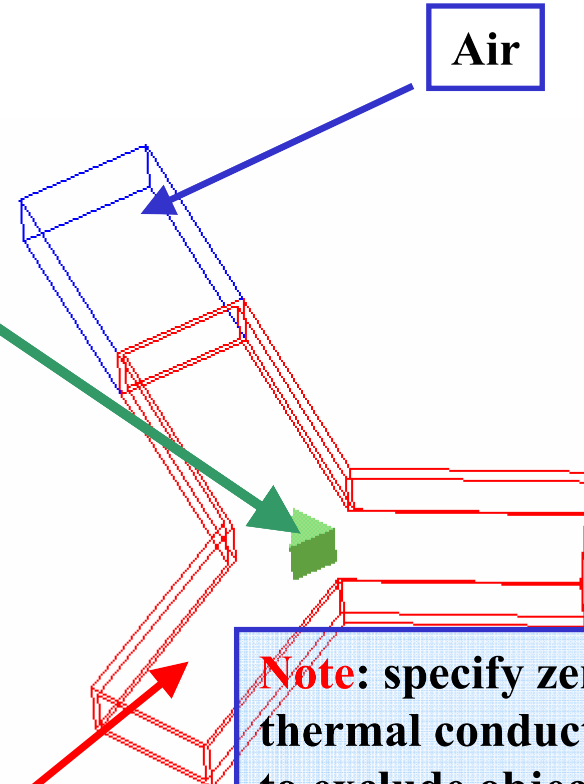
Frequency: 10 GHz
Operating power: 1 KW



Ferrite Circulator Application
-materials-

Ferrite

Thermal Conductivity	4	W/m-K
Mass Density	4600	kg/m**3
Specific Heat	750	J/kg-K
Young's Modulus	1.19e+011	N/m**2
Poisson's Ratio	0.2	
Thermal Expansion Coef.	1E-005	1/K

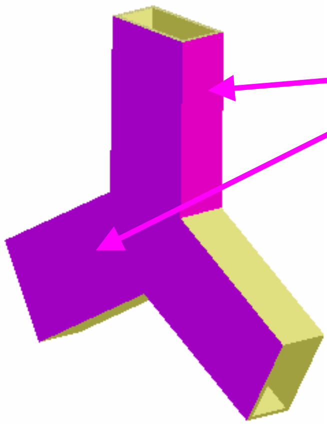


Silver

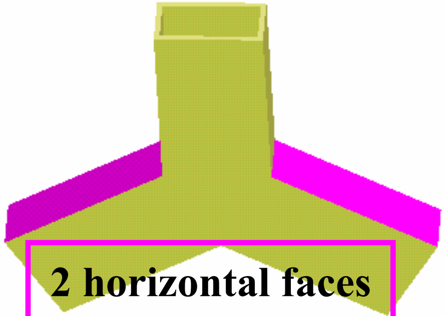
Thermal Conductivity	429	W/m-K
Mass Density	1.05e+004	kg/m**3
Specific Heat	235	J/kg-K
Young's Modulus	7.7e+010	N/m**2
Poisson's Ratio	0.37	
Thermal Expansion Coef.	1.89E-005	1/K

Note: specify zero thermal conductivity to exclude object from thermal simulation; zero Young's modulus to exclude it from stress simulation.

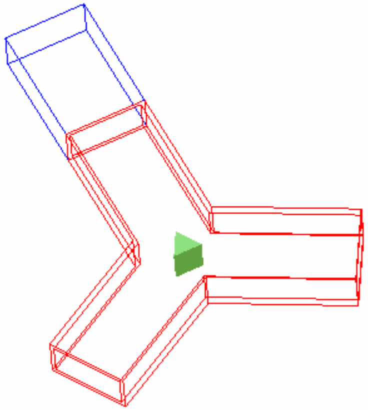
Ferrite Circulator Application
-thermal boundary conditions-

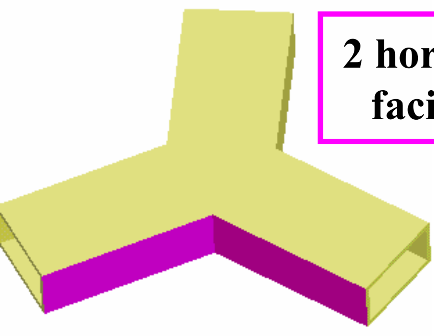


4 vertical faces
(2 shown + 2 symmetric
on the other side)

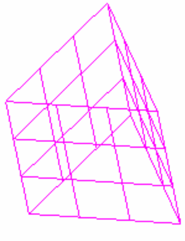


2 horizontal faces
facing “up”





2 horizontal faces
facing “down”



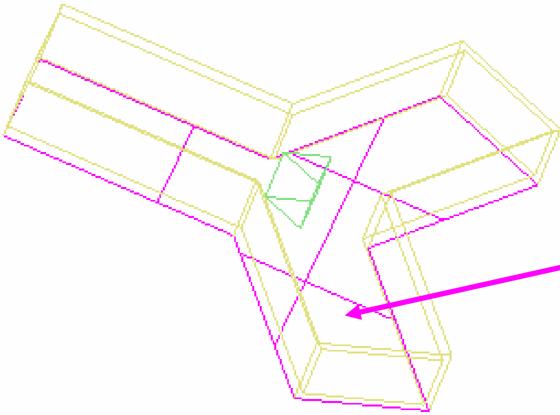
3 side faces
of ferrite
component

convective & radiative boundary conditions

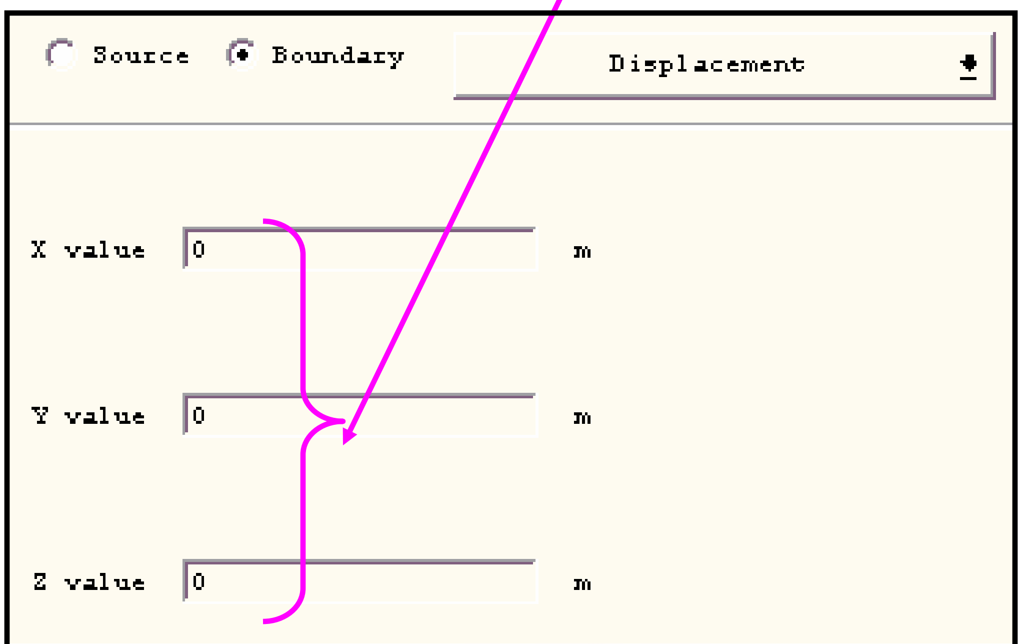
q = C*(TEMP-TEMP_A)*|TEMP-TEMP_A|**FEXP + F*B*(TEMP**4-TEMP_R**4)

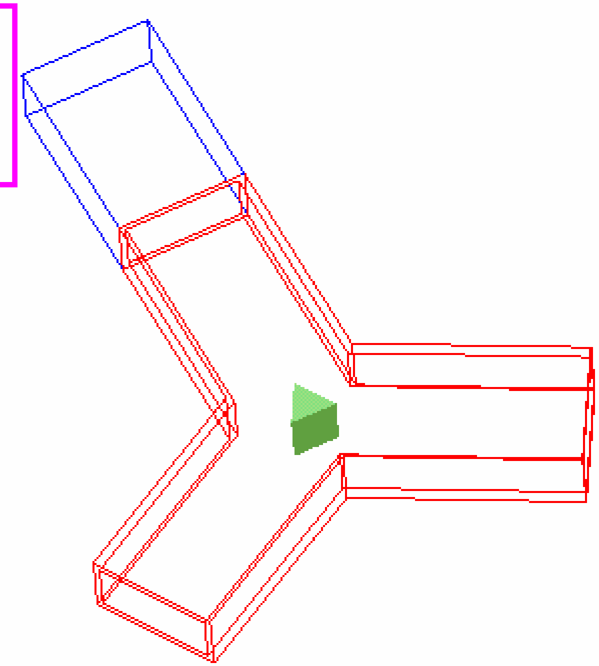
Convection coefficient (C)	10	W/C**ALPHA/m**2
Ambient temperature (TEMP_A)	25	Celsius
Exponent (FEXP)	0	
Radiation emissivity (F)	0.85	
Radiation ref. temp. (TEMP_R)	25	Celsius

Ferrite Circulator Application
-stress boundary condition-



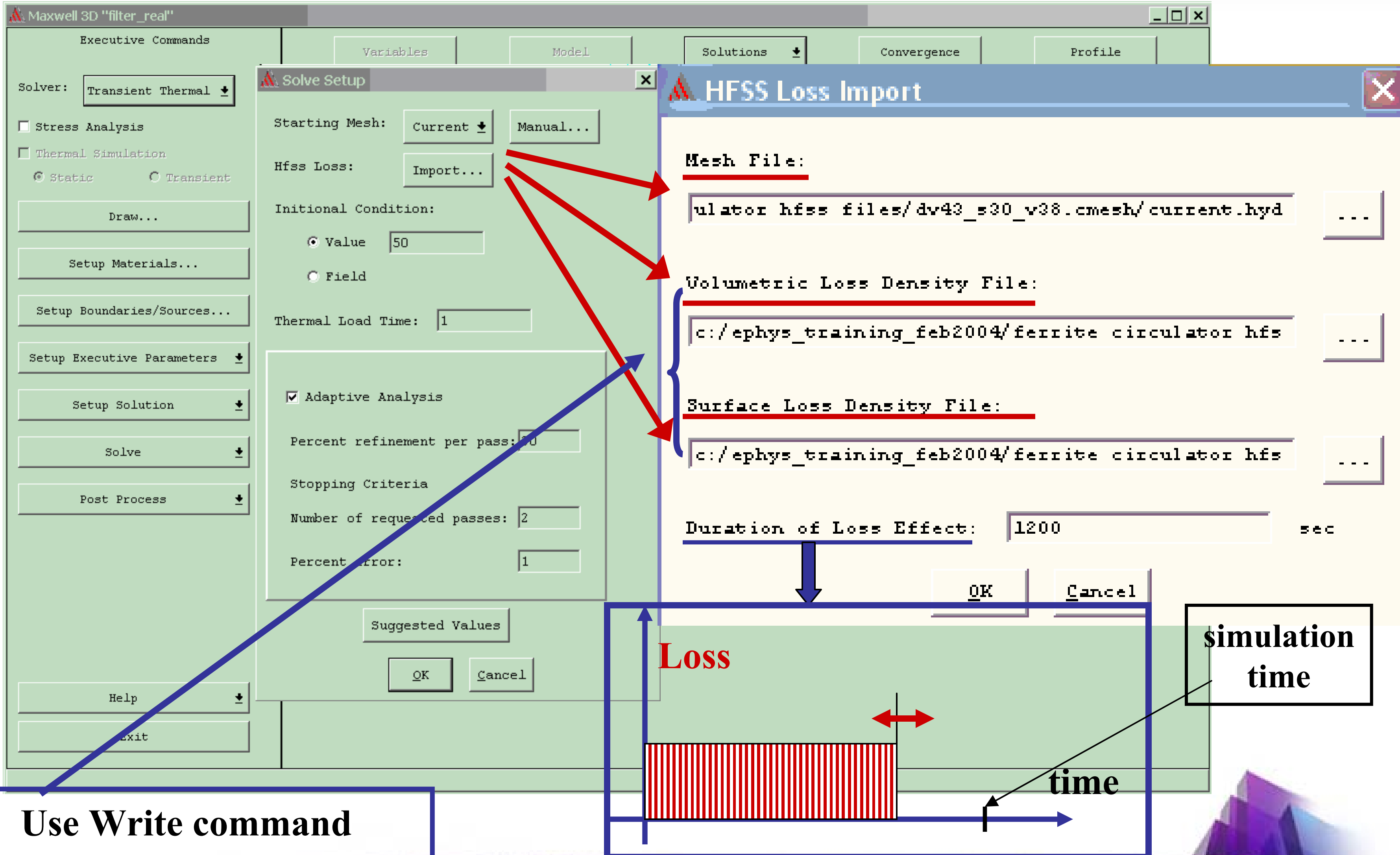
bottom of circulator constrained with homogenous displacement condition





Note: ferrite block is touching at both ends the wave guide

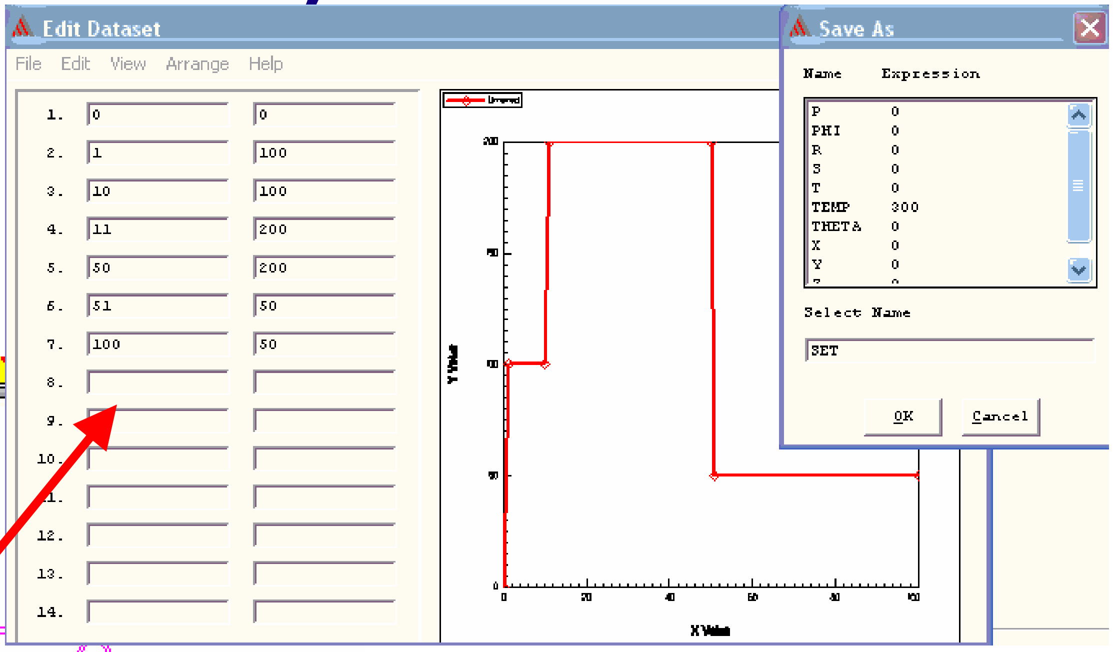
Ferrite Circulator Application
-HFSS sources-

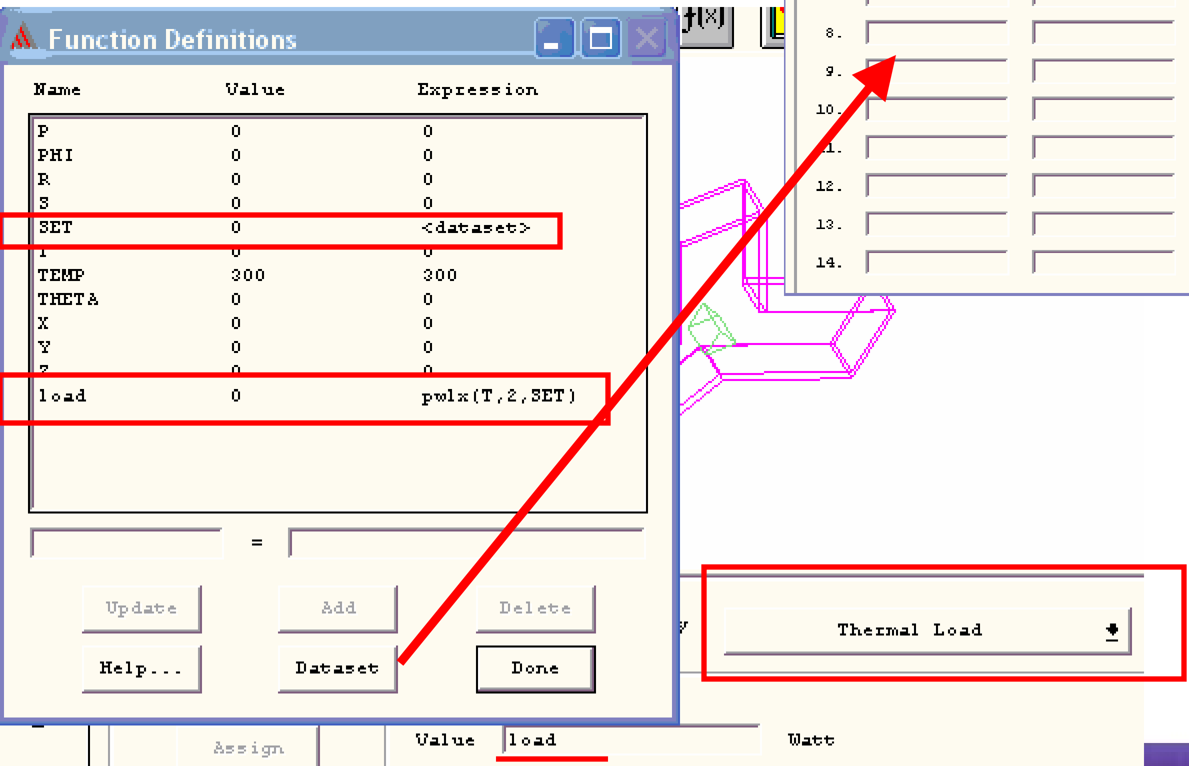


Use Write command
in HFSS post processor
after scaling to actual power

(Creating time dependent thermal loads)

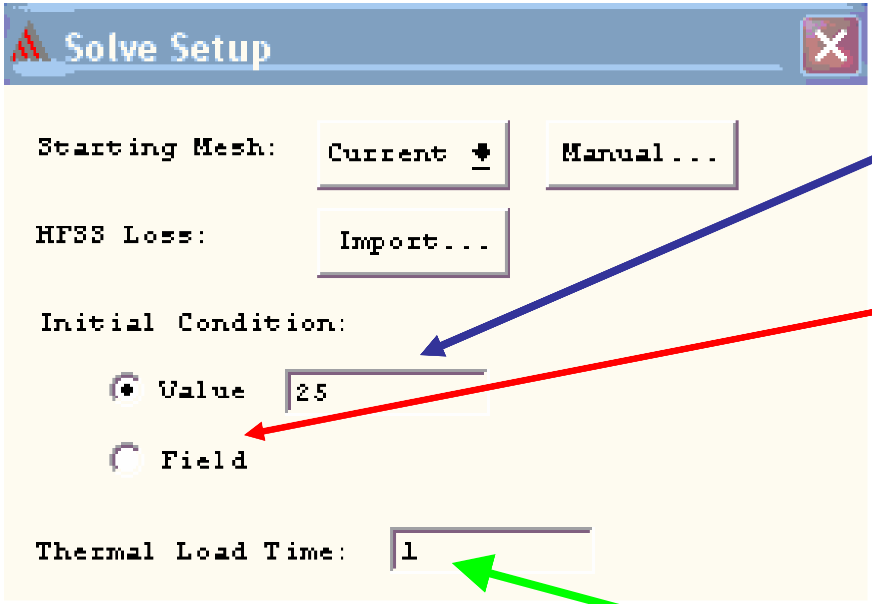
Model/Functions…
Menu Button





1. **Define dataset and save**
2. **Create & add function (load)**
3. **Enter load name as value**
4. **Assign to solid**

Thermal Static Solution Setup



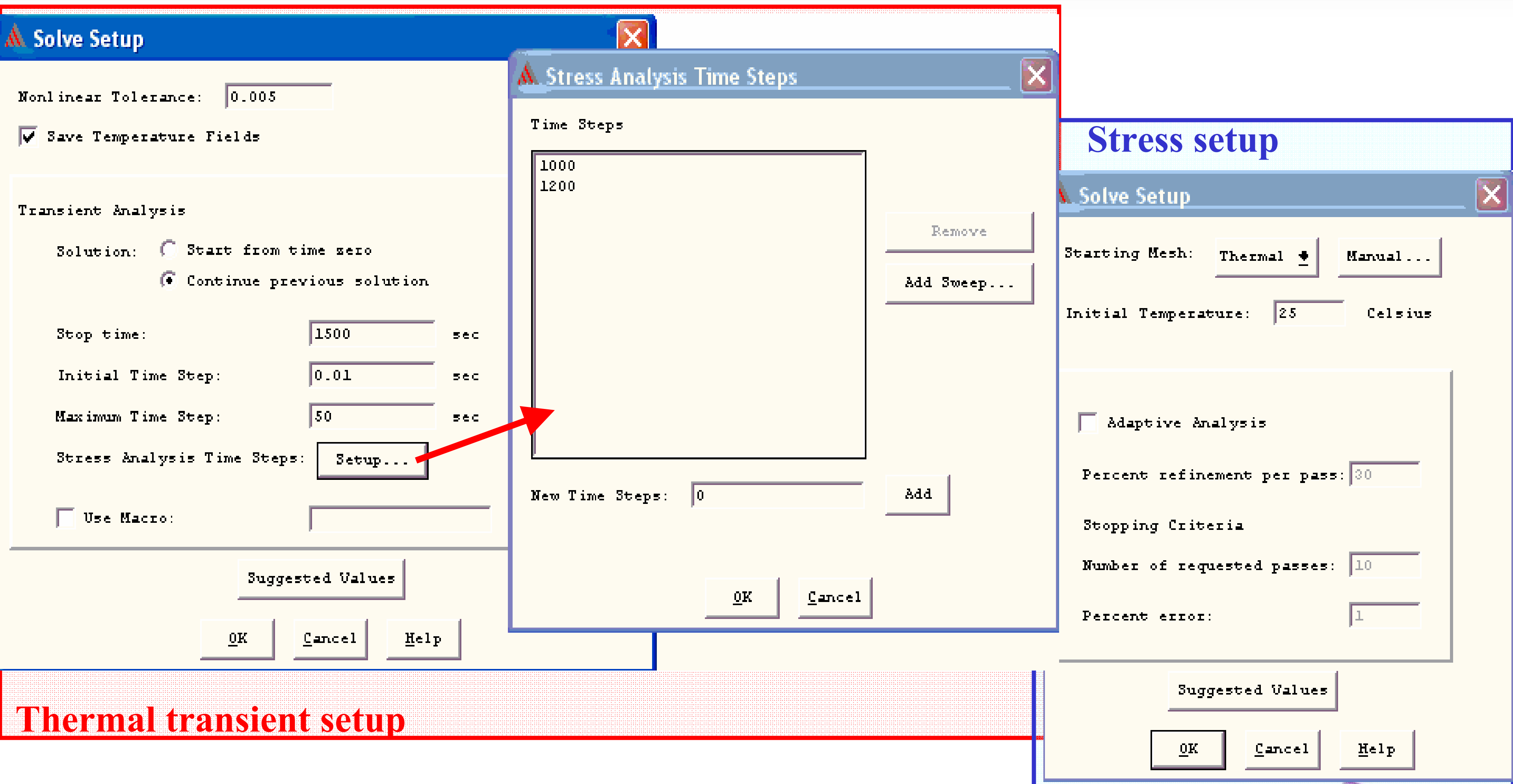
Temperature everywhere in the thermal model at t =0

Field initial condition = non-uniform temperature distribution

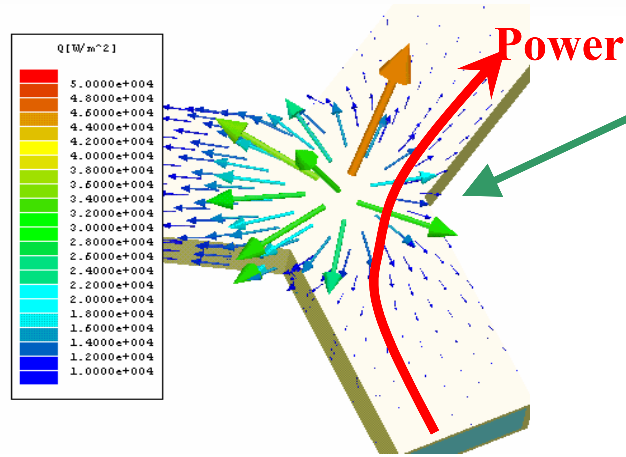
Used in transient thermal mesh generation:

(instructs the adaptive process to consider the combination of sources at specified time)

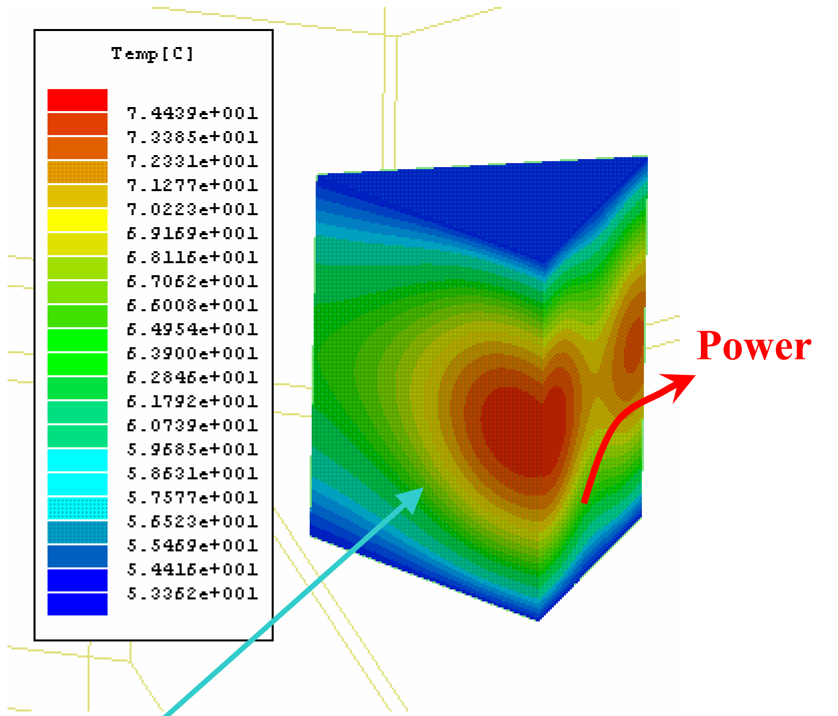
Thermal Transient & Stress Solution Setup

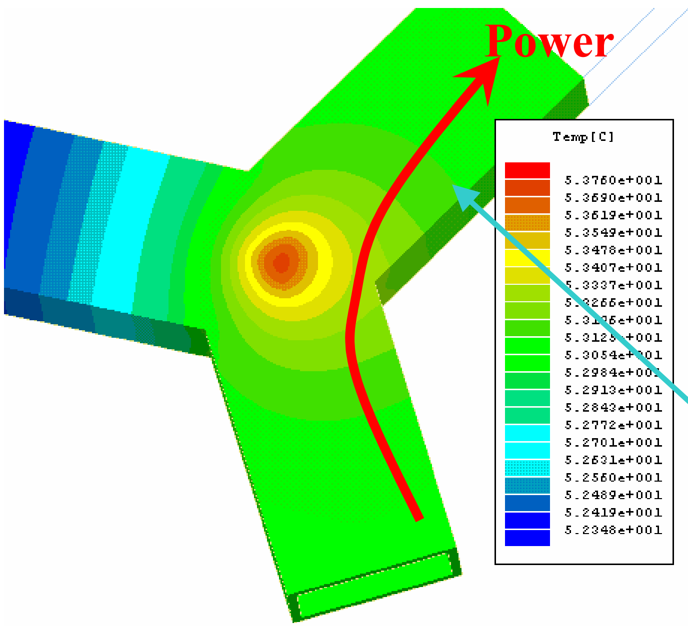


Ferrite Circulator Application
-thermal results, field-



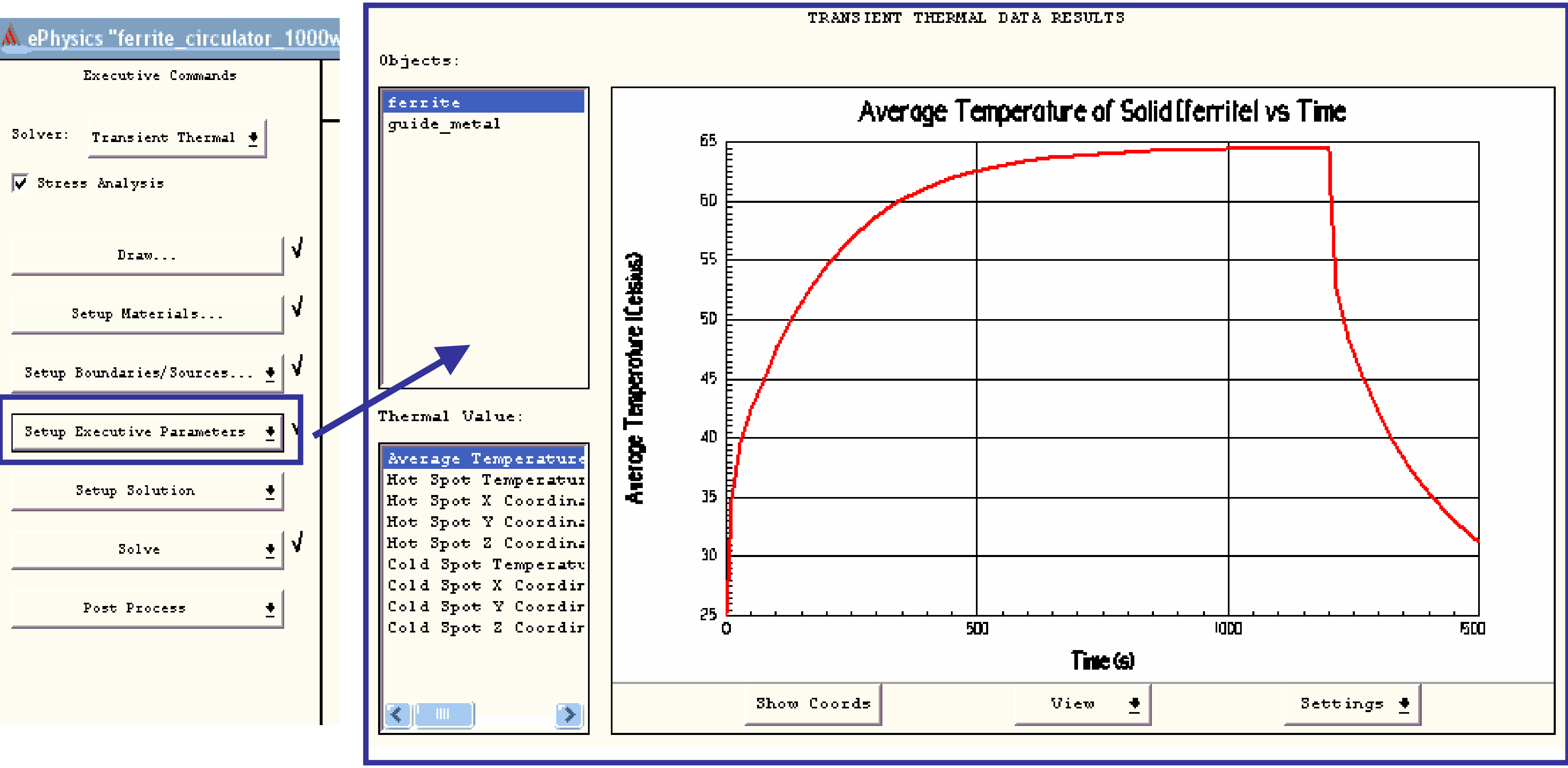
Heat flow distribution at t = 1,200 s



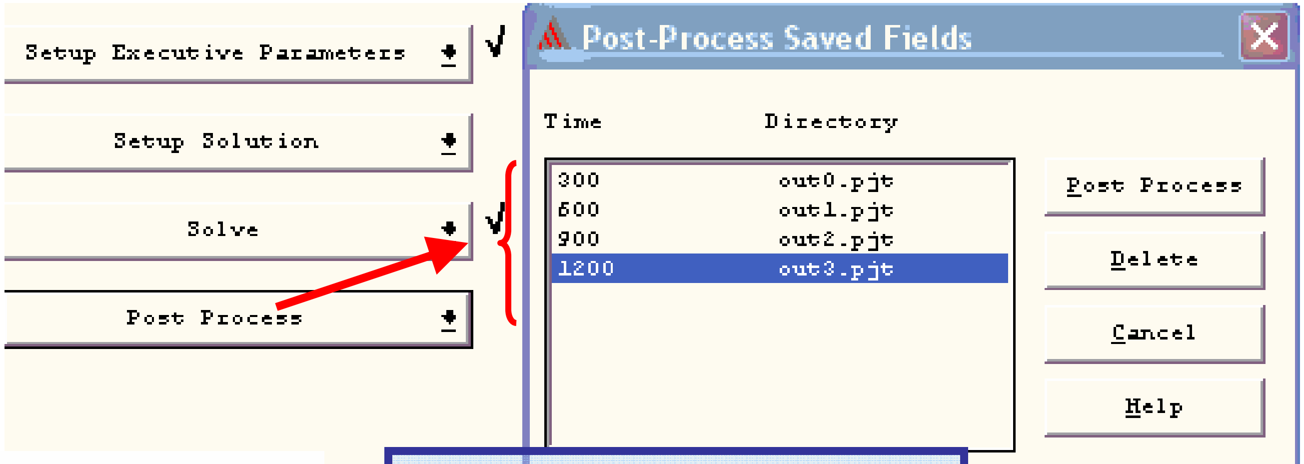


Temperature distribution at t = 1,200 s

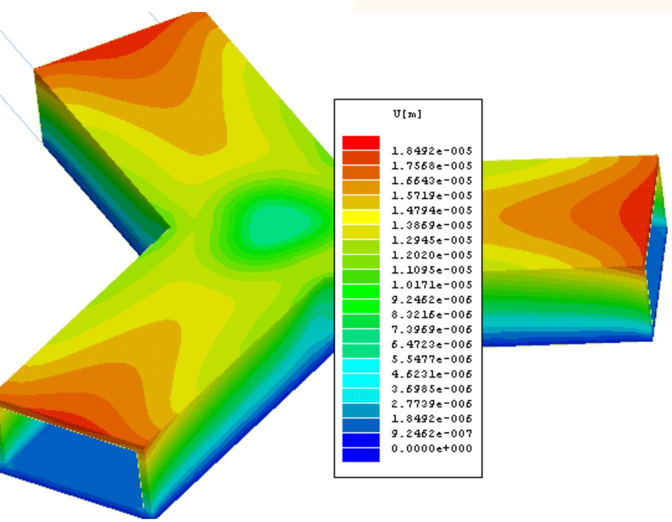
Ferrite Circulator Application
-thermal results, exec param-



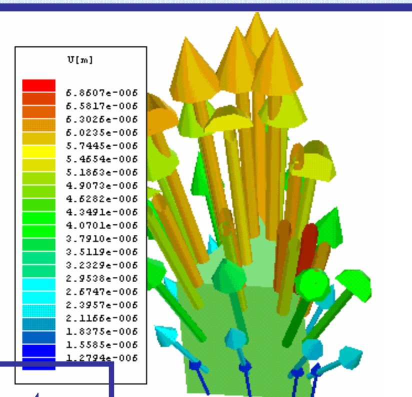
Ferrite Circulator Application
-stress results-



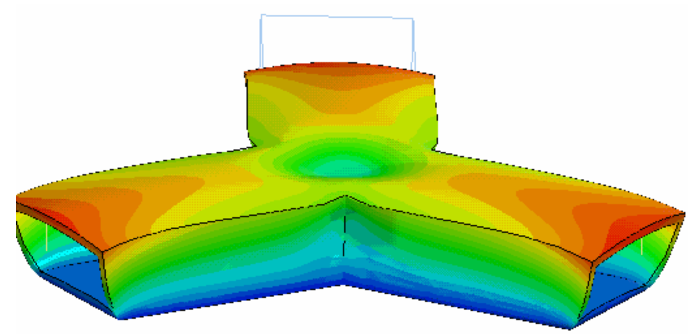
Deformation plots



magnitude

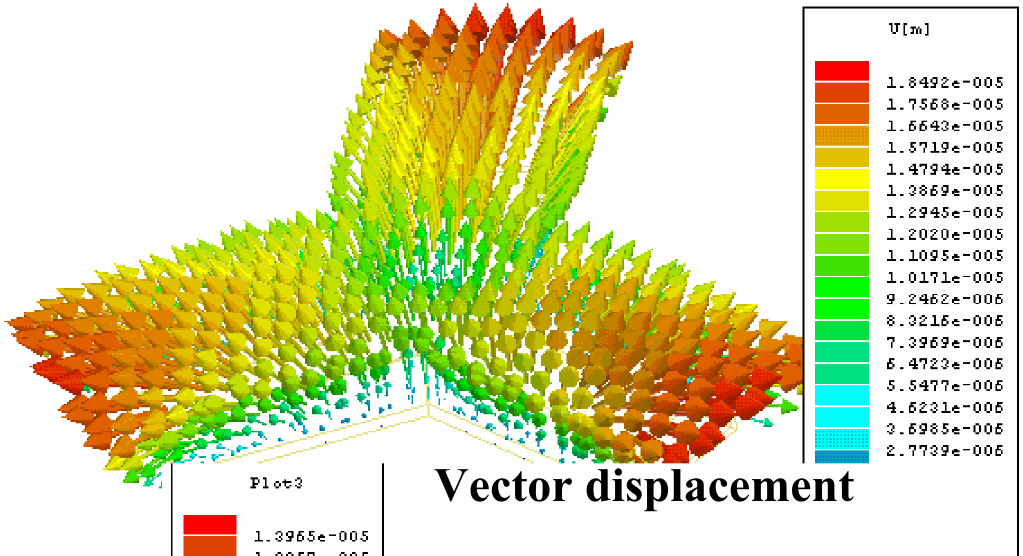


vector

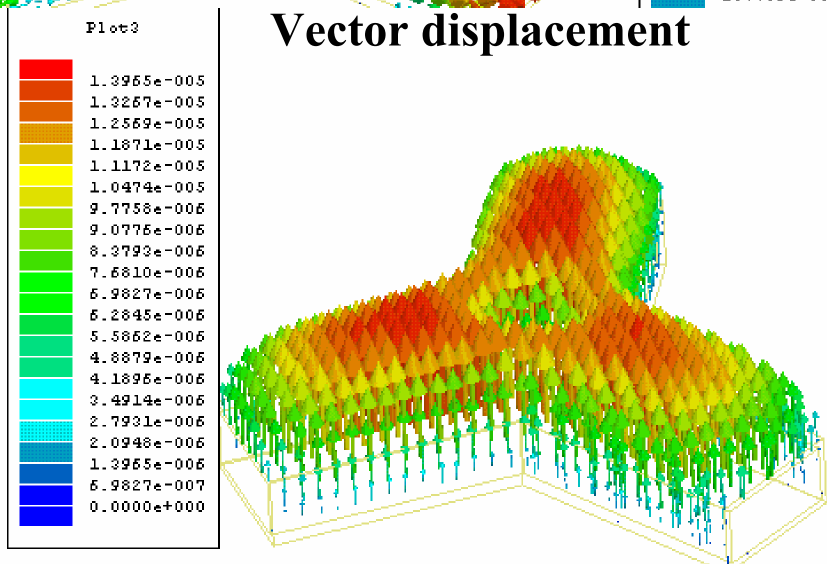


Scaled deformation

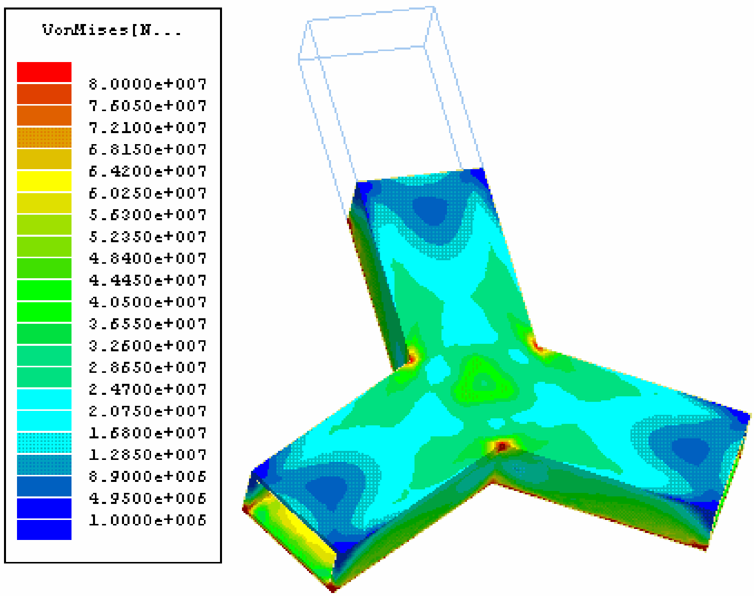
Ferrite Circulator Application -stress results-



Vector displacement

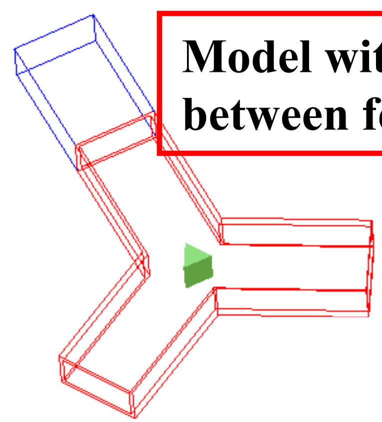


Y component of vector displacement



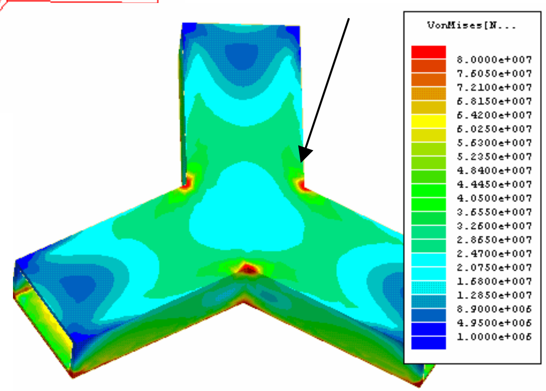
Von Mises stress

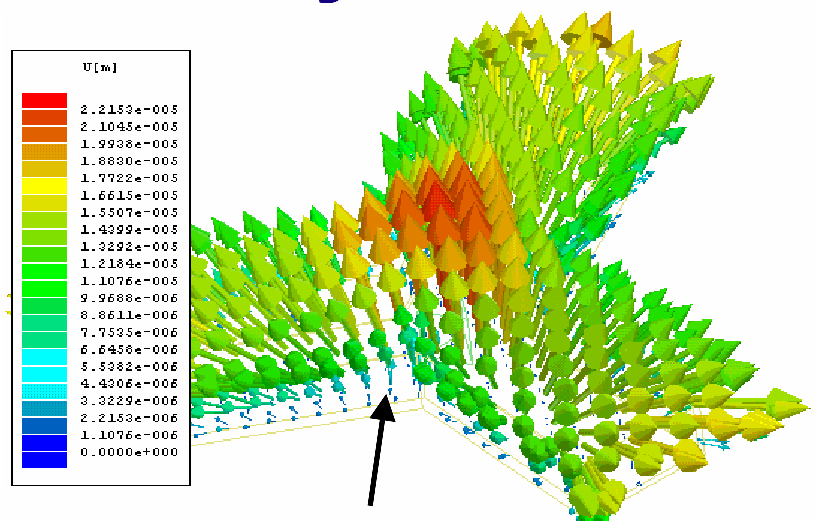
Ferrite Circulator Application -what ifs!?… and whys?-



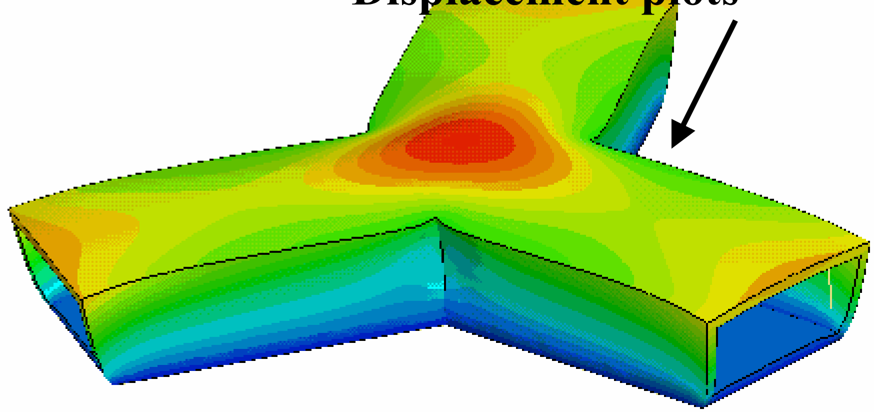
Model with 25 um air gap between ferrite and wave guide

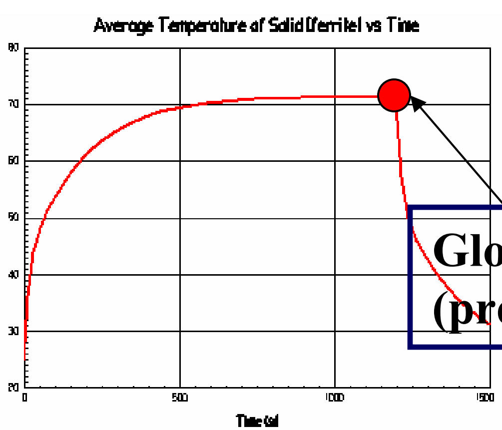
Von Mises stress





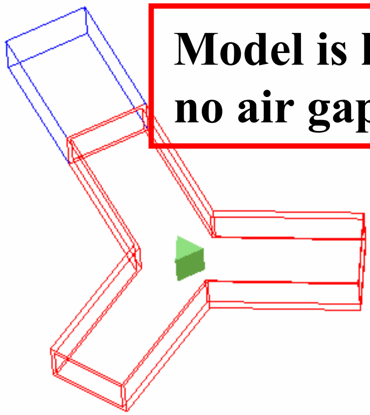
Displacement plots



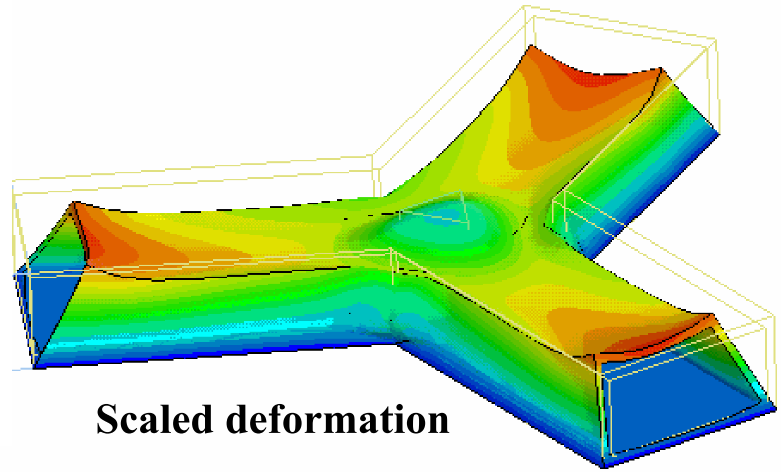


Global: steady state temperature T = 71.4 C
(previous temperature T’ = 64.4 C)

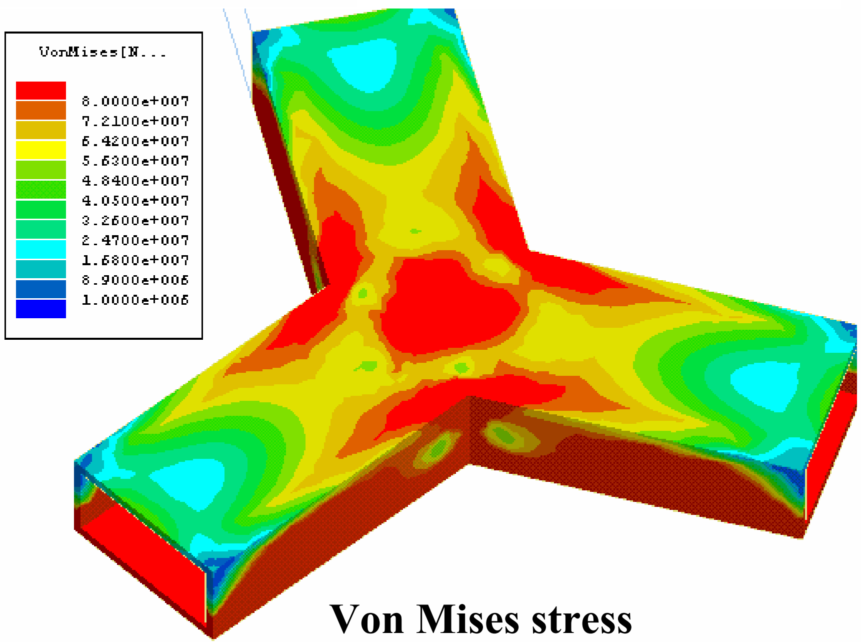
Ferrite Circulator Application
-what ifs!?... and whys?-



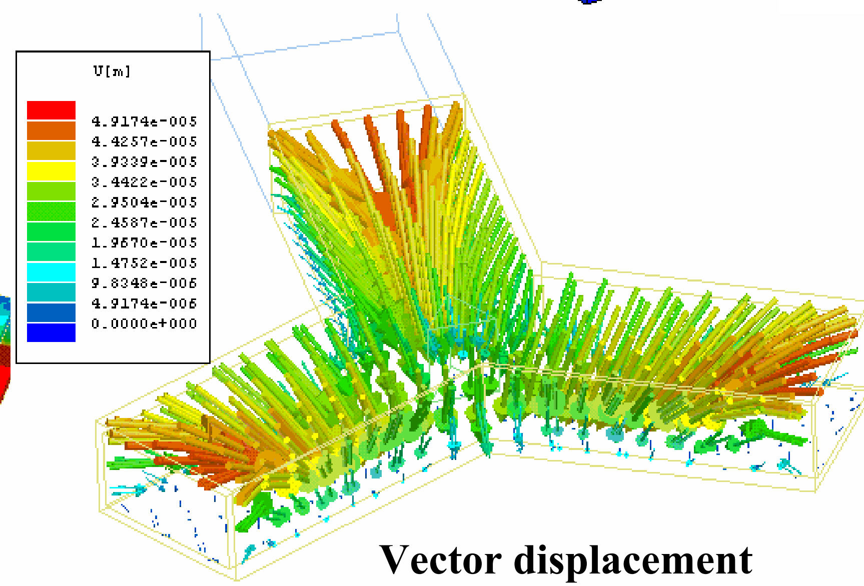
Model is kept at -50 °C,
no air gap above the ferrite



Scaled deformation

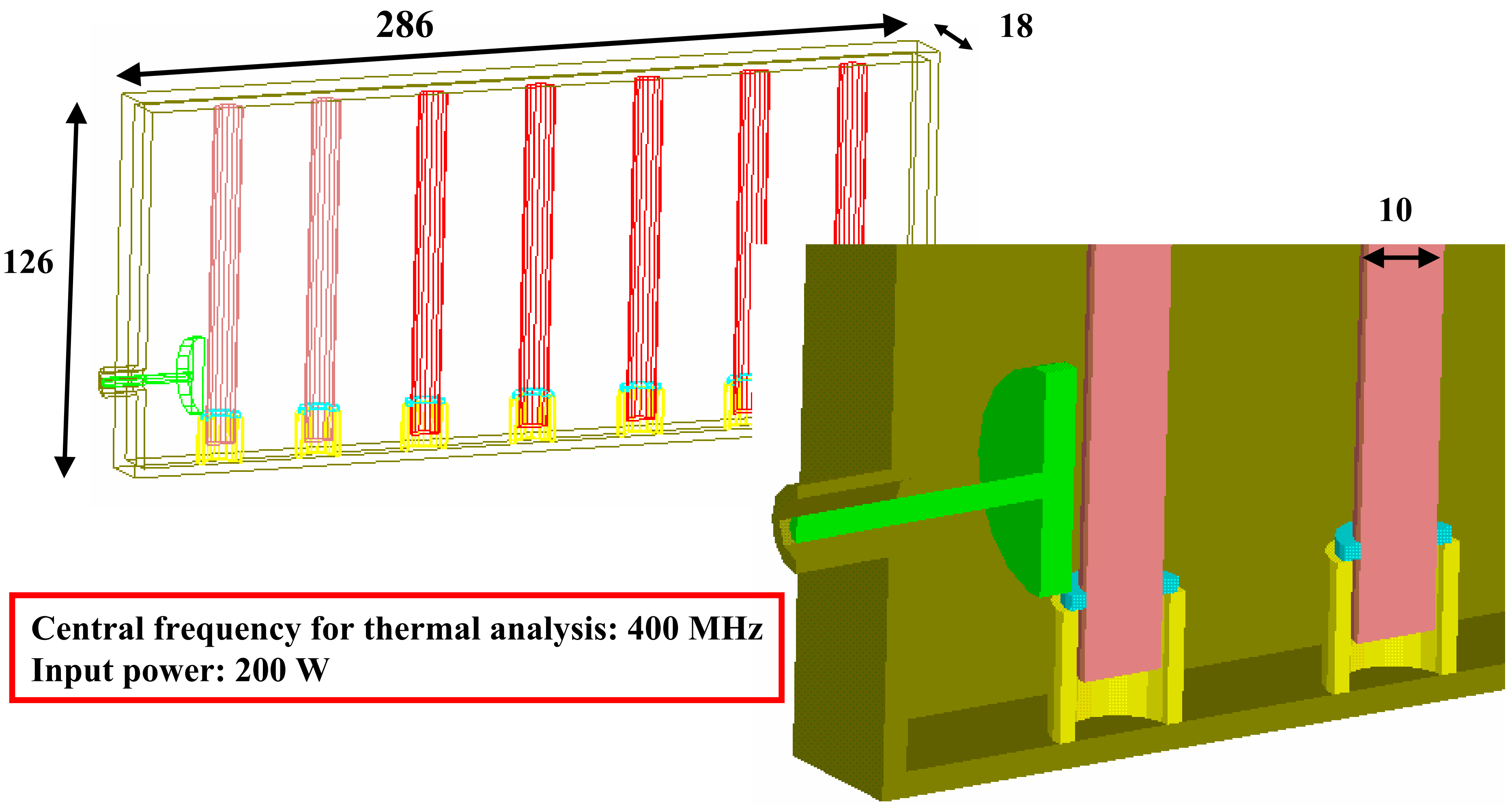


Von Mises stress



Vector displacement

Chebyshev Filter Application
-model data-

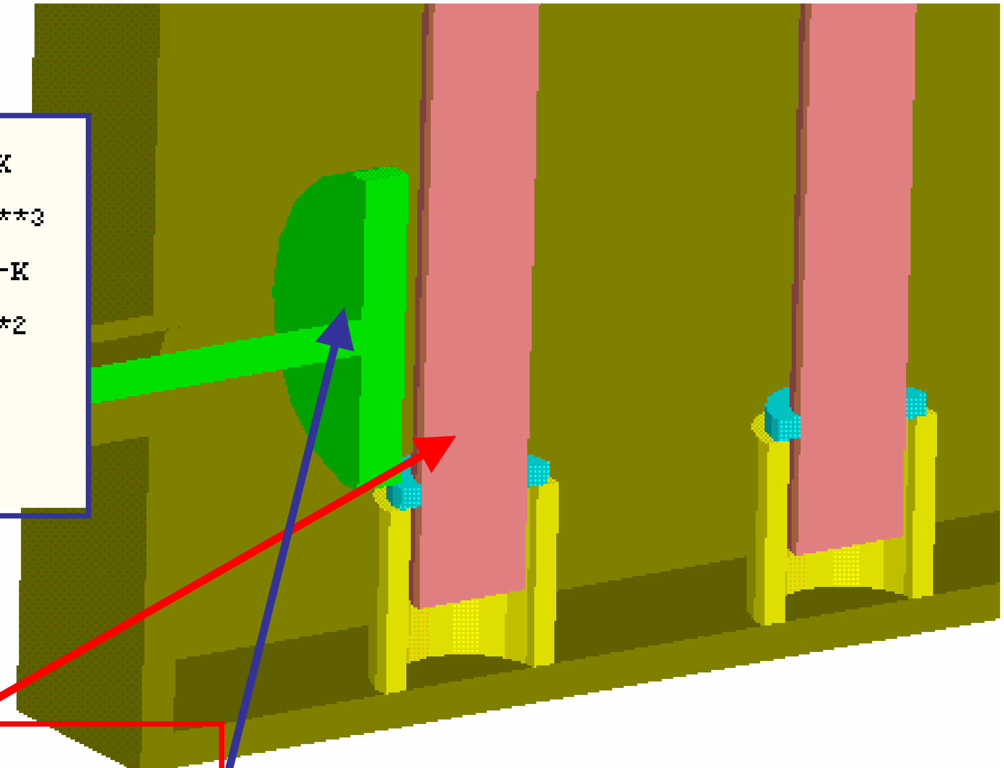


Central frequency for thermal analysis: 400 MHz
Input power: 200 W

Chebyshev Filter Application -materials-

"Non_structural" aluminum:

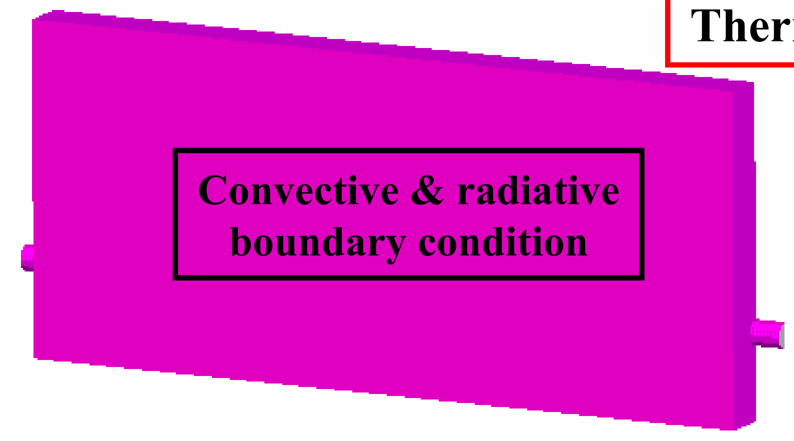
Thermal Conductivity	237.5	W/m-K
Mass Density	2689	kg/m**3
Specific Heat	951	J/kg-K
Young's Modulus	0	N/m**2
Poisson's Ratio	0.31	
Thermal Expansion Coef.	2.33E-005	1/K

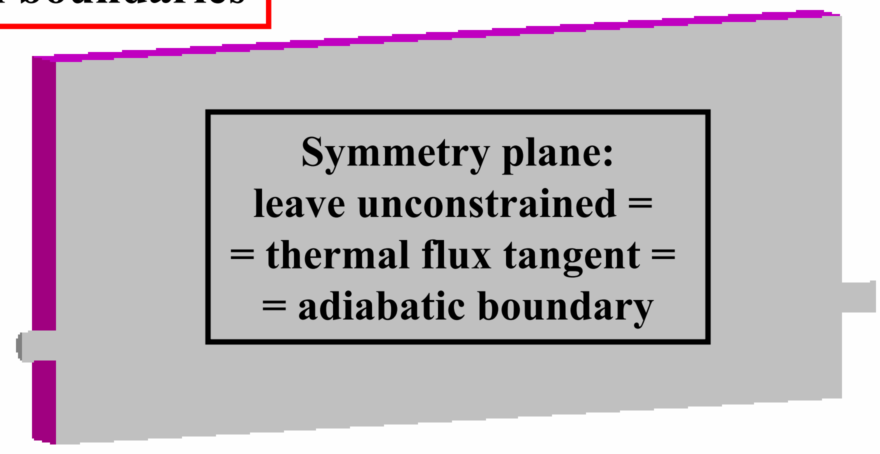


Aluminum: for rods & housing
Non-structural aluminum: rest of the metallic objects (to exclude them from stress analysis but not from thermal analysis)

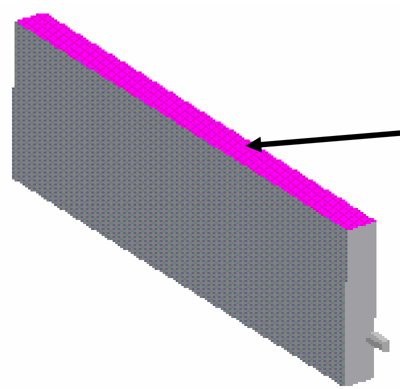
Chebyshev Filter Application
-boundary conditions-

Thermal boundaries



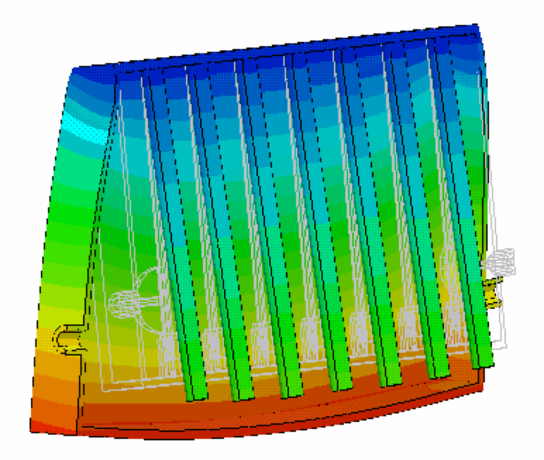


Stress boundary

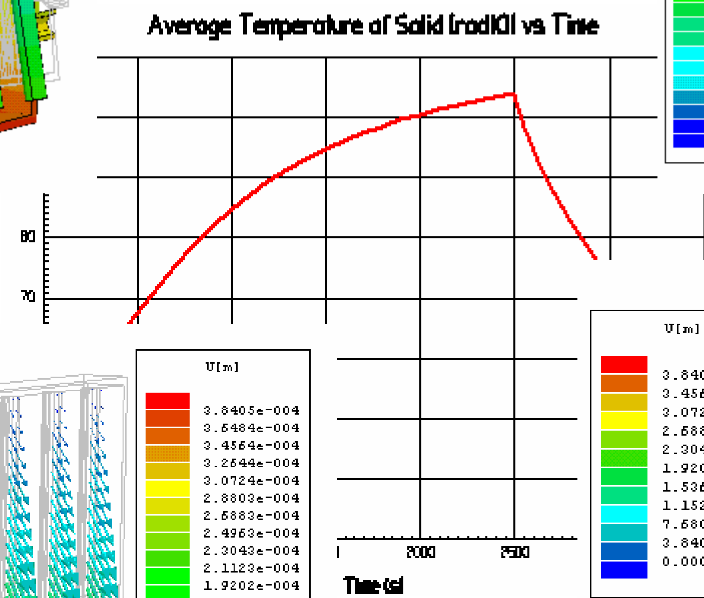


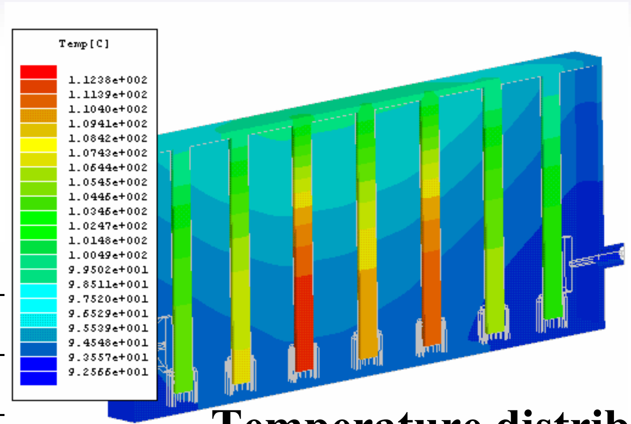
Zero X, Y, Z displacement on top face

Chebyshev Filter Application -results-

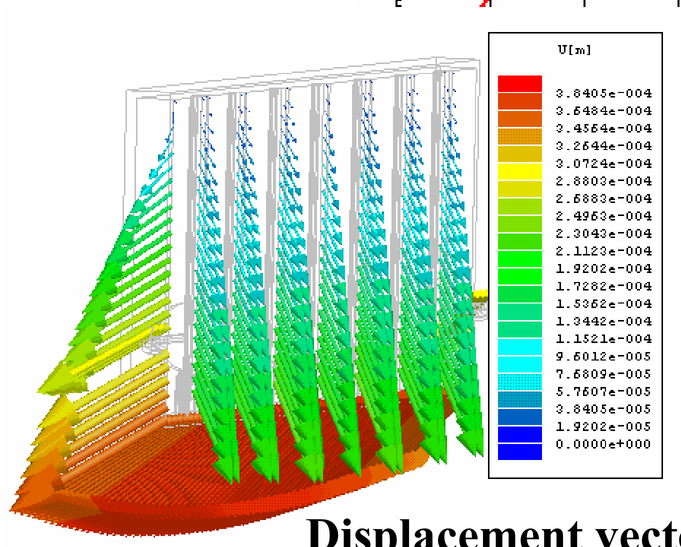


Scaled deformation

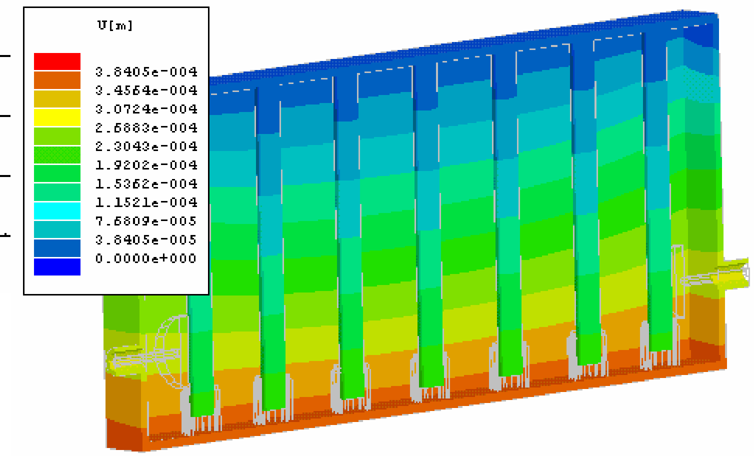




Temperature distribution

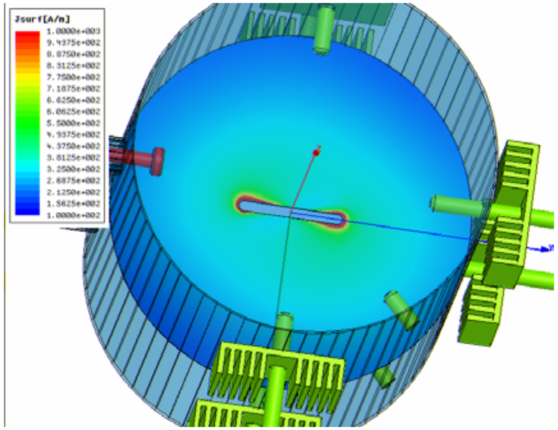


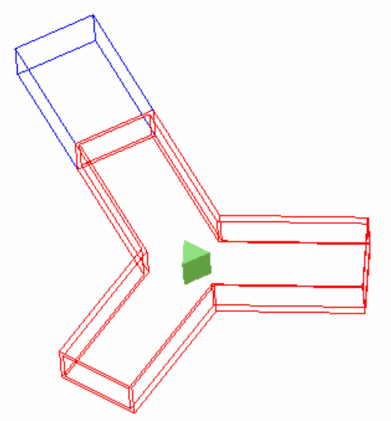
Displacement vector

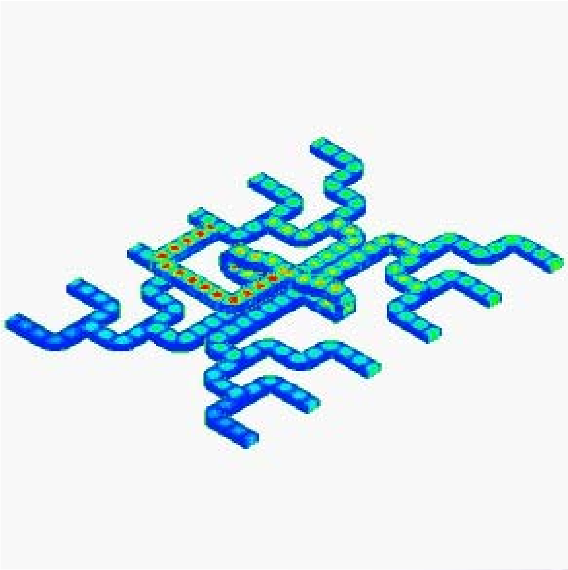


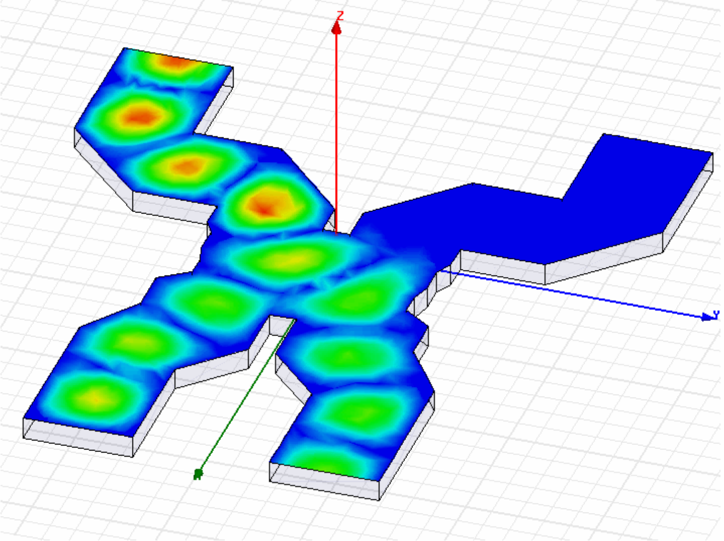
Magnitude of displacement

High Power HF Components

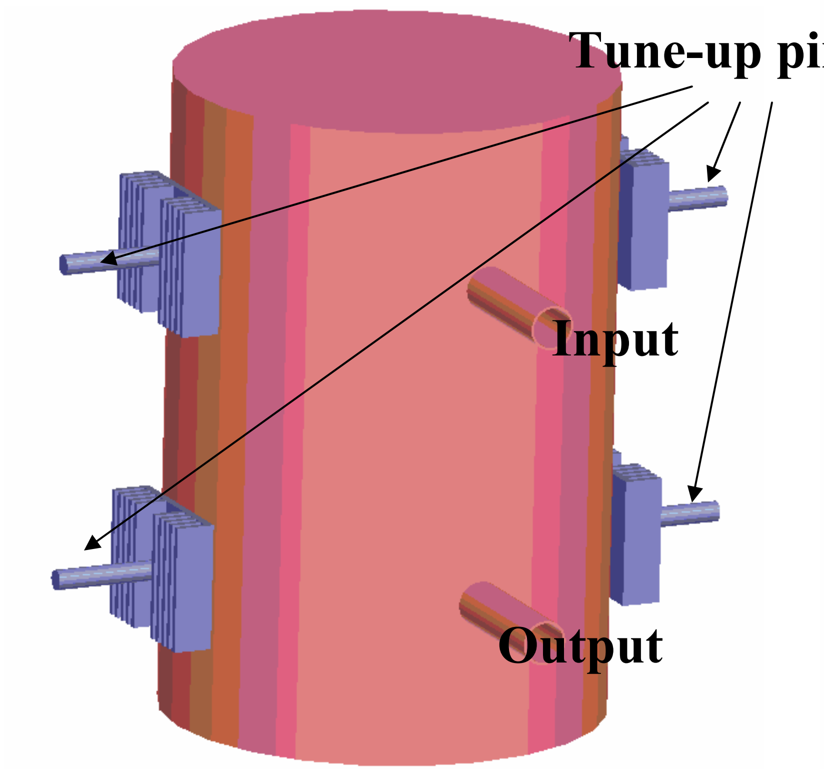


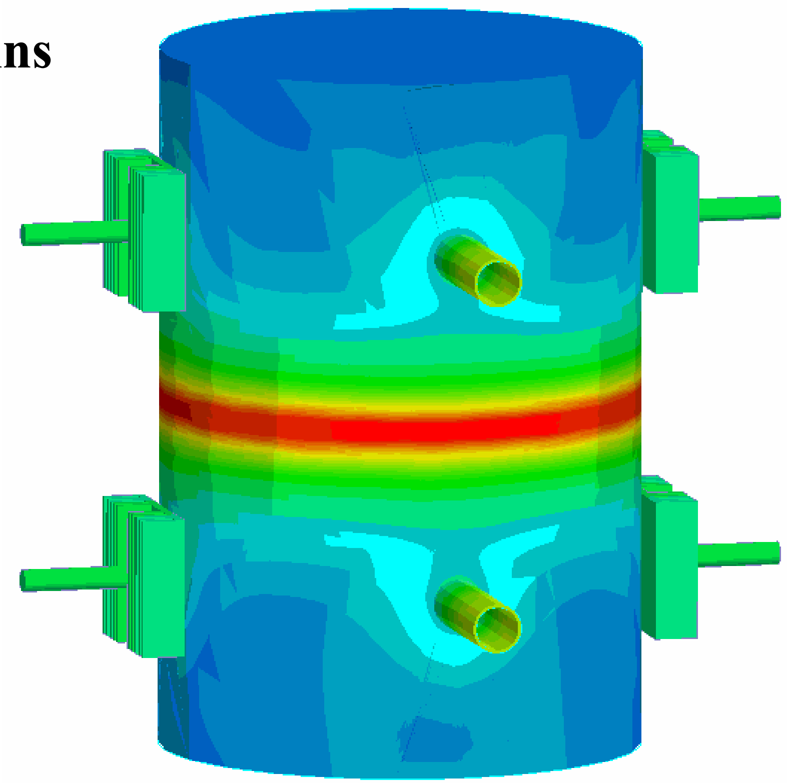






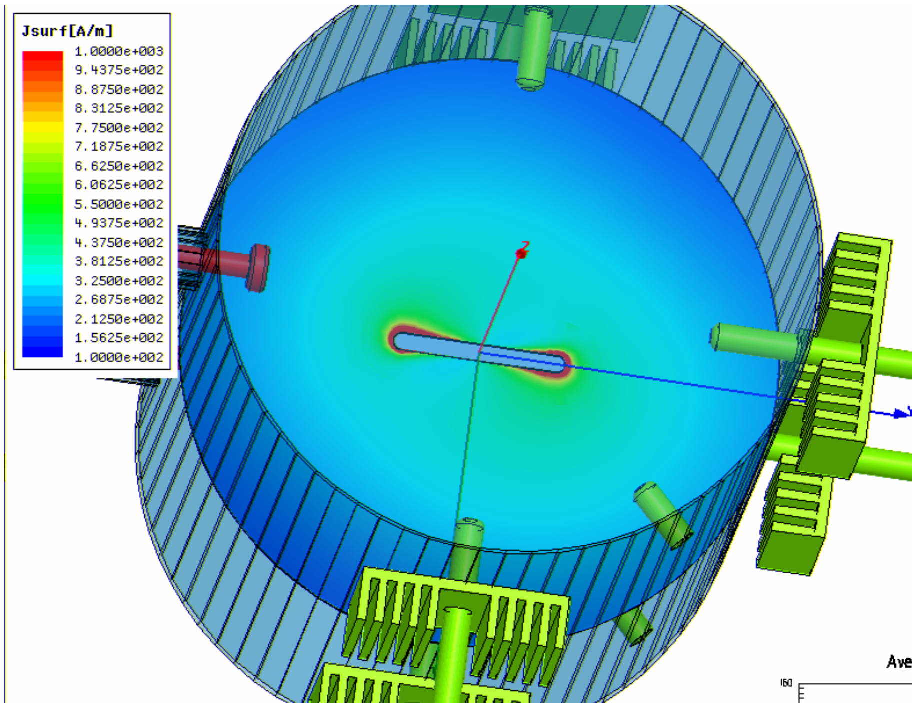
High Power Handling
HF (760 MHz) filters

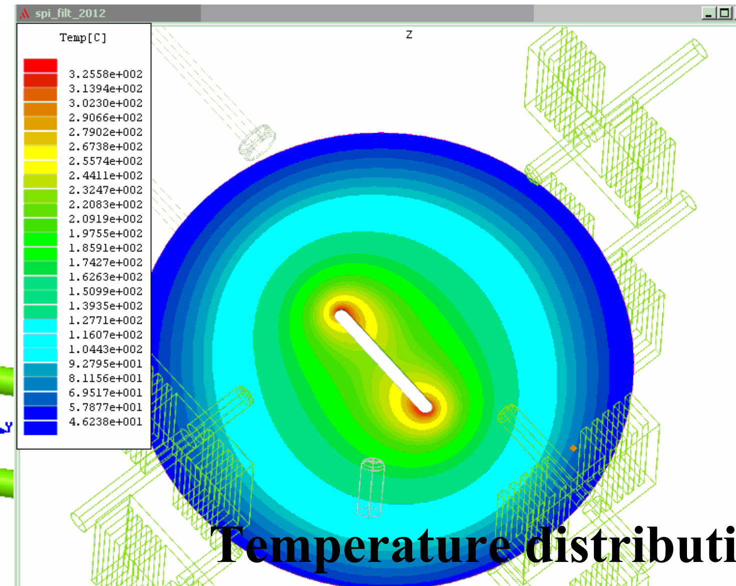




Outer body temperature distribution

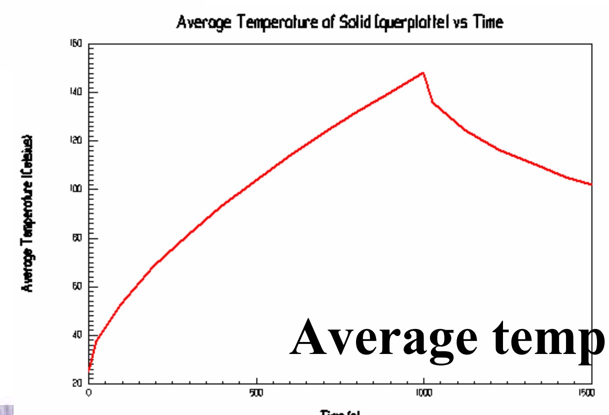
760 MHz Filter, High Power Input (KW range)





Temperature distribution at t = 1000 s

Surface current density distribution calculated by HFSS

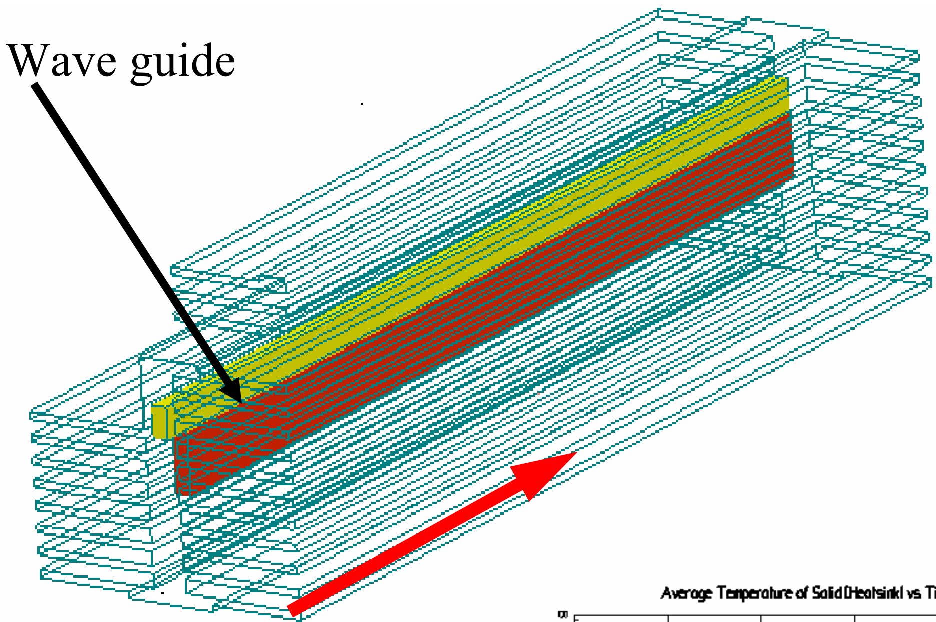


Average temperature of mid-plate

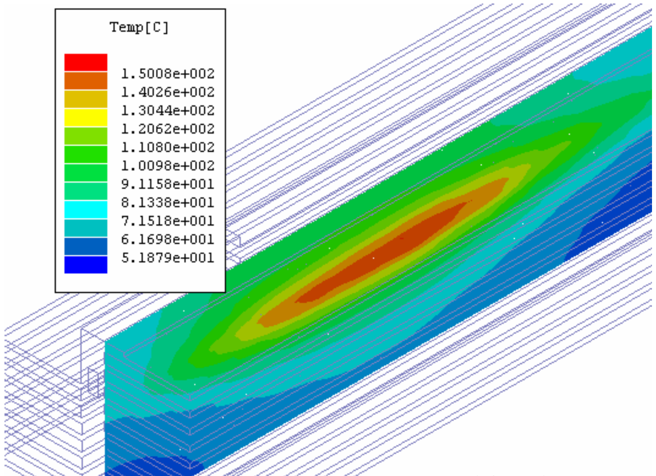
Microtech Model

Very good match with experimental data!

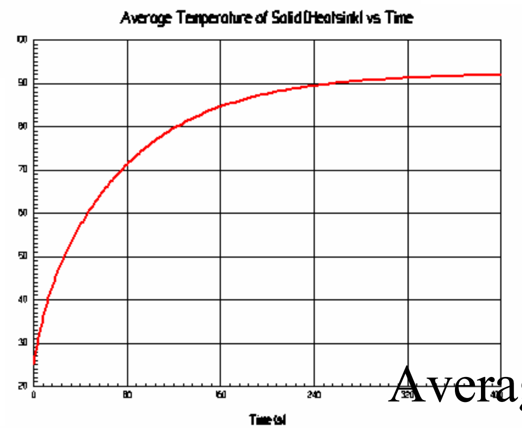
Wave guide



Air velocity = 76 m/s

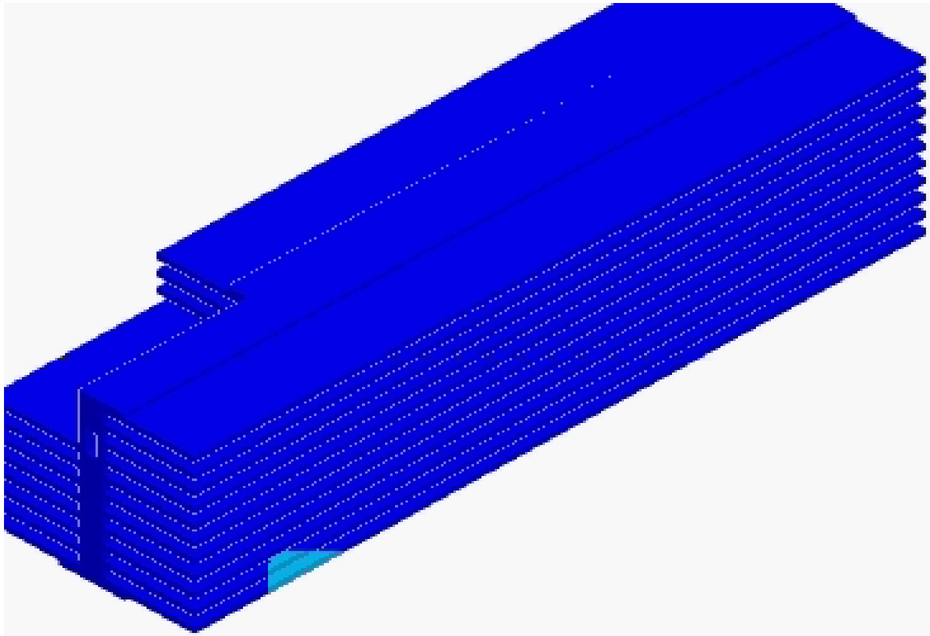


Temperature profile in a plane containing the "hot spot"



Average heat-sink temperature

Microtech Model



Procedure to calculate forced convection coefficient

Fluid velocity

-Calculate specific CFD numbers:

- Reynolds number
- Nusselt number

$$\mathrm{Re} = \frac{u \cdot L}{\nu}$$

Laminar flow

Mixed flow

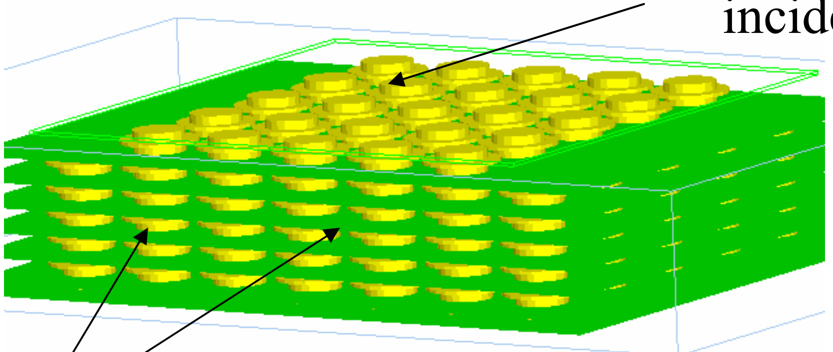
$$Nu = 0.664 \cdot \mathrm{Re}^{0.5} \cdot \mathrm{Pr}^{0.333} \quad if \quad \mathrm{Re} \leq 5 \cdot 10^{5}$$

$$Nu = \mathrm{Pr}^{0.333} \cdot (0.037 \cdot \mathrm{Re}^{0.8} - 871) \quad if \; \mathrm{Re} \geq 5 \cdot 10^{5}$$

- Calculate convection coefficient

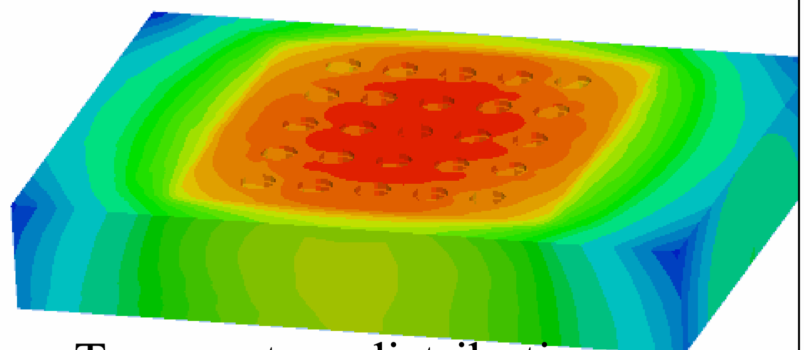
$$H = \frac{Nu \cdot \sigma}{L}$$

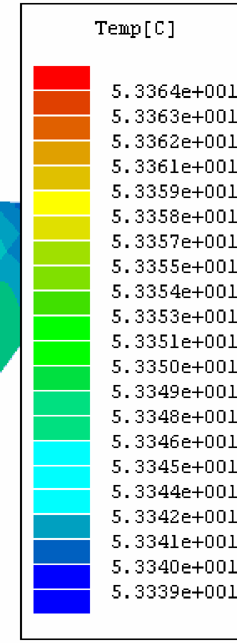
IC structure in HF incident field



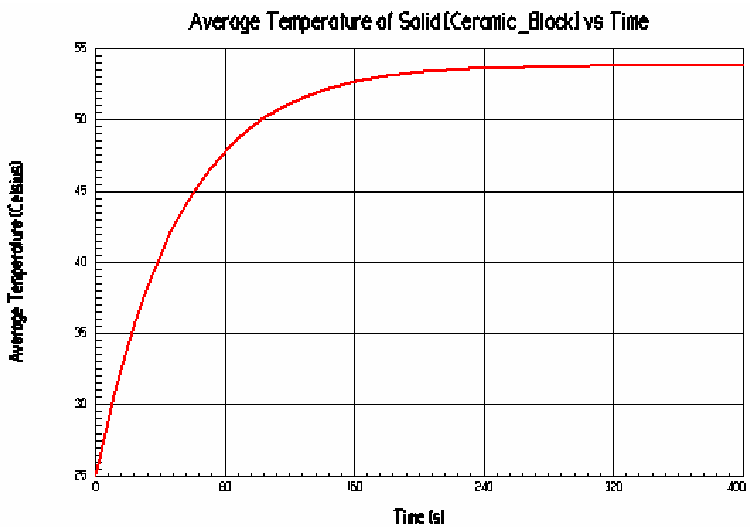
Top plane heated by incident wave

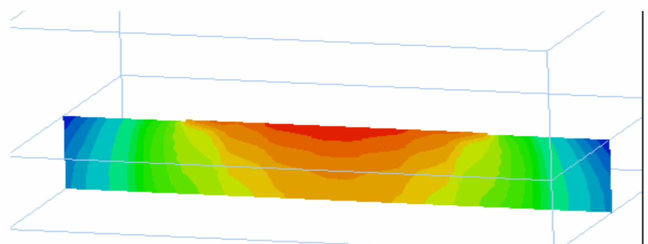
Metal ground planes & vias imbedded in ceramic block

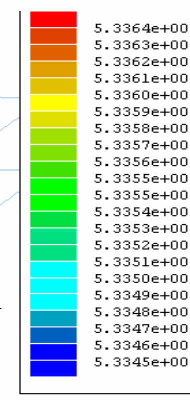




Temperature distribution on ceramic block after 200 s



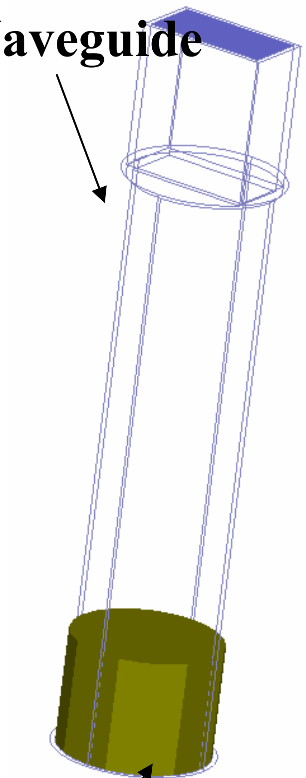




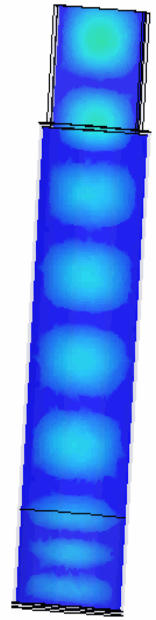
Temperature distribution on cross section

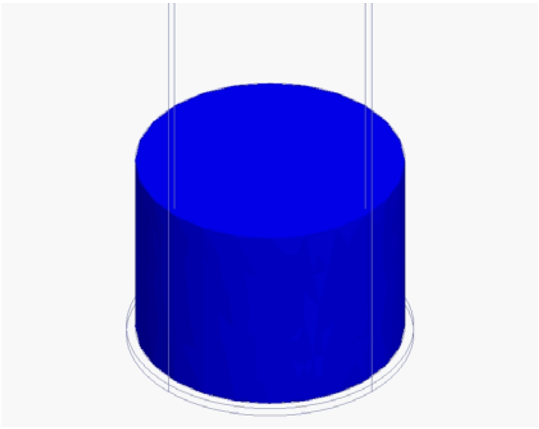
Microwave Heating
Industrial Size Applicator

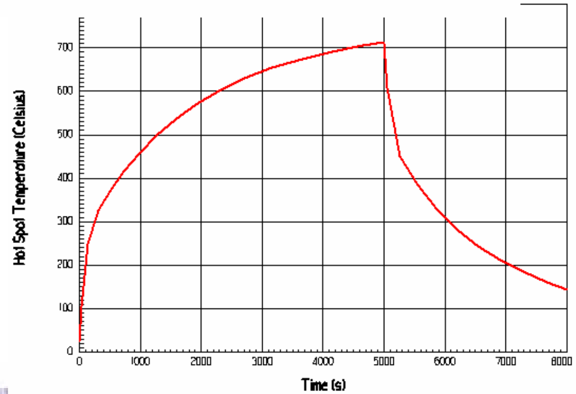
915 MHz,
20 KW
Waveguide



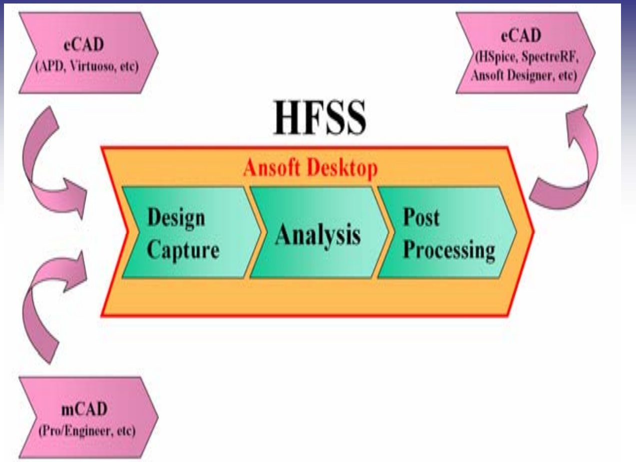
Mineral ore







The Benefits of HFSS & ePhysics



- HFSS provides an environment for 3D EM-based design flow automation
- Virtual Prototyping reduces engineering time, speeds time to market
- HFSS uniquely provides assured accuracy for a broad set of applications to complement the highest level of automation
- Evaluate thermal and stress consequences of electromagnetic fields with ePhysics