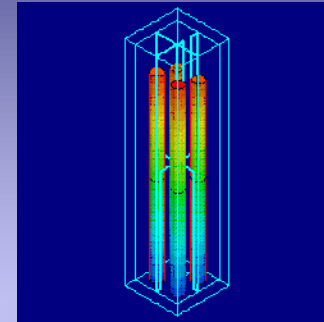
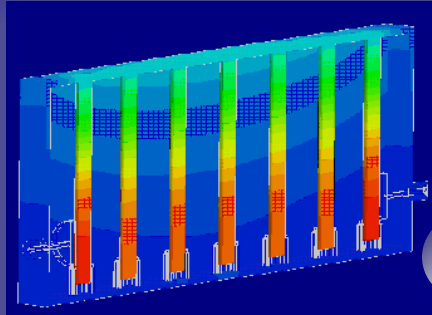
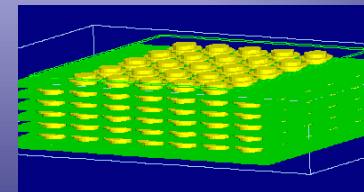
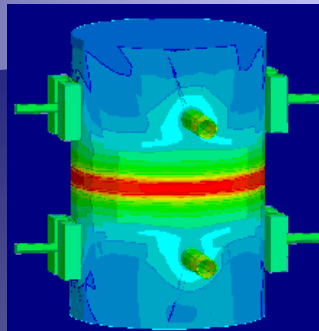


ANSOFT



HFSS & ePhysics Features for the Simulation of Microwave Power Applications

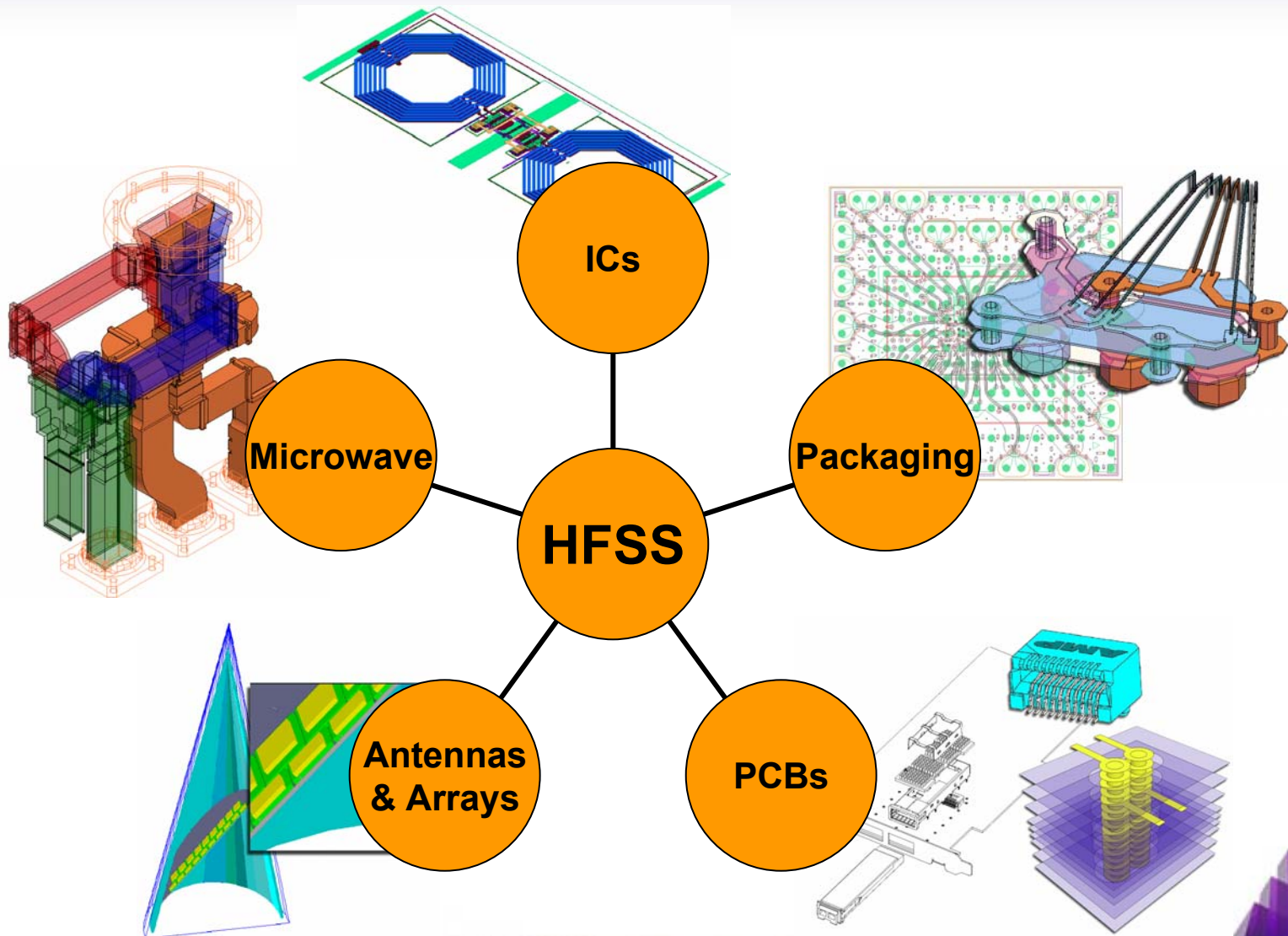


Bogdan C. Ionescu

Brad Brim

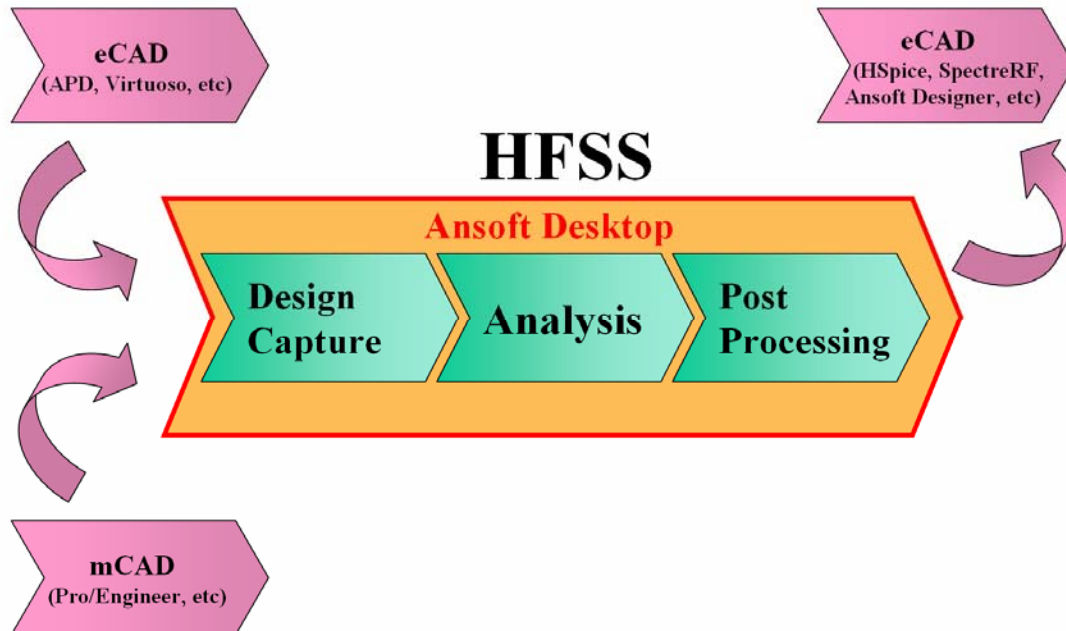
Ansoft Corporation

HFSS Applications

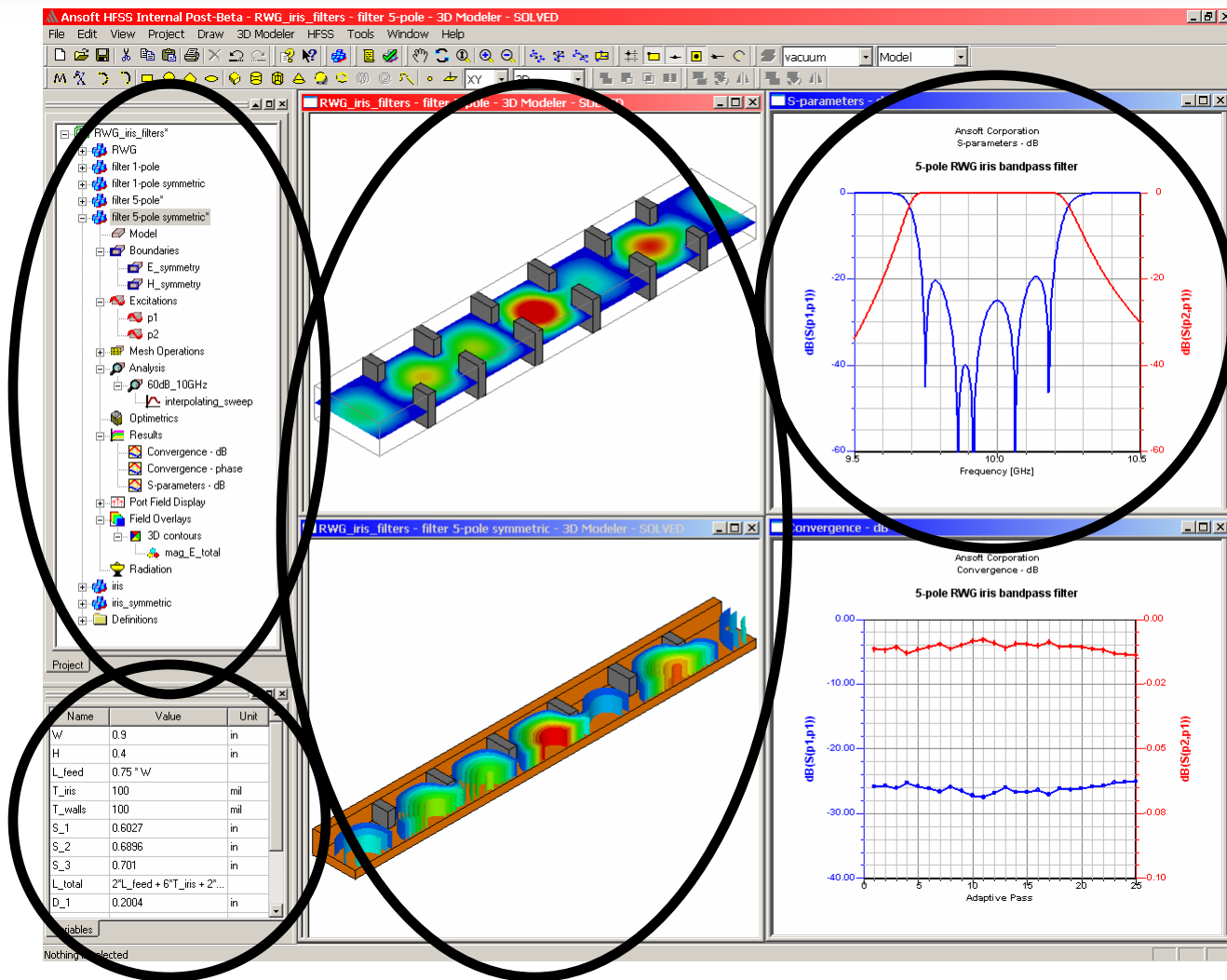


The Ansoft Desktop

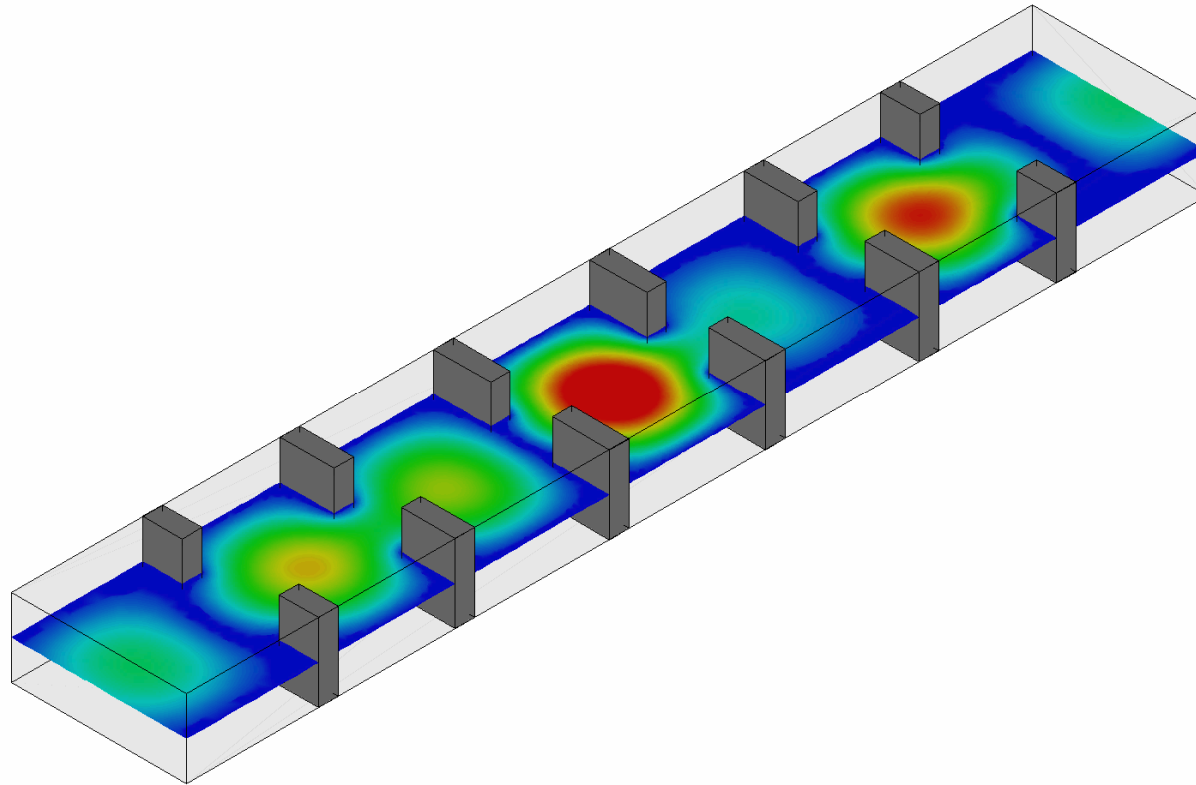
- ◆ HFSS is a “design environment” enabling an automated 3D EM-based design flow
 - ◆ design flow management with a familiar use model
 - ◆ parametric design database creation and editing
 - ◆ parametric data management and access



An HFSS Design Example

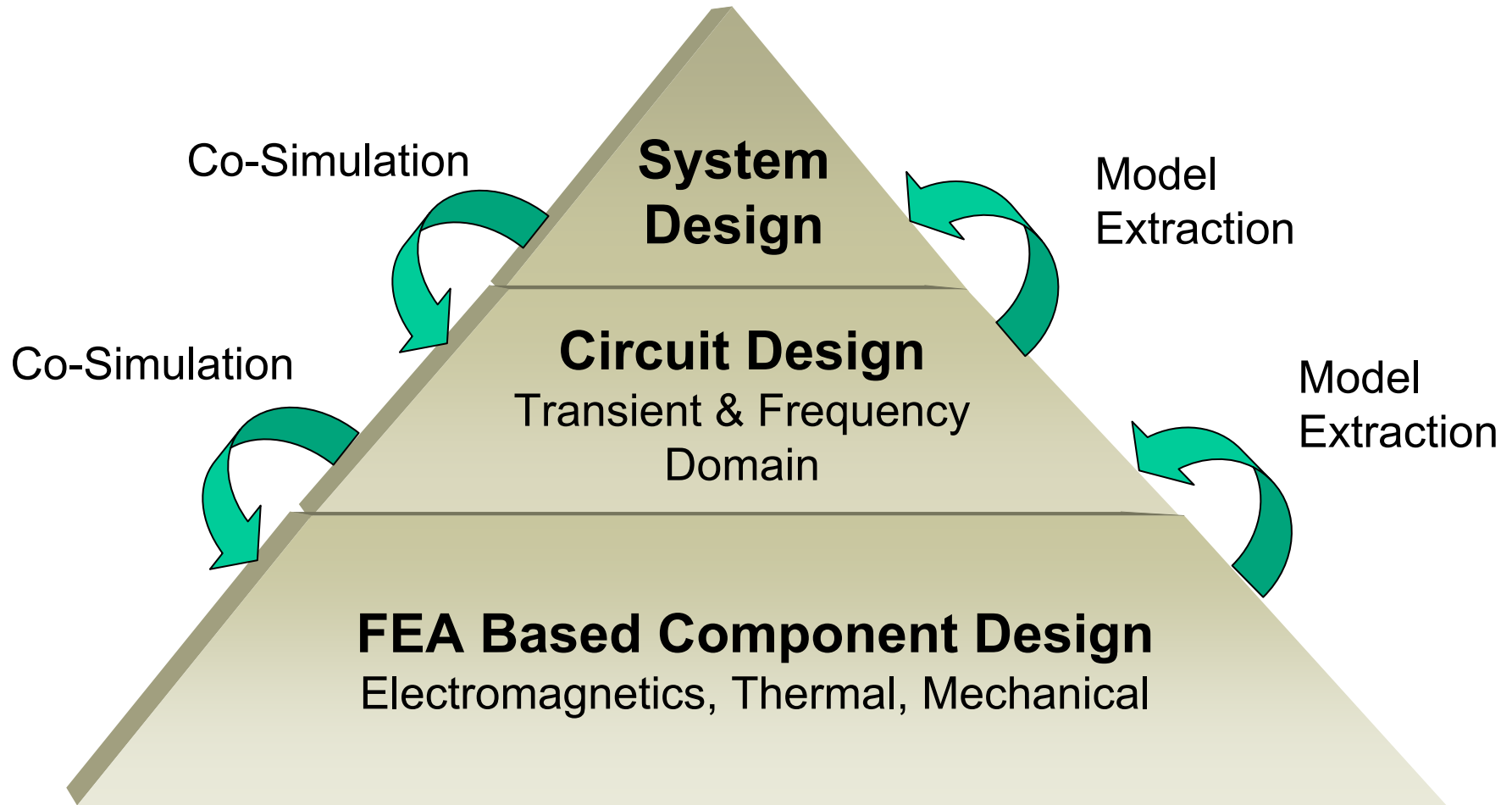


High Power HF Components



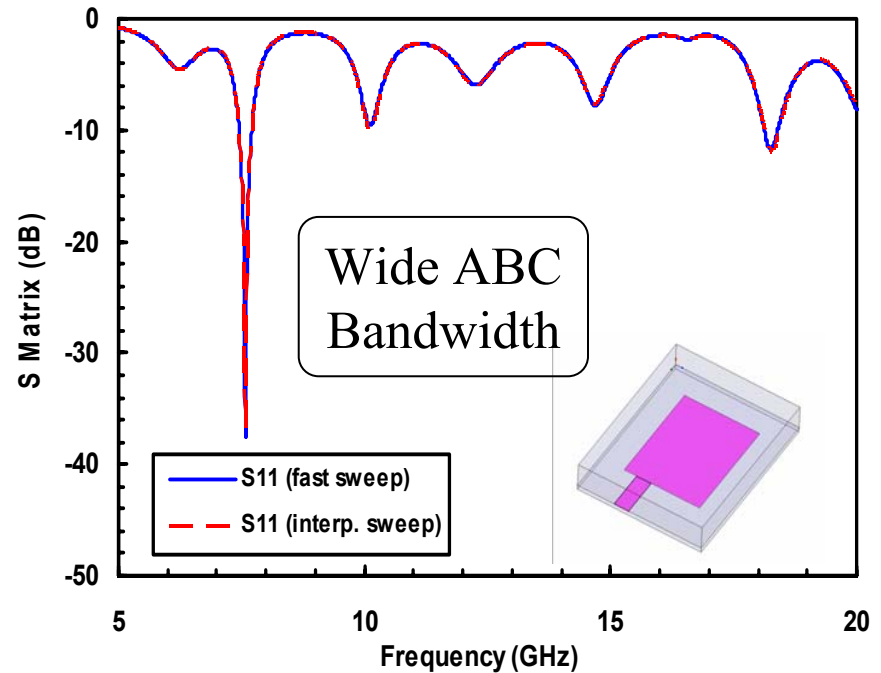
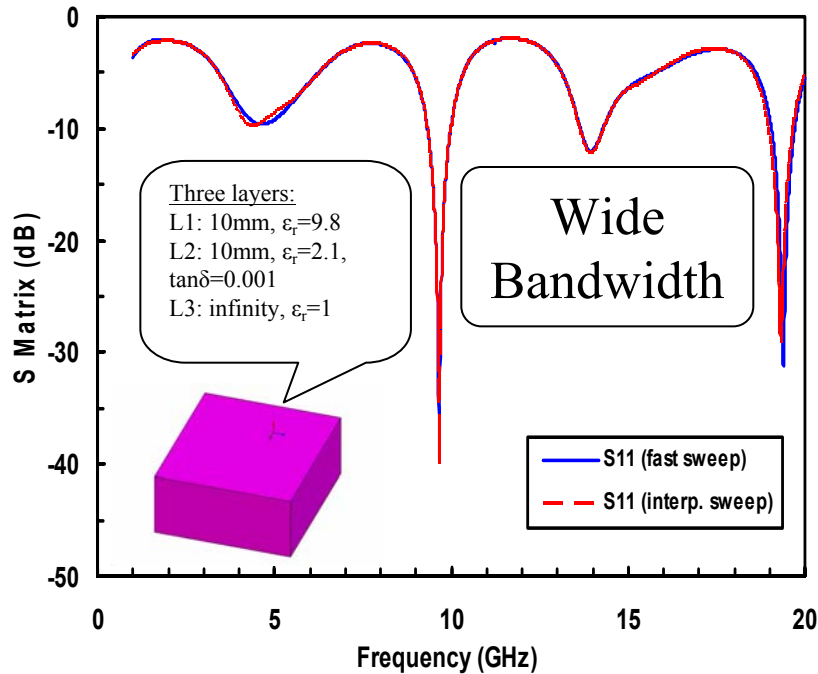
Pass band iris filter

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



Ansoft Designer Internal Build - [HFSS_Integration - TopLevelCircuit - Schematic]

File Edit View Project Draw Schematic Circuit Tools Window Help

HFSS_Integration*
TopLevelCircuit*
Data
Alumina
HFSS-OptiGuide
Excitations
Ports
Port1
Port2
Analysis
Optimetrics
Results
Definitions
Components
Materials

Port1

HFSS Design

Port2

W=5.3mm
S=0.25mm
P=10mm

W=2.7mm
S=0.5mm
P=10mm

W=2.7mm
P=10mm

W=2.7mm
P=10mm

W=2.7mm
S=0.5mm
P=10mm

W=5.3mm
S=0.25mm
P=10mm

1 New Page

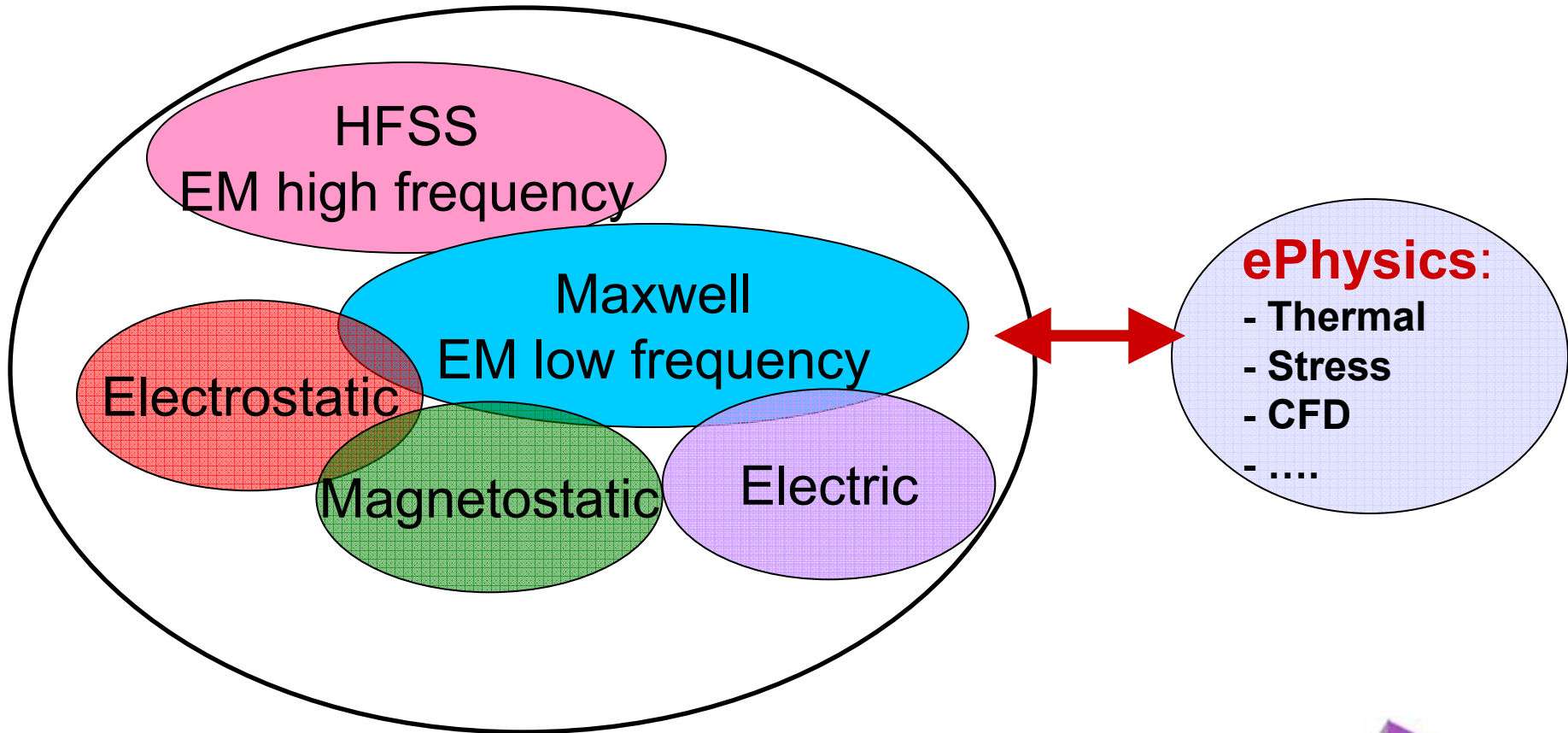
Name	Value	Unit
NPortData	HFSS-OptiGuide	
\$width	14.8570192	mm
\$length	7.824547736	mm
\$height	0.45*\$width	
Ystart	8mm+\$length	

Param Values General Symbol

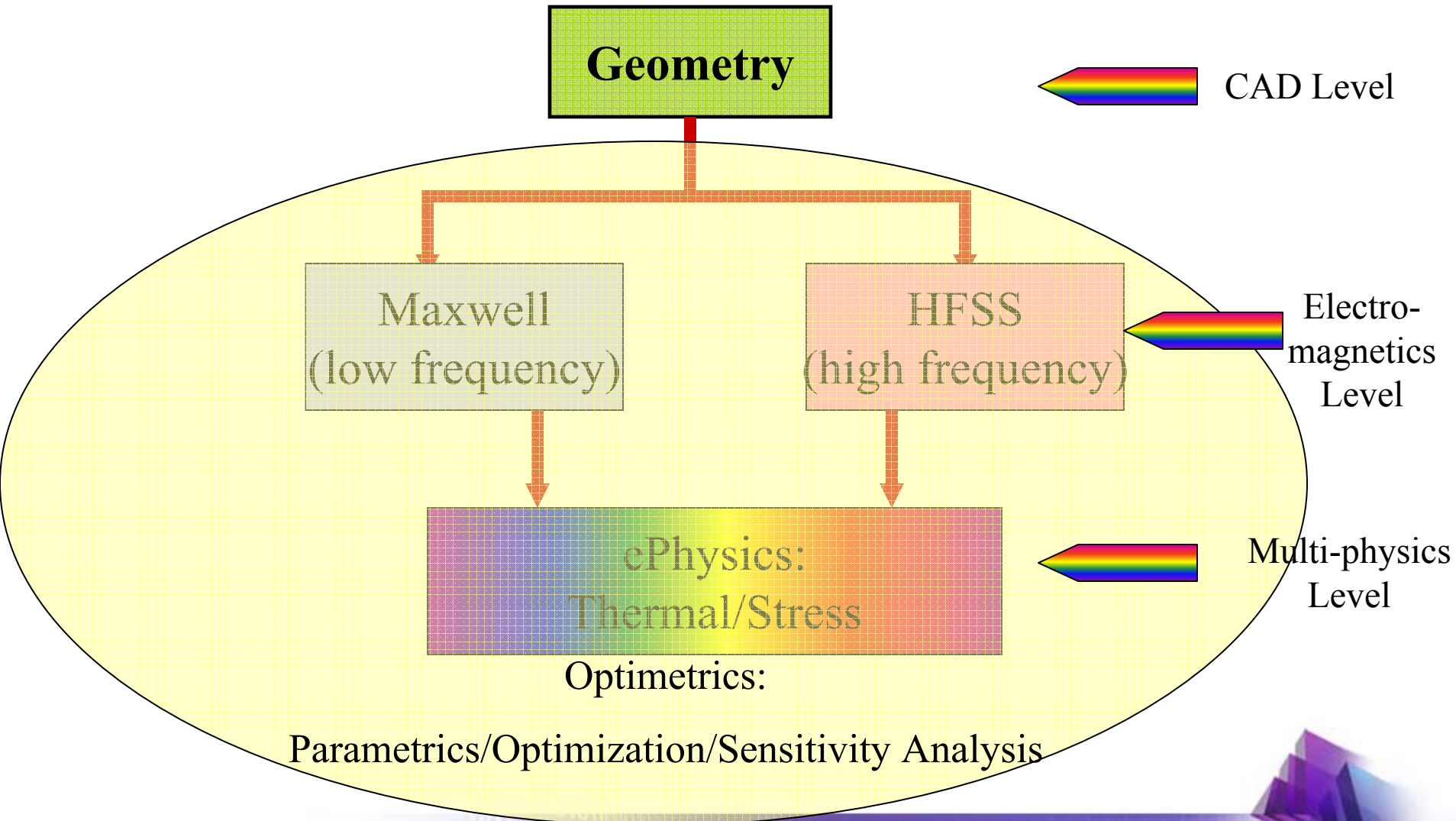
Ready

NUM

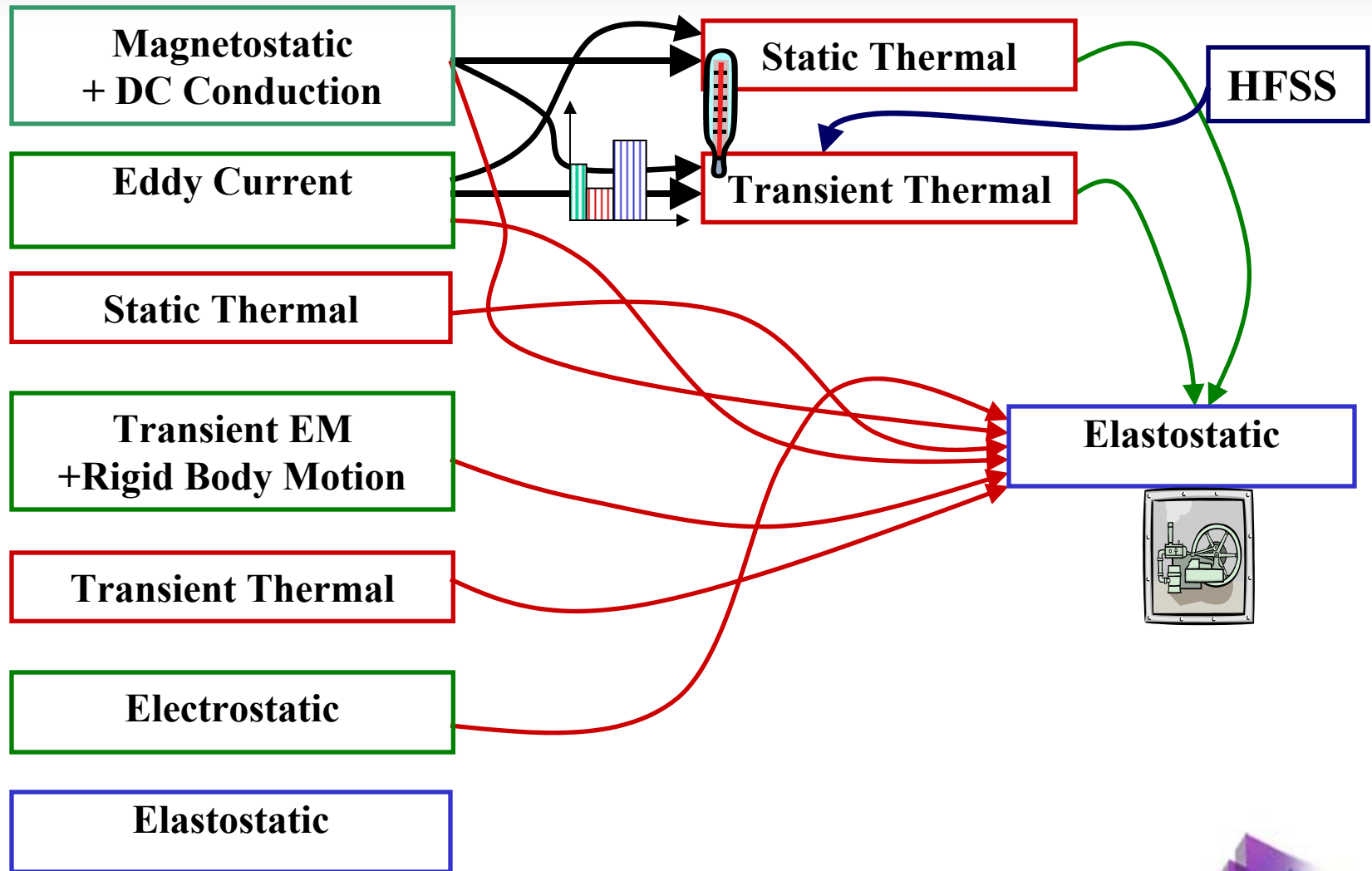
ePhysics for Electromagnetic Applications



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)

Boundary conditions (prescribed temperature, convection, radiation)

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

From HFSS

From ePhysics

2,3

ALL mesh files are necessary!

4

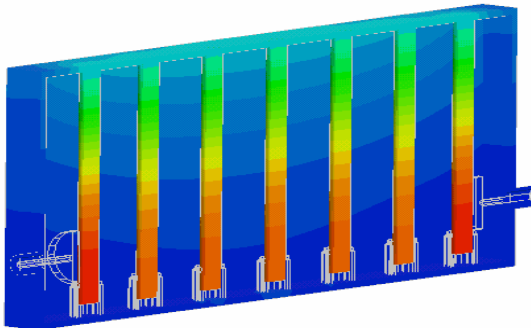
OUT:

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:

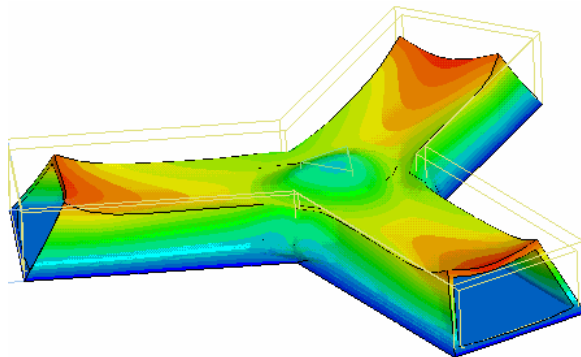
Geometry (already there, with origin in . sm3 from HFSS)

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

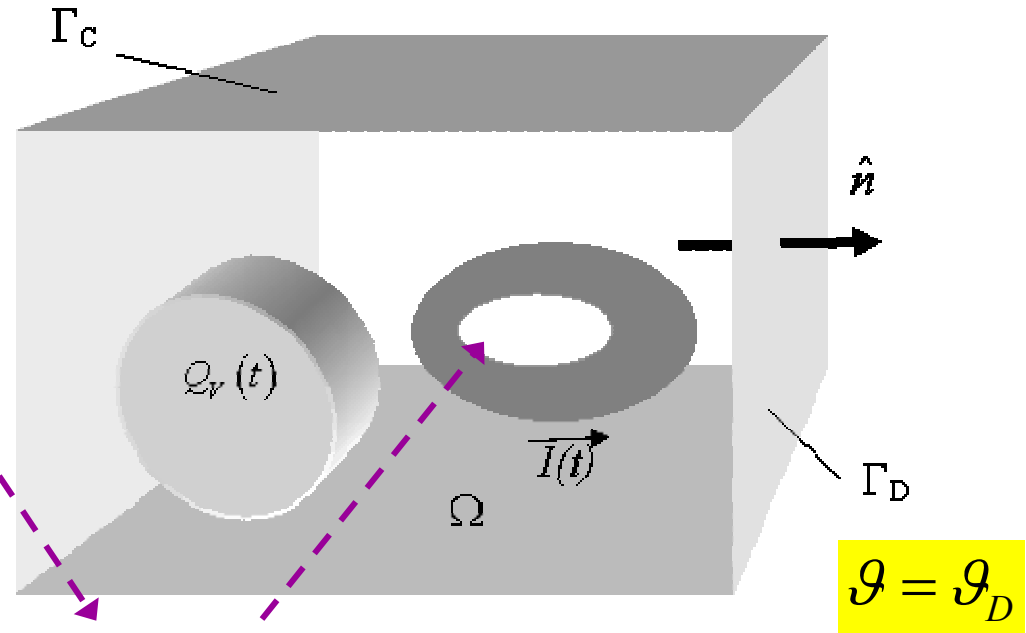
$$\vec{q} \cdot \hat{n} = q_c(\mathcal{G}) = h(\mathcal{G})(\mathcal{G} - \mathcal{G}_r)$$

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

$$\vec{q} = -\mathbf{k} \nabla \mathcal{G}$$

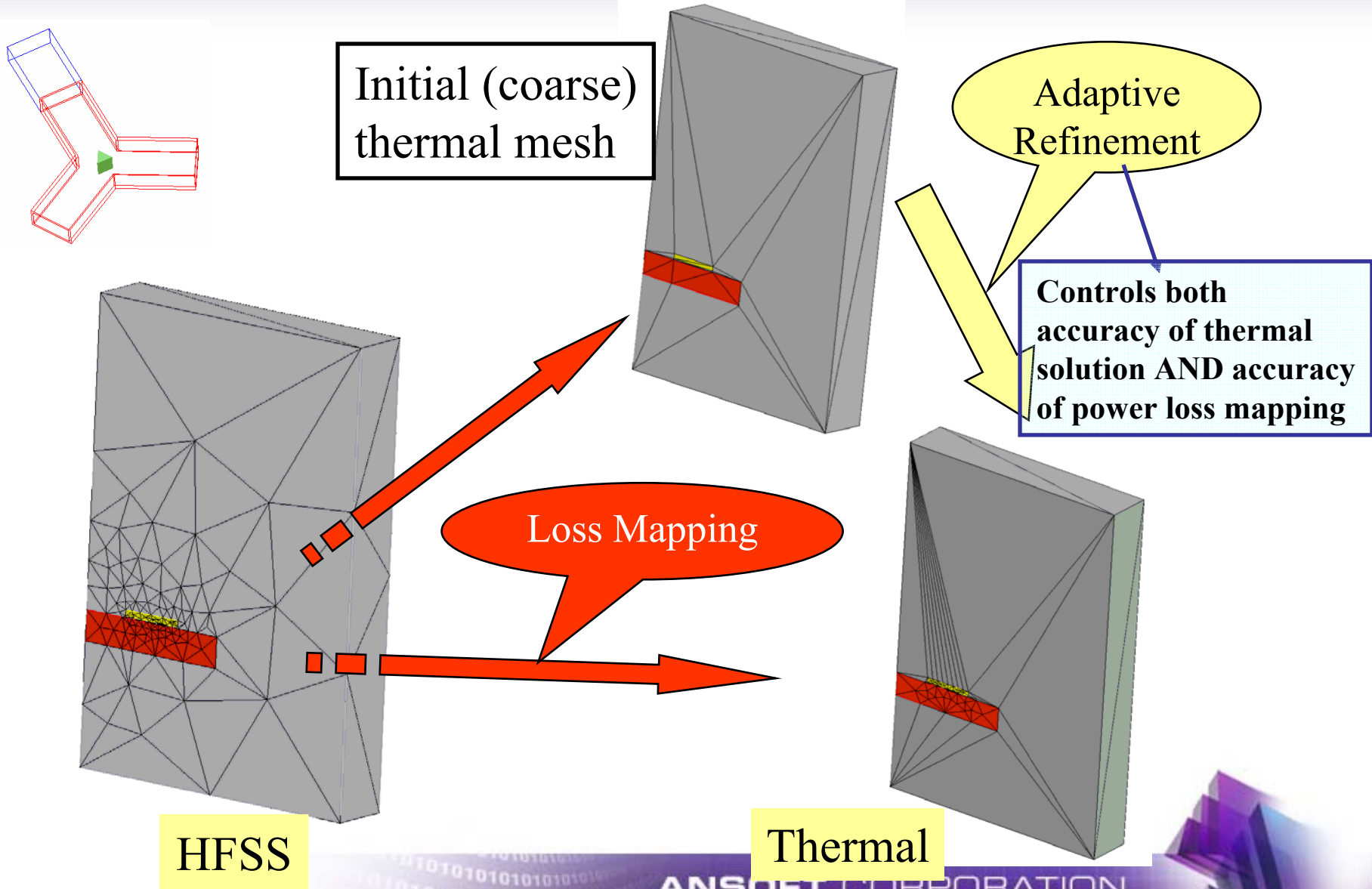
initial condition

$$\mathcal{G}(0, \vec{x}) = \mathcal{G}_0(\vec{x})$$



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

Solution Process HFSS - Thermal

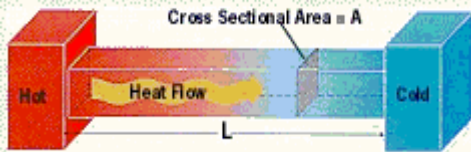


Heat Transfer Mechanisms

Conduction

$$H = kA (T_2 - T_1)/L$$

(joules/second)

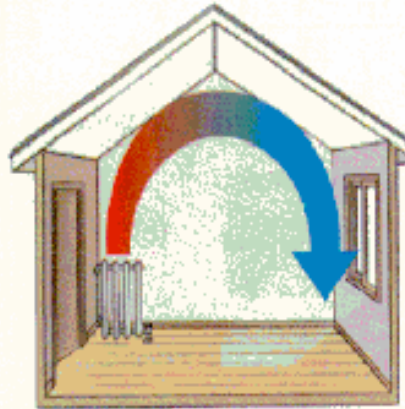


T_2

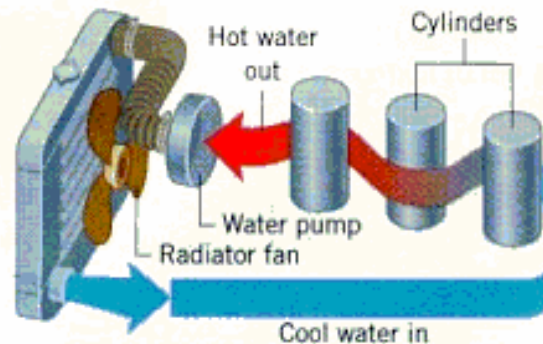
T_1

k = thermal conductivity [J/s-m-C]

Convection

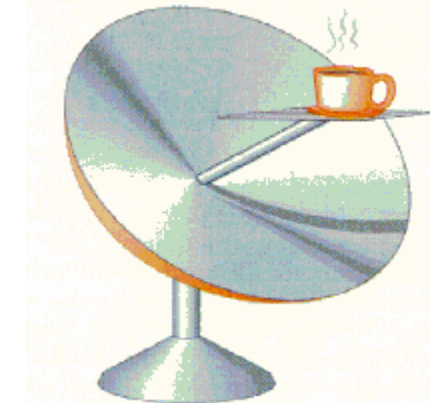
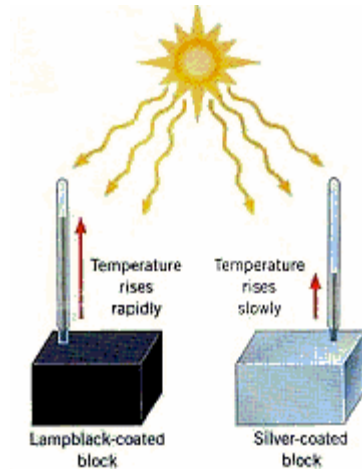


Natural

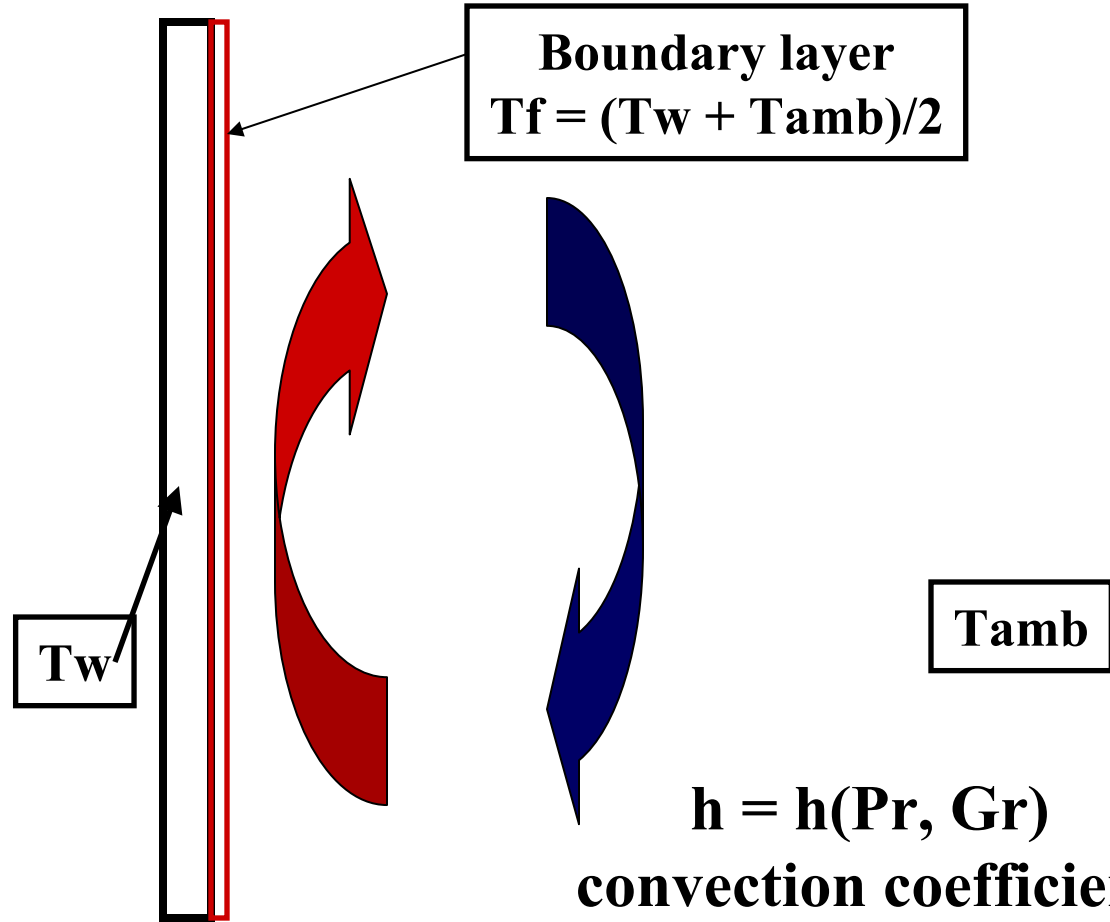


Forced

Radiation



Convection Mechanism on a Vertical Wall



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

Frequently Used Thermal Sources

Source Boundary

Thermal Load

Value Watt

On solids

Source Boundary

Surface Heat Load

Value Watt/m**2

On surfaces,
surface can be
between objects

Frequently Used Thermal Boundary Conditions



Source Boundary Temperature

Value Celsius



Source Boundary Heat Transfer

Thermal Flux Density = $H \cdot (TEMP - TEMP_A)$

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

Ambient temperature (TEMP_A) Celsius

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



Source Boundary Convection_Radiation

$q = C \cdot (TEMP - TEMP_A) \cdot |TEMP - TEMP_A|^{FEXP} + F \cdot B \cdot (TEMP^{**4} - TEMP_R^{**4})$

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

Ambient temperature (TEMP_A) Celsius

Exponent (FEXP)

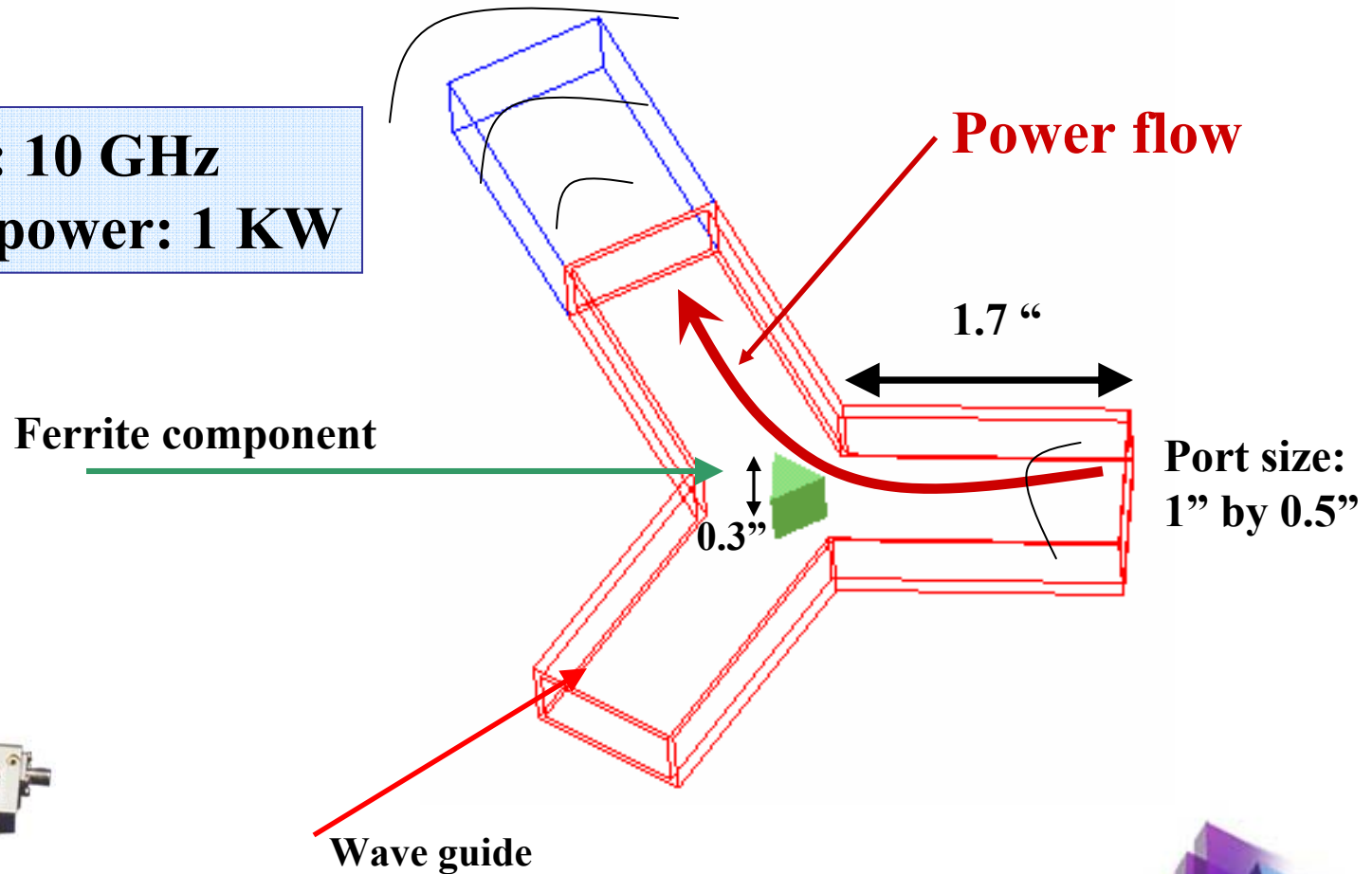
Radiation emissivity (F)

Radiation ref. temp. (TEMP_R) Celsius



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

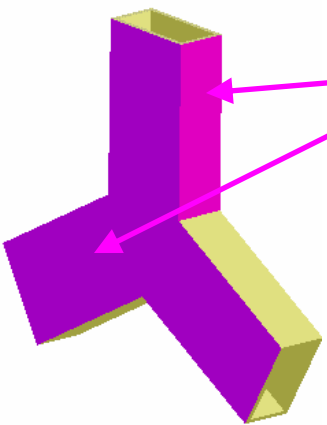
Silver

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

Air

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

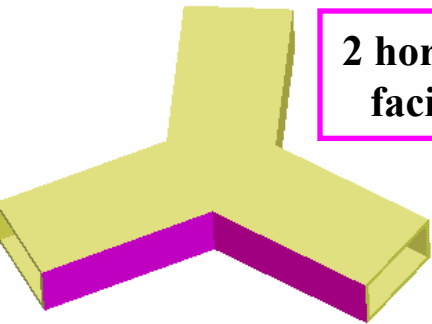
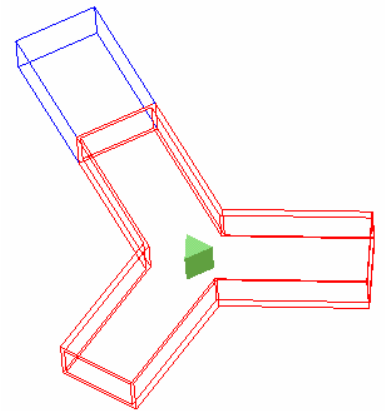
Ferrite Circulator Application -thermal boundary conditions-



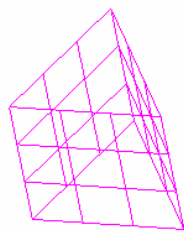
4 vertical faces
(2 shown + 2 symmetric
on the other side)



2 horizontal faces
facing "up"



2 horizontal faces
facing "down"



3 side faces
of ferrite
component

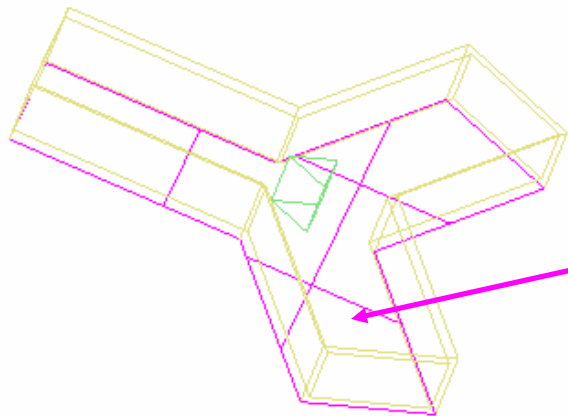
convective & radiative boundary conditions

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

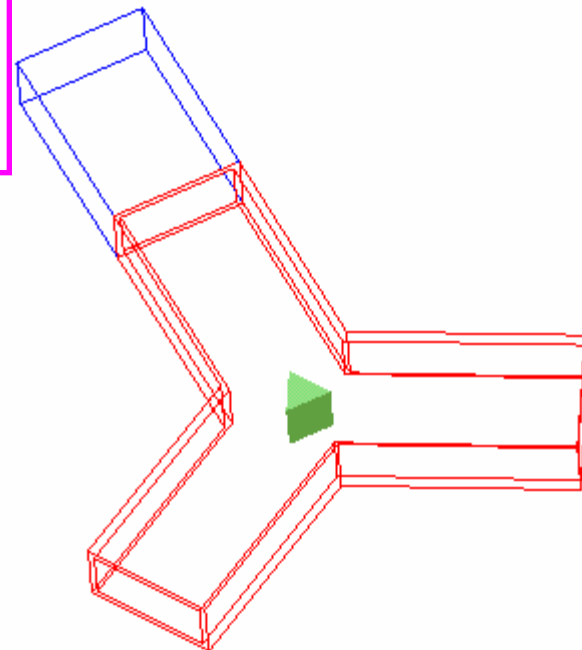
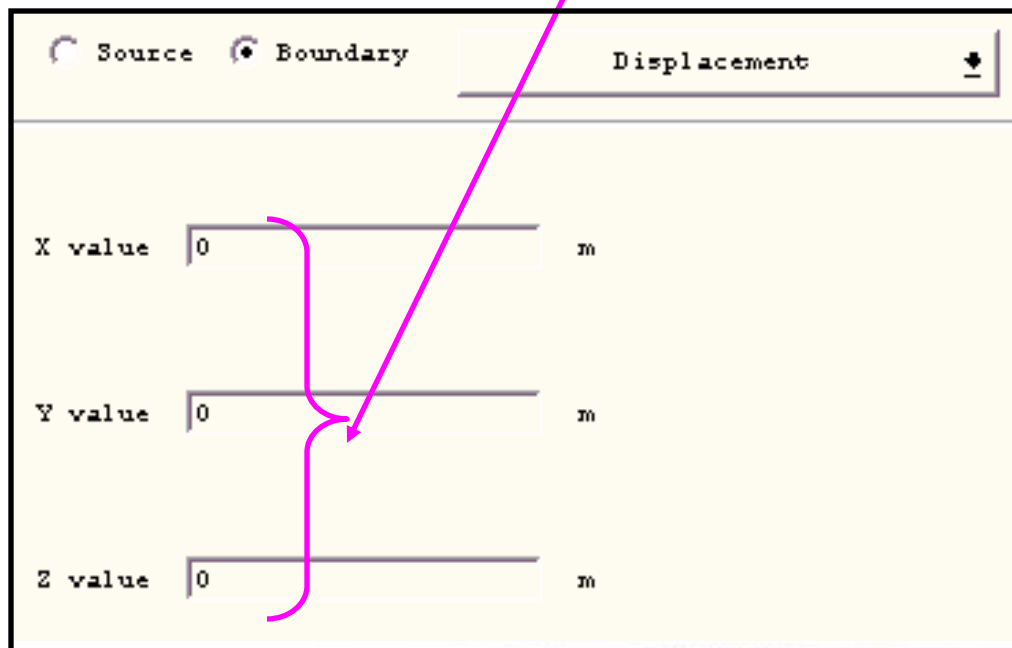
Convection coefficient (C)	<input type="text" value="10"/>	W/C**ALPHA/m**2
Ambient temperature (TEMP_A)	<input type="text" value="25"/>	Celsius
Exponent (FEXP)	<input type="text" value="0"/>	
Radiation emissivity (F)	<input type="text" value="0.85"/>	
Radiation ref. temp. (TEMP_R)	<input type="text" value="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-

The image shows the ANSYS HFSS software interface. The **Solve Setup** panel is visible, with the **Hfss Loss** section set to **Import...**. The **HFSS Loss Import** dialog box is open, showing the following fields:

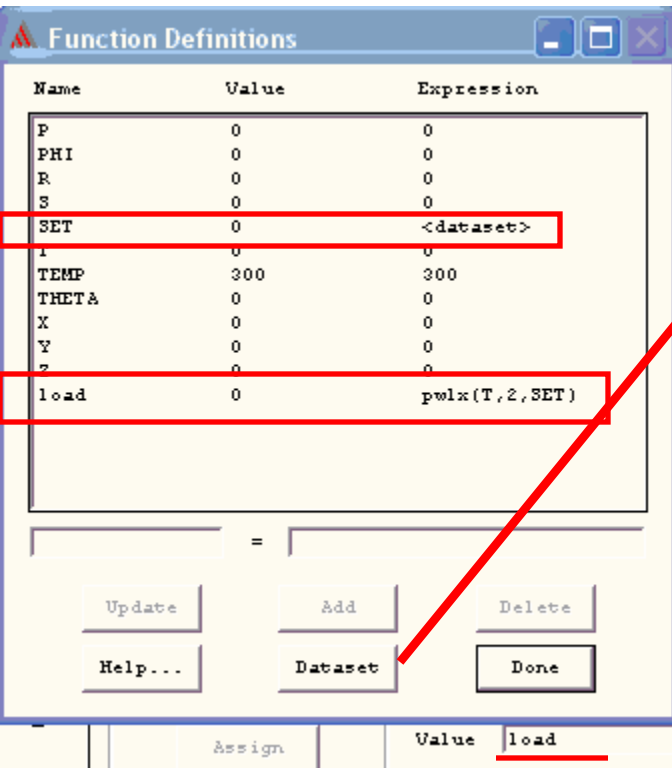
- Mesh File:** `ulator hfss files/dv43_s30_v38.cmesh/current.hyd`
- Volumetric Loss Density File:** `c:/ephys_training_feb2004/ferrite circulator hfss`
- Surface Loss Density File:** `c:/ephys_training_feb2004/ferrite circulator hfss`
- Duration of Loss Effect:** `1200` sec

A blue arrow points from the **Write** command in the HFSS post processor to the **Import...** button in the **HFSS Loss Import** dialog. A red box highlights the **Loss** vs **time** graph in the HFSS post processor, with a **simulation time** label pointing to the x-axis.

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

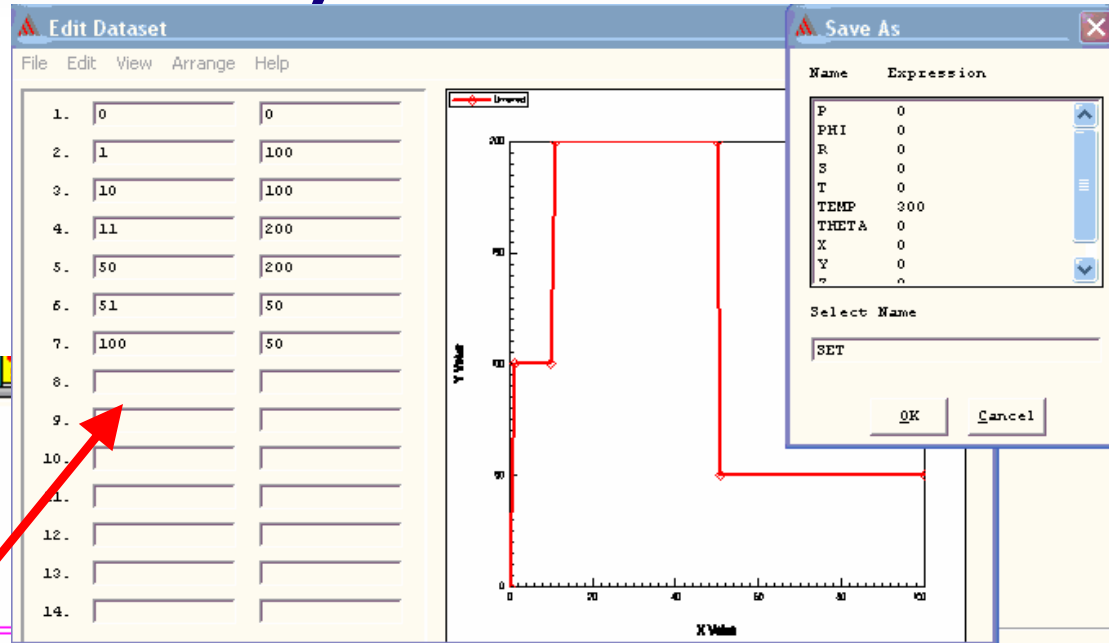
(Creating time dependent thermal loads)

**Model/Functions...
Menu Button**



Function Definitions dialog box showing a table of variables and their expressions. The 'SET' and 'load' rows are highlighted with red boxes. A red arrow points from the 'load' row to the 'Edit Dataset' dialog box.

Name	Value	Expression
P	0	0
PHI	0	0
R	0	0
S	0	0
SET	0	<dataset>
T	0	0
TEMP	300	300
THETA	0	0
X	0	0
Y	0	0
Z	0	0
load	0	pwlx(T,2,SET)



Two dialog boxes are shown. The 'Edit Dataset' dialog box contains a table with two columns and 14 rows. The 'Save As' dialog box contains a table with two columns and several rows, and a 'Select Name' field with 'SET' entered.

1.	0	0
2.	1	100
3.	10	100
4.	11	200
5.	50	200
6.	51	50
7.	100	50
8.		
9.		
10.		
11.		
12.		
13.		
14.		

Name	Expression
P	0
PHI	0
R	0
S	0
T	0
TEMP	300
THETA	0
X	0
Y	0
Z	0

Select Name: SET

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

Thermal Load

Thermal Static Solution Setup

Solve Setup

Starting Mesh:

HFSS Loss:

Initial Condition:

Value

Field

Thermal Load Time:

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

Solve Setup

Nonlinear Tolerance: 0.005

Save Temperature Fields

Transient Analysis

Solution: Start from time zero
 Continue previous solution

Stop time: 1500 sec

Initial Time Step: 0.01 sec

Maximum Time Step: 50 sec

Stress Analysis Time Steps: Setup...

Use Macro:

Suggested Values

OK Cancel Help

Stress Analysis Time Steps

Time Steps

1000
1200

Remove

Add Sweep...

New Time Steps: 0 Add

OK Cancel

A red arrow points from the 'Setup...' button in the main dialog to the 'Stress Analysis Time Steps' dialog.

Stress setup

Solve Setup

Starting Mesh: Thermal Manual...

Initial Temperature: 25 Celsius

Adaptive Analysis

Percent refinement per pass: 30

Stopping Criteria

Number of requested passes: 10

Percent error: 1

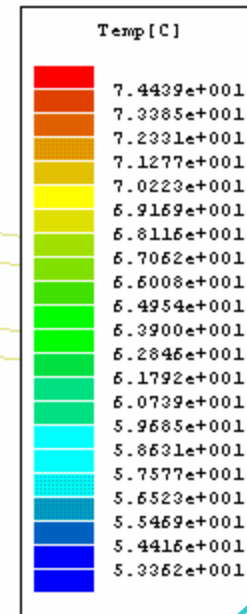
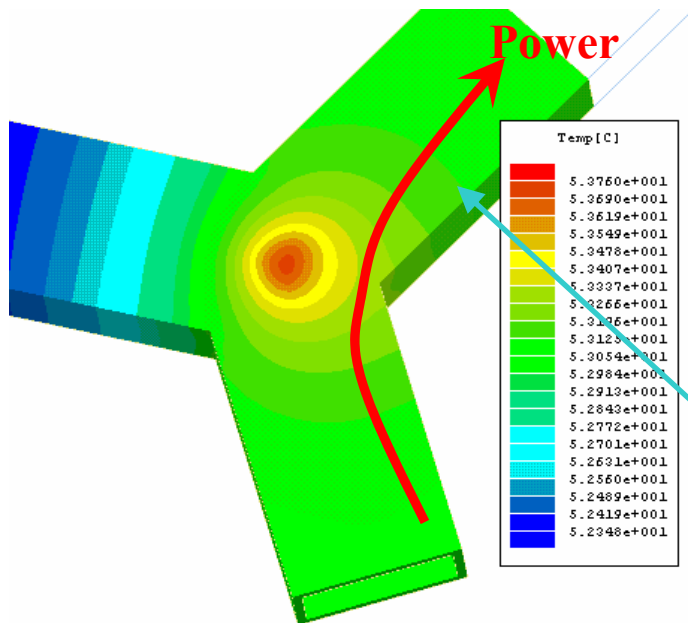
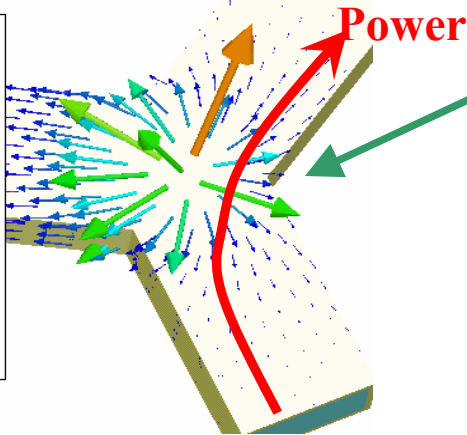
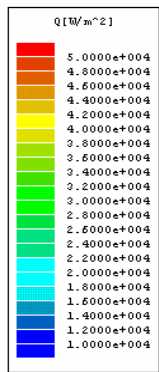
Suggested Values

OK Cancel Help

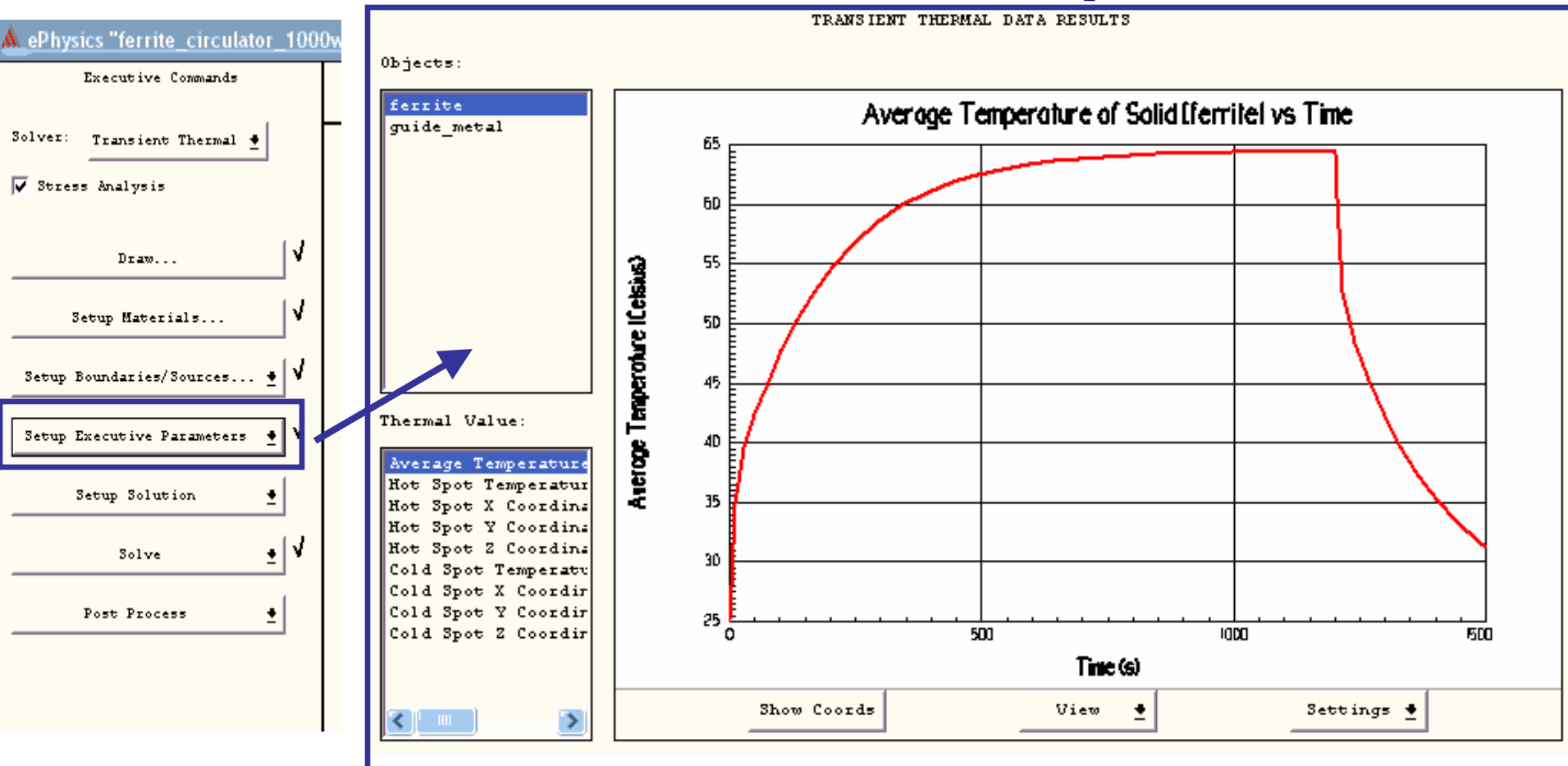
Thermal transient setup

Ferrite Circulator Application

-thermal results, field-

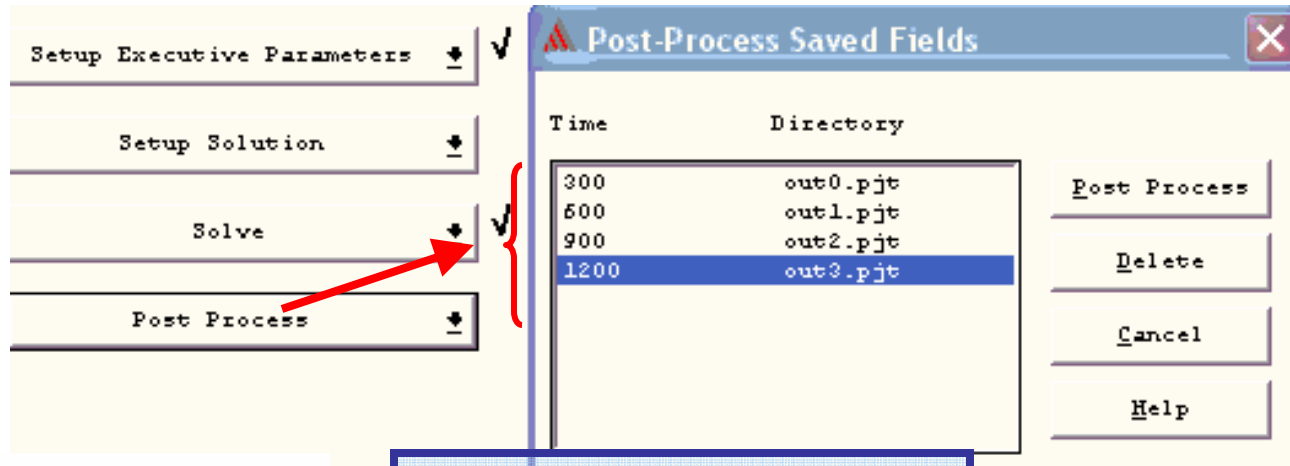


Ferrite Circulator Application -thermal results, exec param-

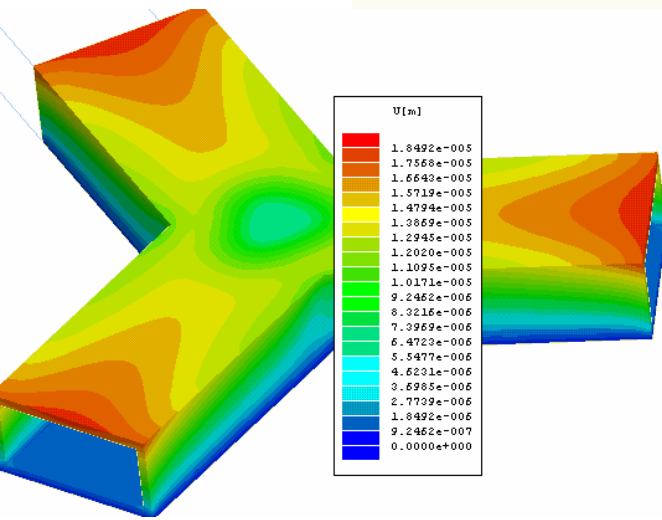


Ferrite Circulator Application

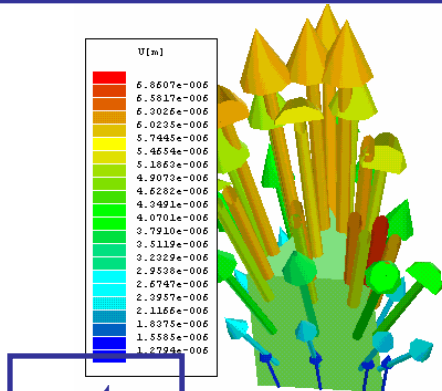
-stress results-



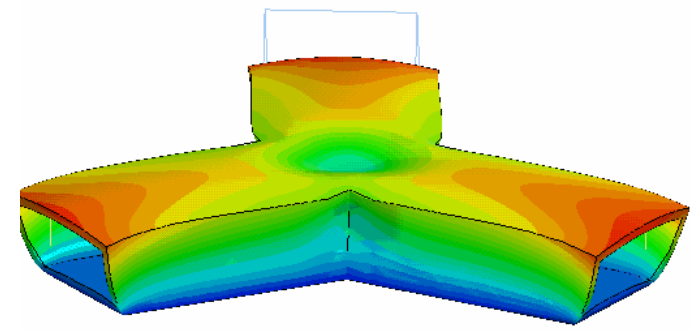
Deformation plots



magnitude



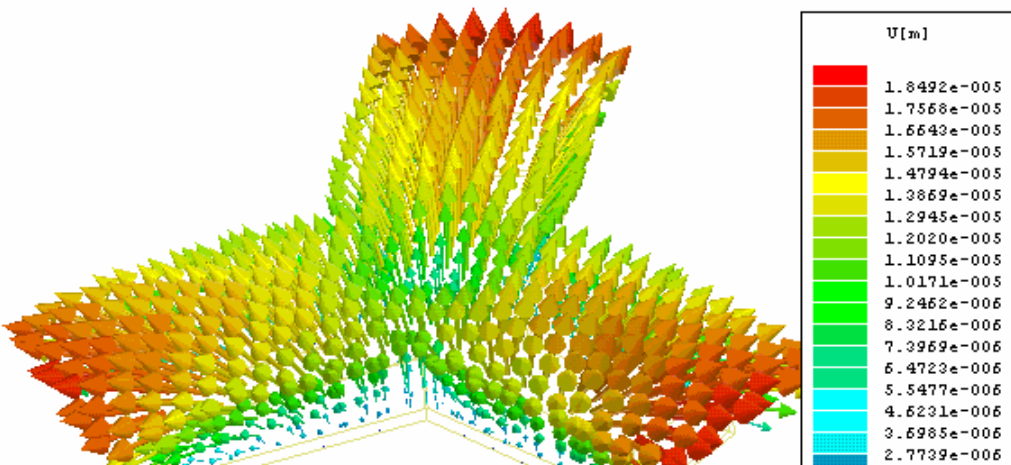
vector



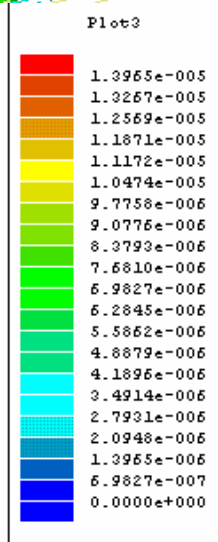
Scaled deformation

Ferrite Circulator Application

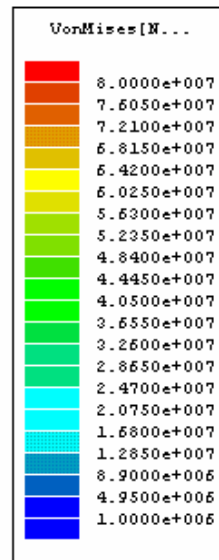
-stress results-



Vector displacement



Y component of vector displacement

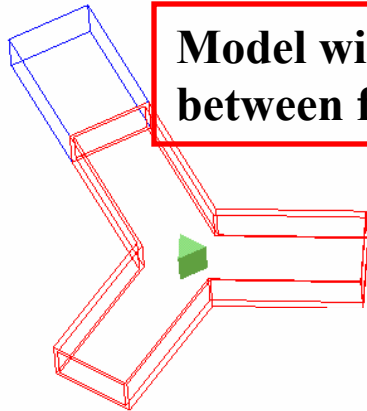


Von Mises stress

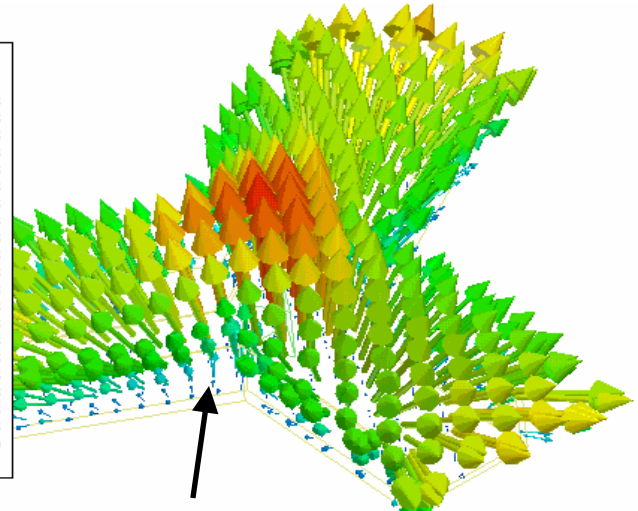
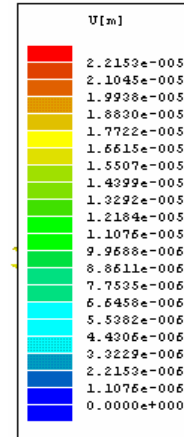
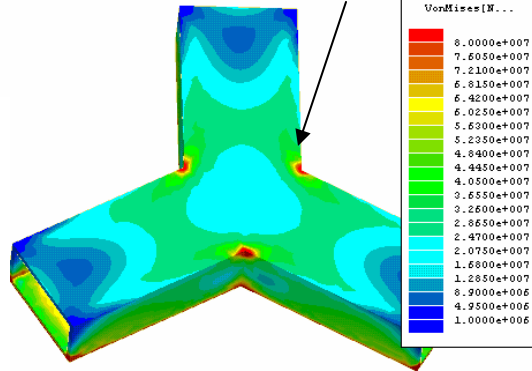
Ferrite Circulator Application

-what ifs!?!... and whys?-

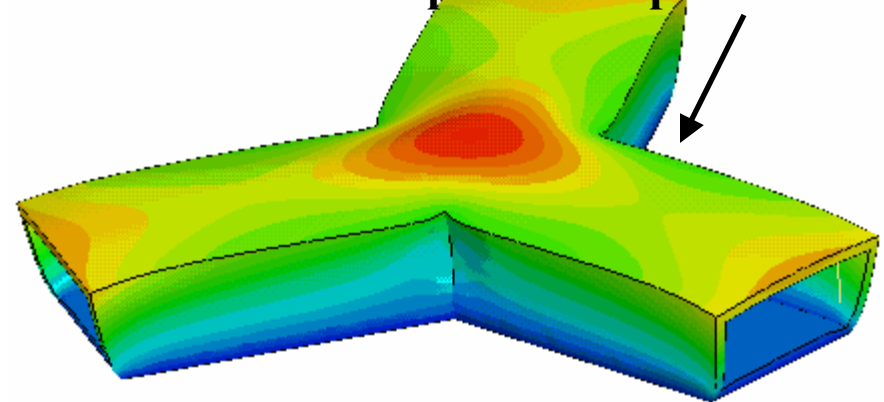
Model with 25 um air gap between ferrite and wave guide



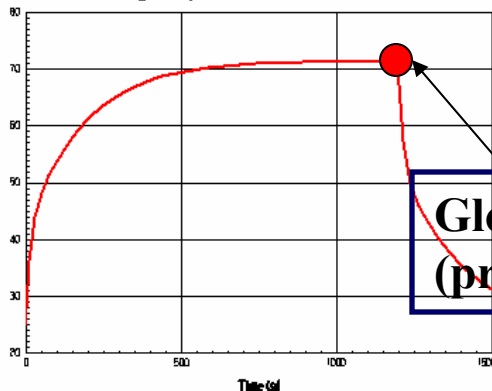
Von Mises stress



Displacement plots



Average Temperature of Solid (ferrite) vs Time

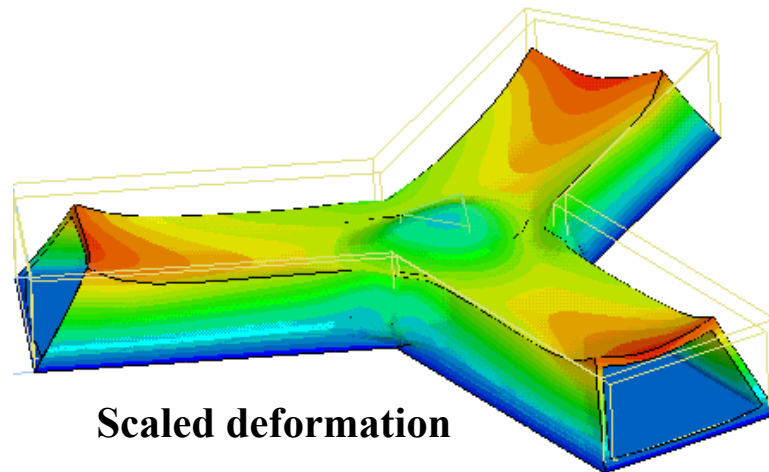
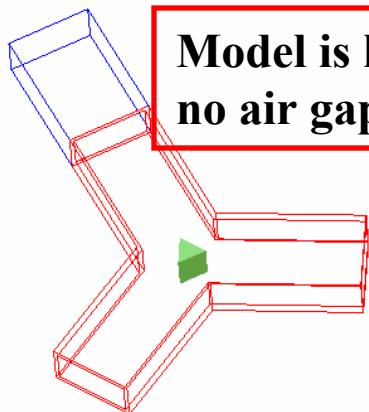


**Global: steady state temperature $T = 71.4\text{ C}$
(previous temperature $T' = 64.4\text{ C}$)**

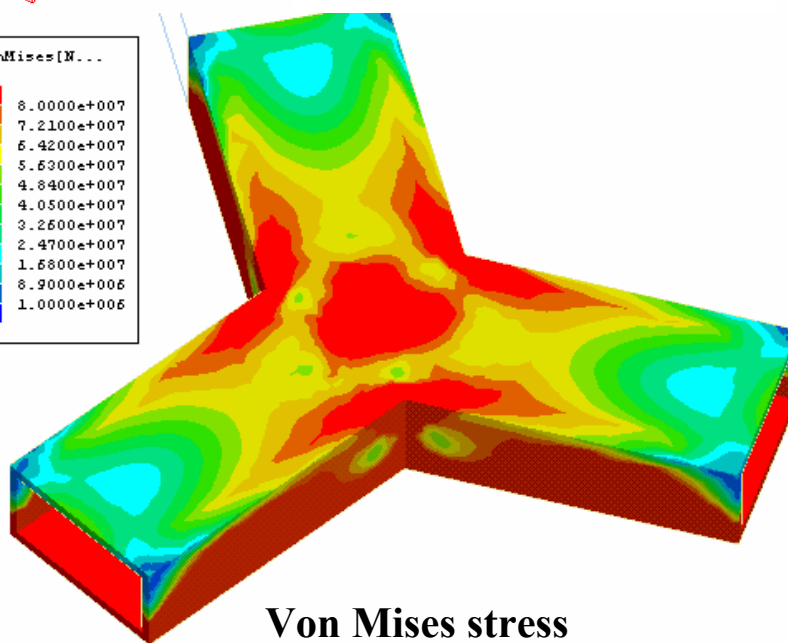
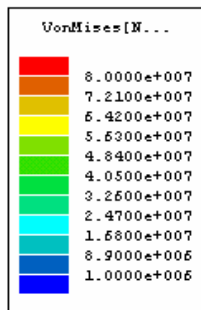
Ferrite Circulator Application

-what ifs!?!... and whys?-

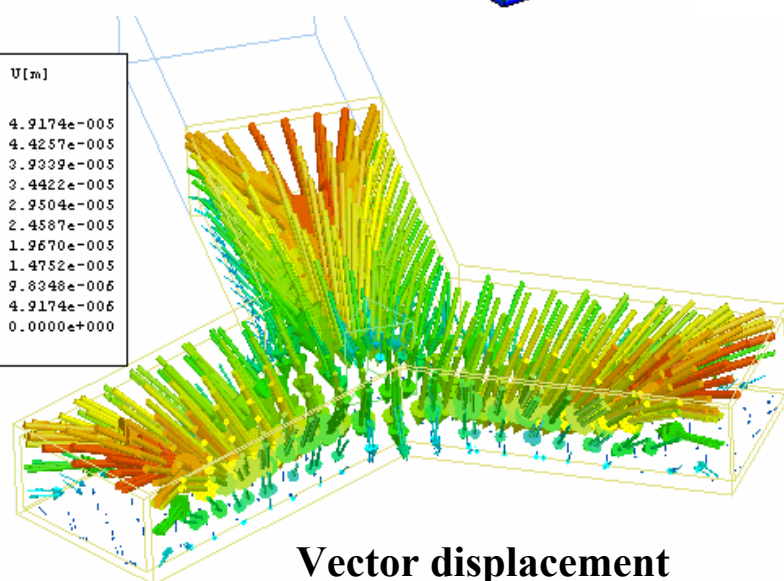
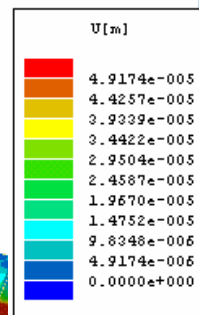
Model is kept at $-50\text{ }^{\circ}\text{C}$,
no air gap above the ferrite



Scaled deformation



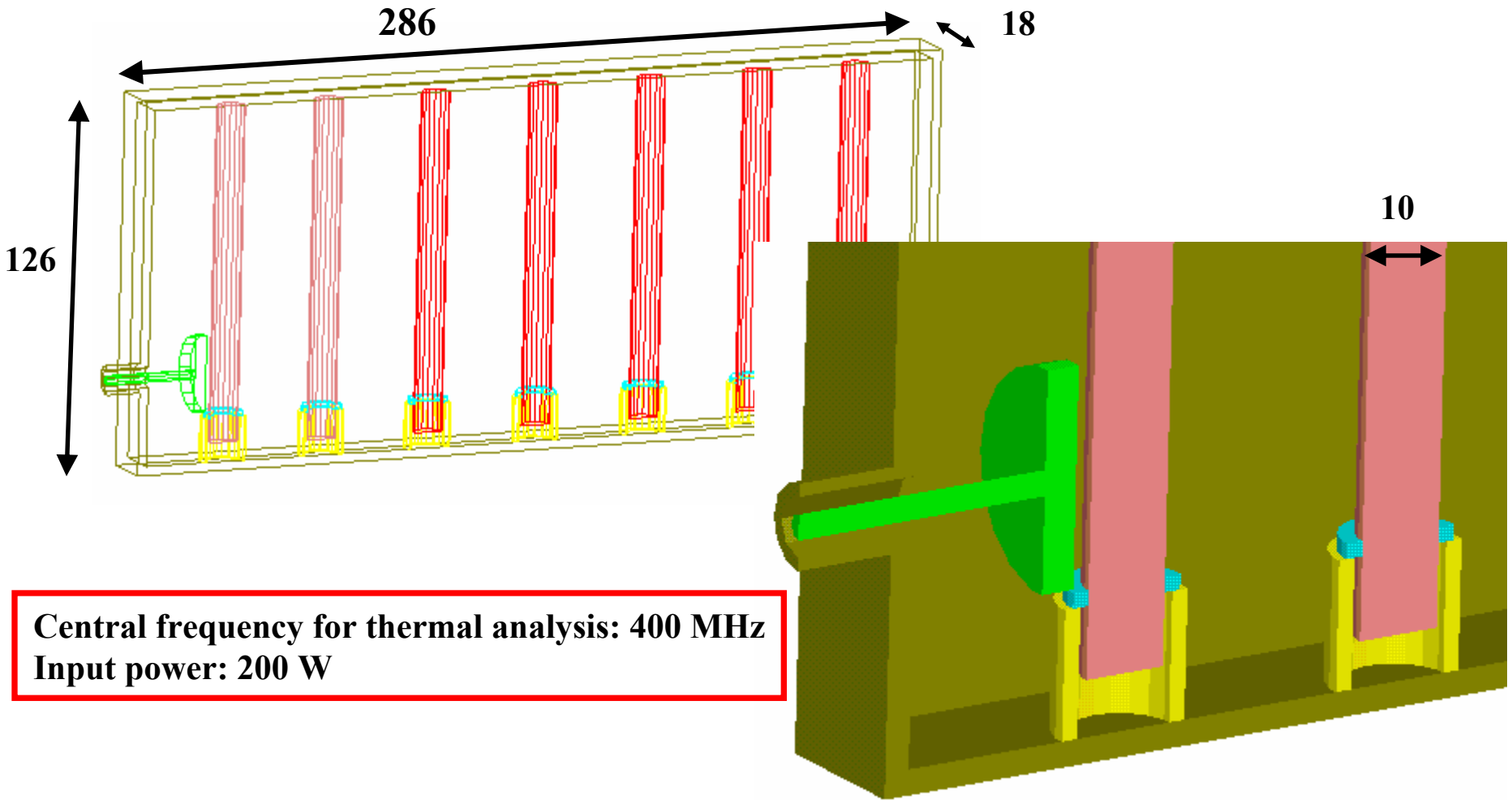
Von Mises stress



Vector displacement

Chebyshev Filter Application

-model data-

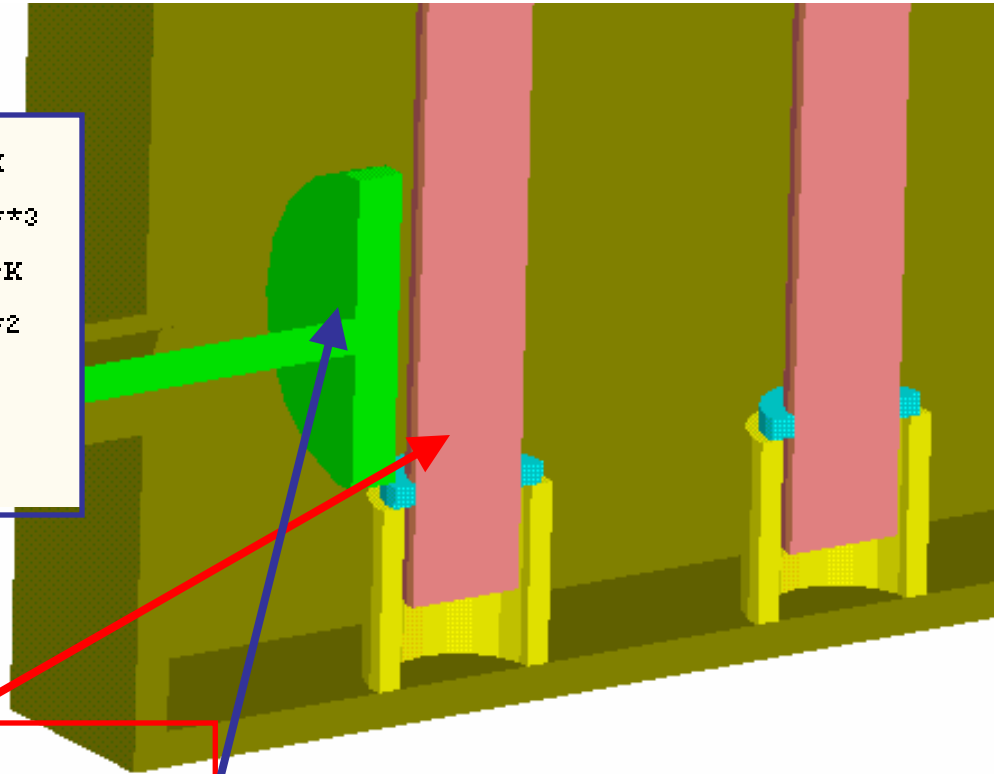


Chebyshev Filter Application

-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

Convective & radiative
boundary condition

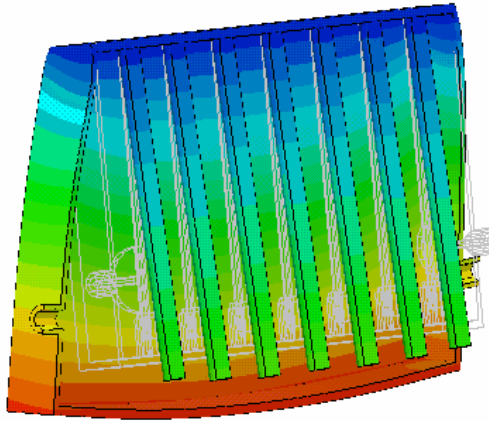
Symmetry plane:
leave unconstrained =
= thermal flux tangent =
= adiabatic boundary

Stress boundary

Zero X, Y, Z displacement
on top face

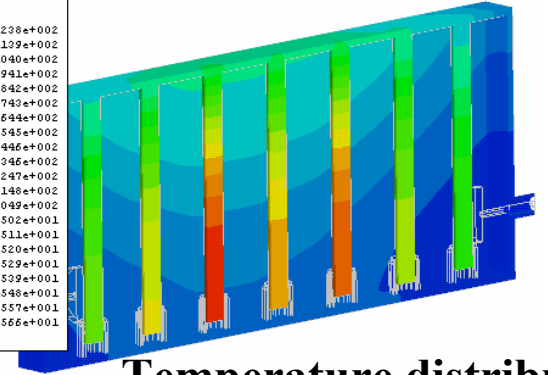
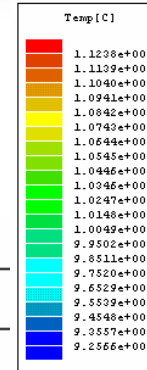
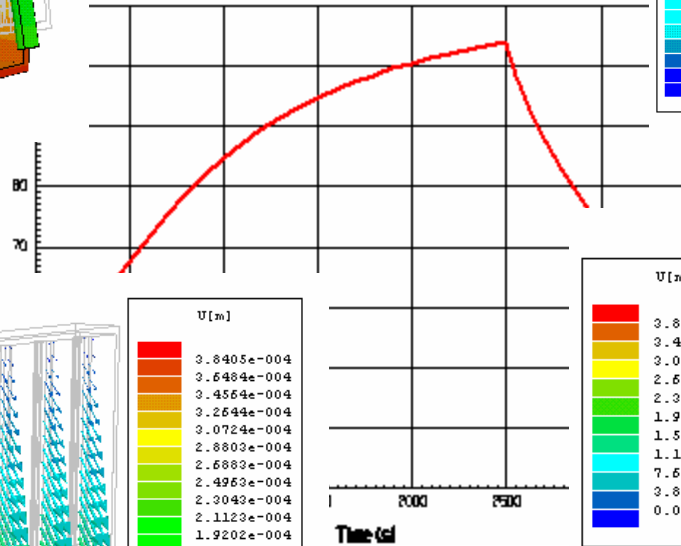
Chebyshev Filter Application

-results-

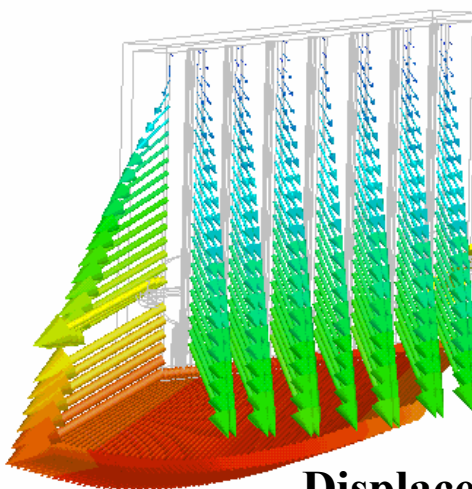


Scaled deformation

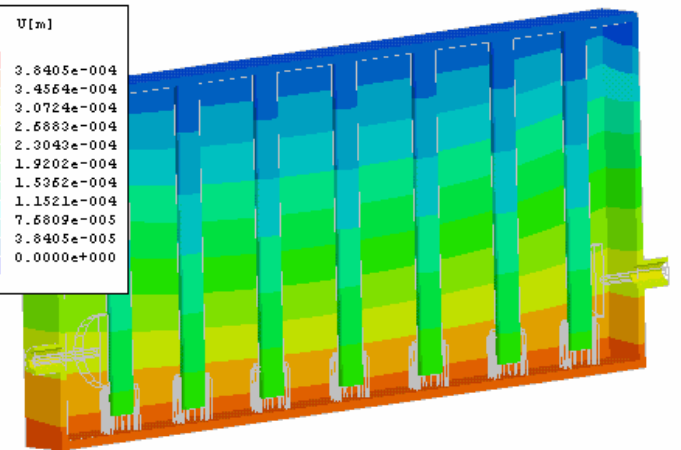
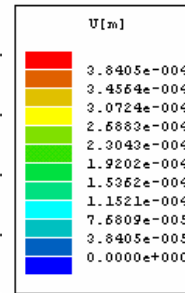
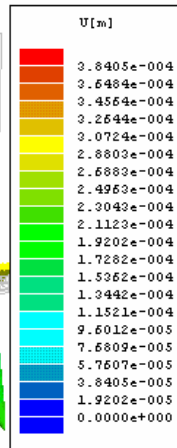
Average Temperature of Solid (rod) vs Time



Temperature distribution

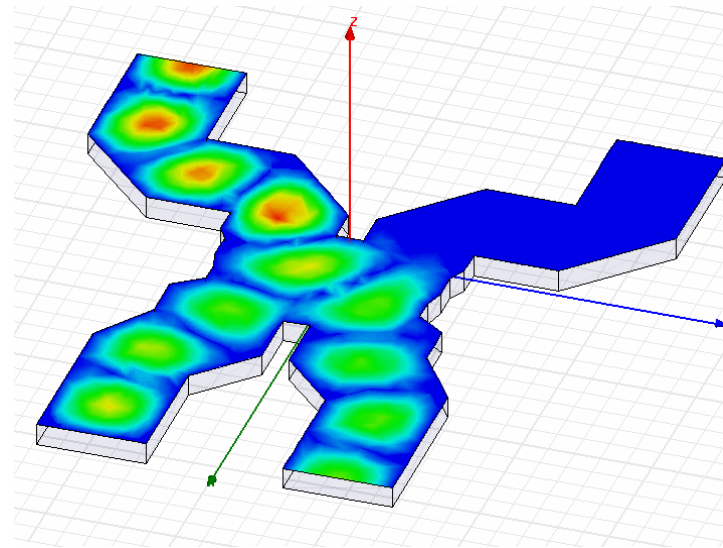
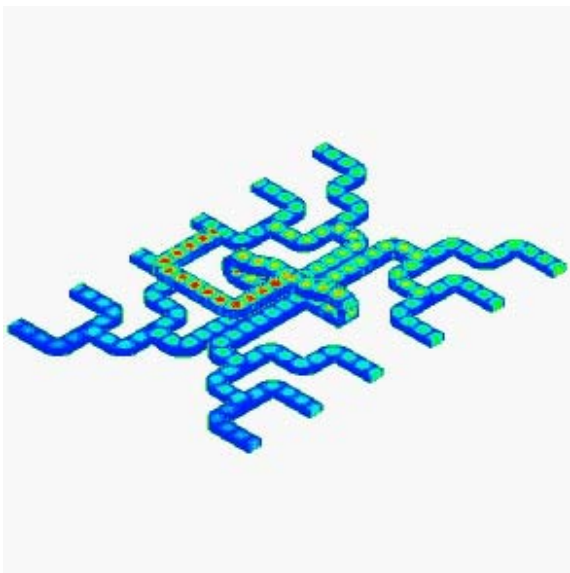
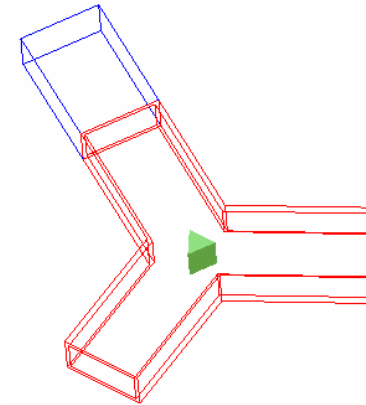
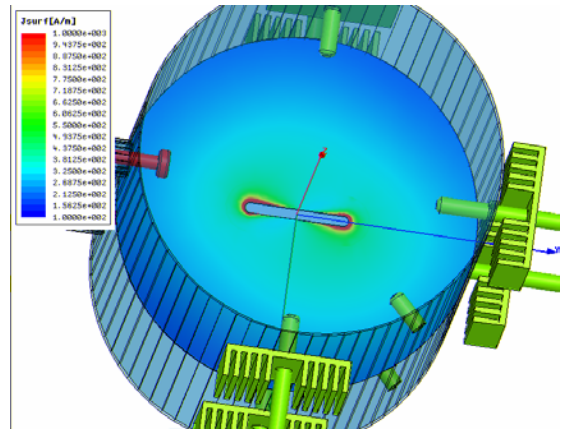


Displacement vector

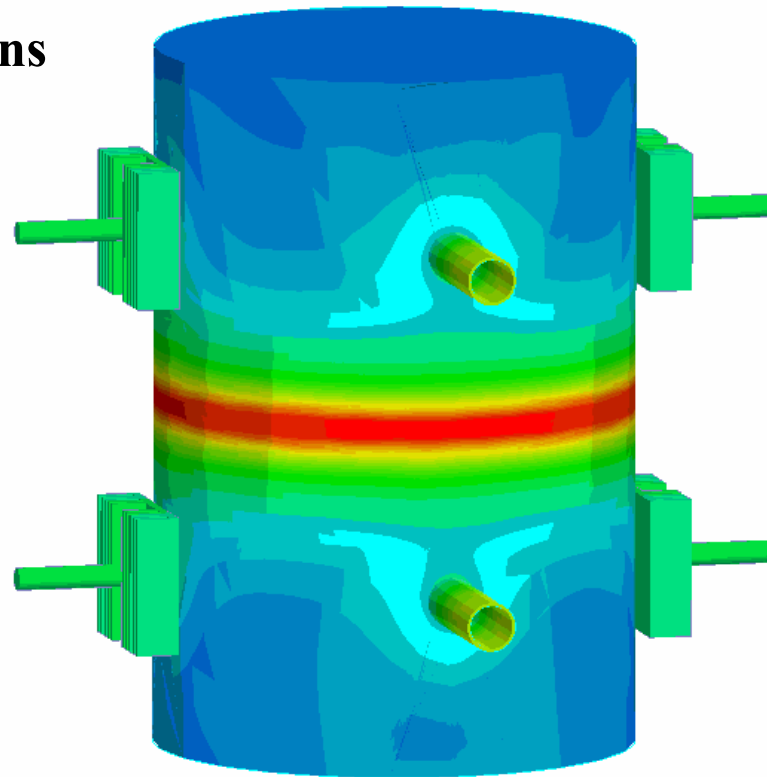
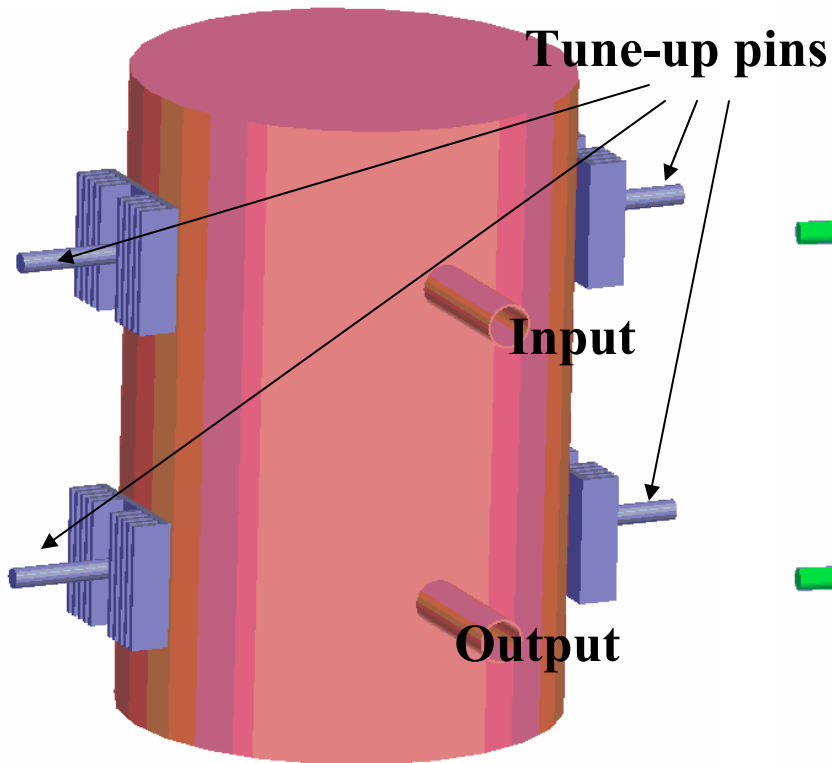


Magnitude of displacement

High Power HF Components

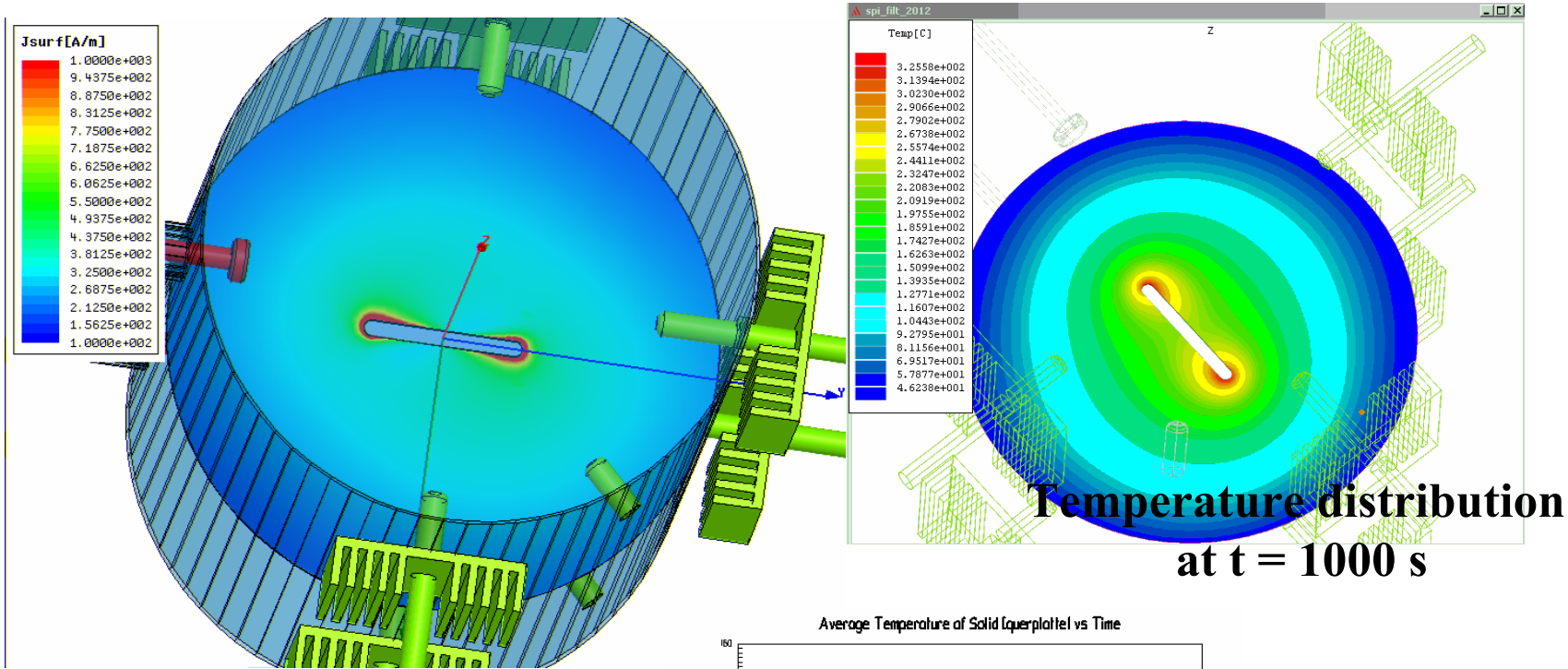


High Power Handling HF (760 MHz) filters

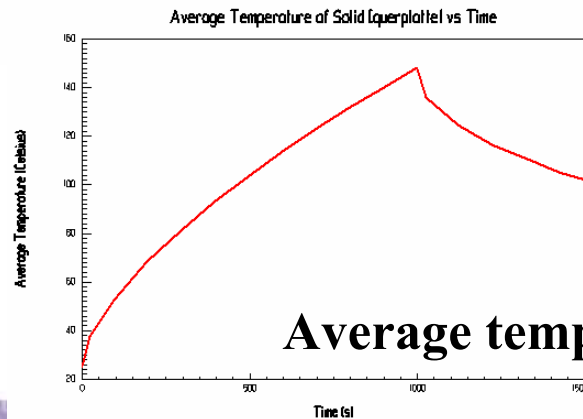


Outer body temperature distribution

760 MHz Filter, High Power Input (KW range)



Surface current density distribution calculated by HFSS

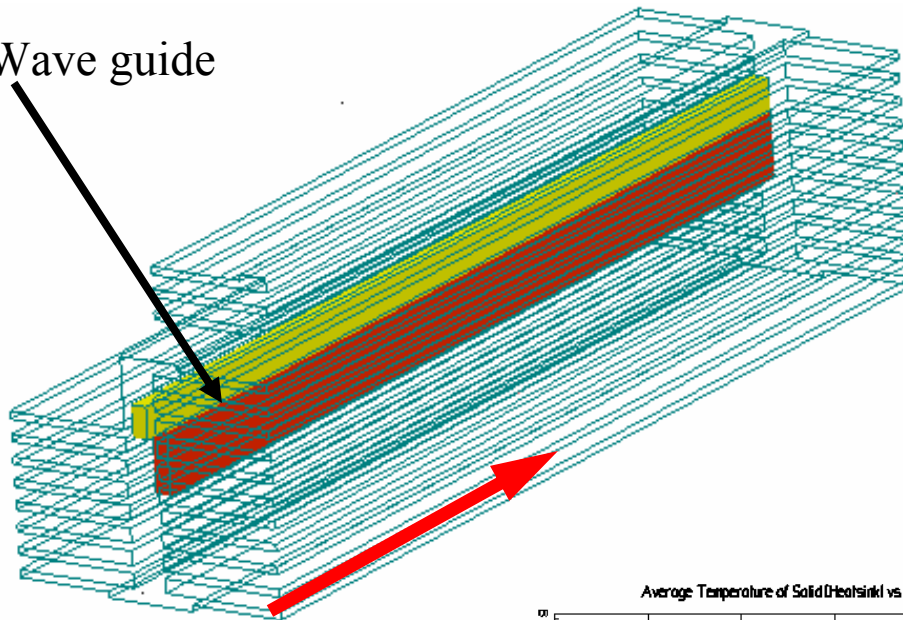


Average temperature of mid-plate

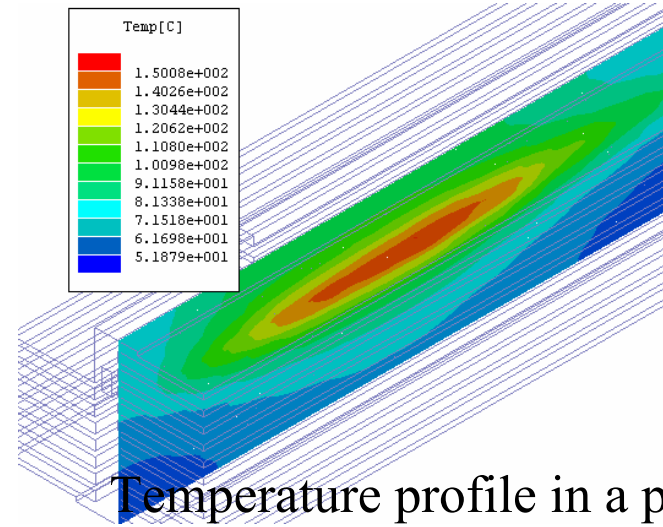
Microtech Model

Very good match with experimental data!

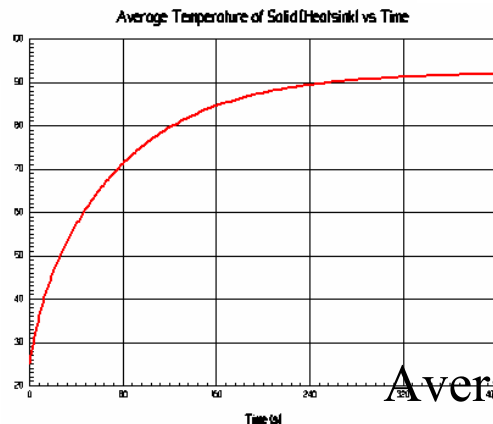
Wave guide



Air velocity = 76 m/s

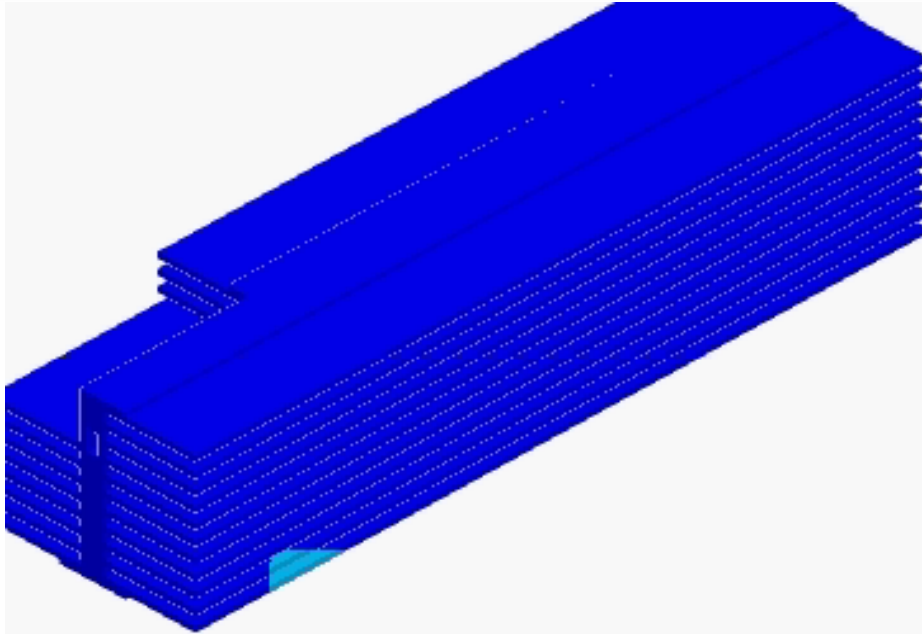


Temperature profile in a plane containing the "hot spot"



Average heat-sink temperature

Microtech Model



Procedure to calculate forced convection coefficient

- Calculate specific CFD numbers:

- Reynolds number
- Nusselt number

Fluid velocity

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

Laminar flow

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

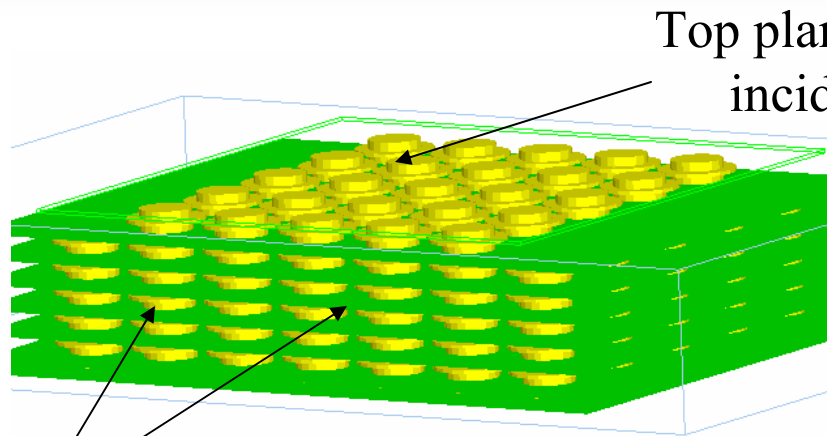
Mixed flow

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

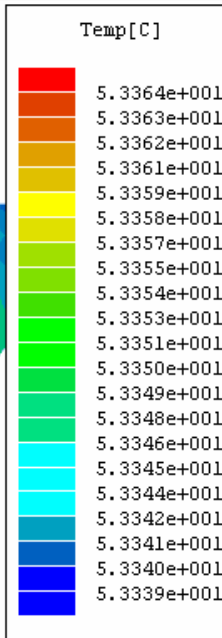
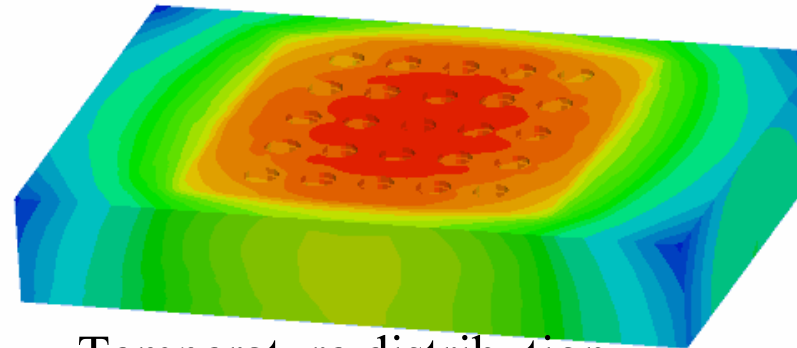
- Calculate convection coefficient

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

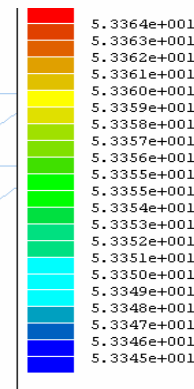
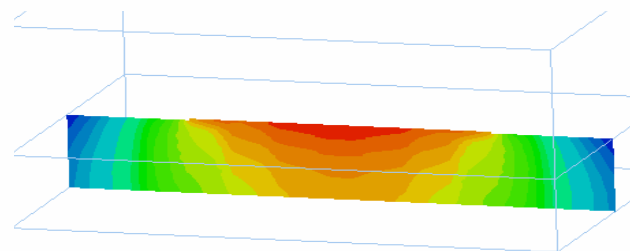
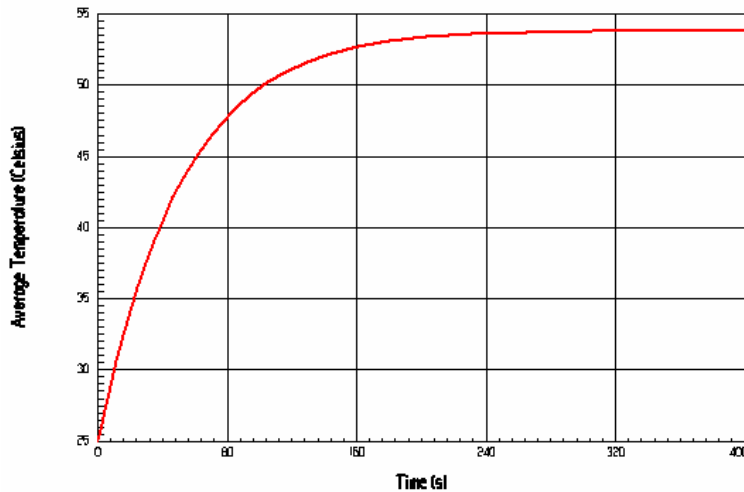
IC structure in HF incident field



Metal ground planes & vias imbedded in ceramic block



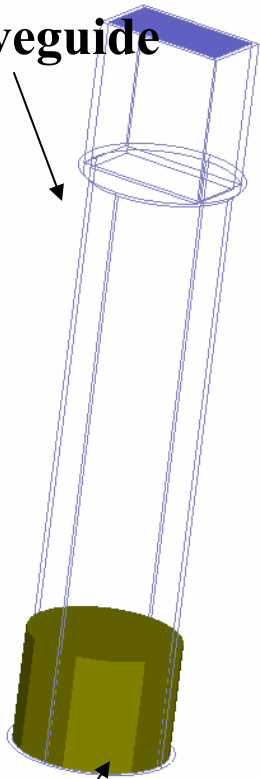
Average Temperature of Solid [Ceramic_Block] vs Time



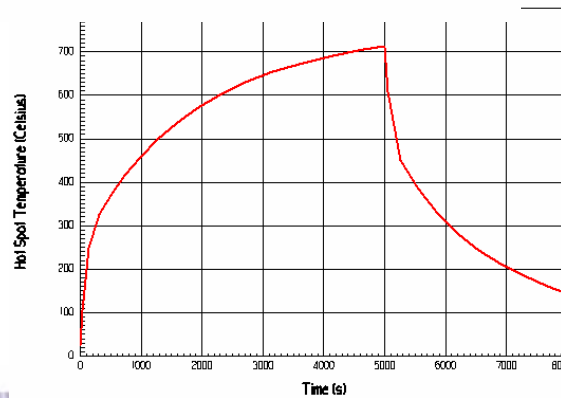
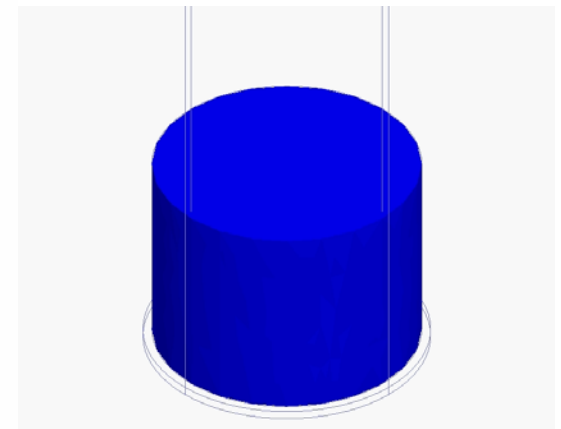
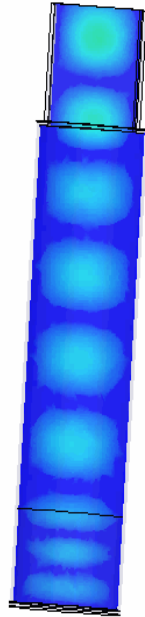
Microwave Heating Industrial Size Applicator

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

