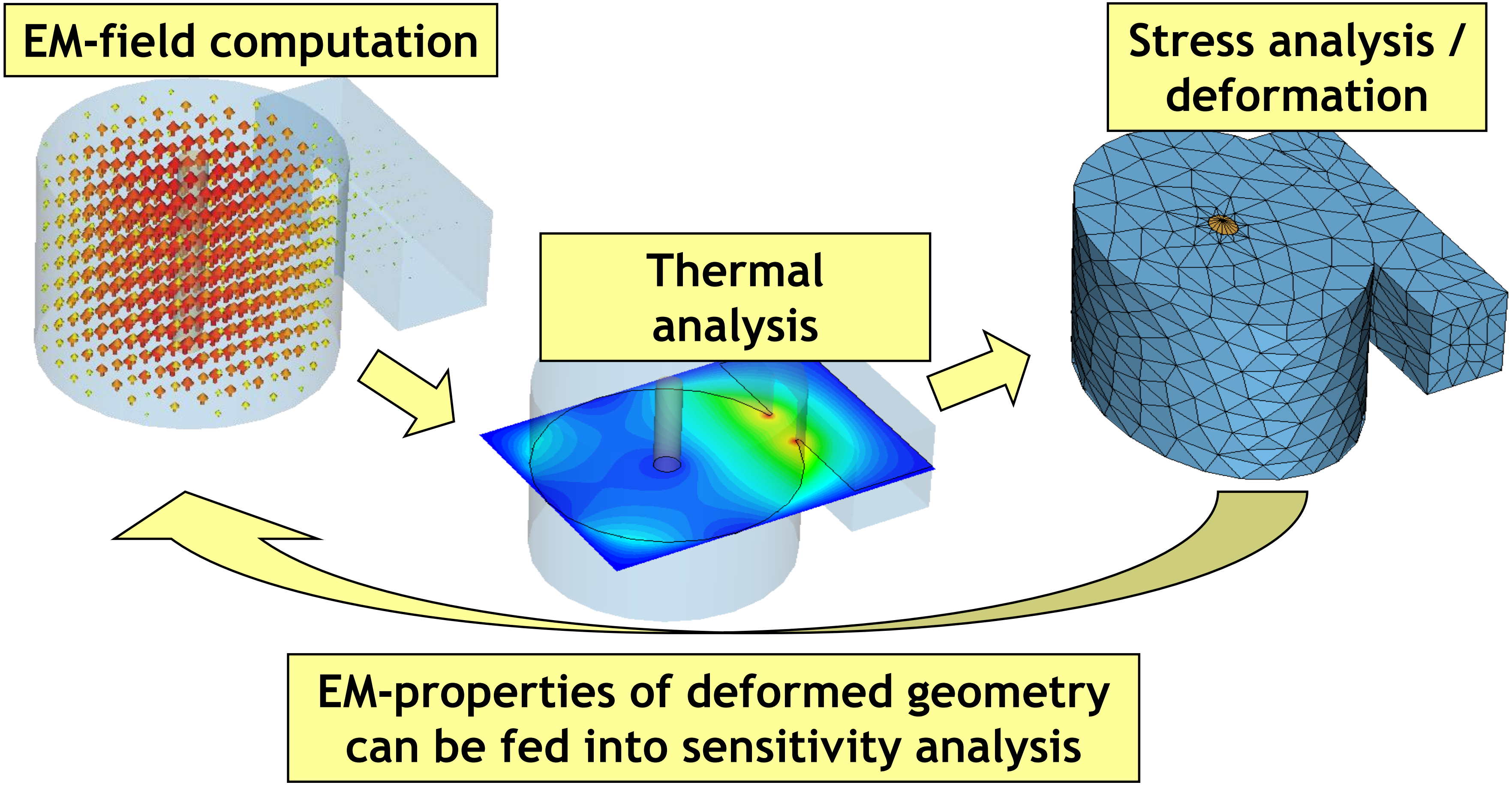
A Glimpse into Multiphysic-Analyses using CST STUDIO SUITE™

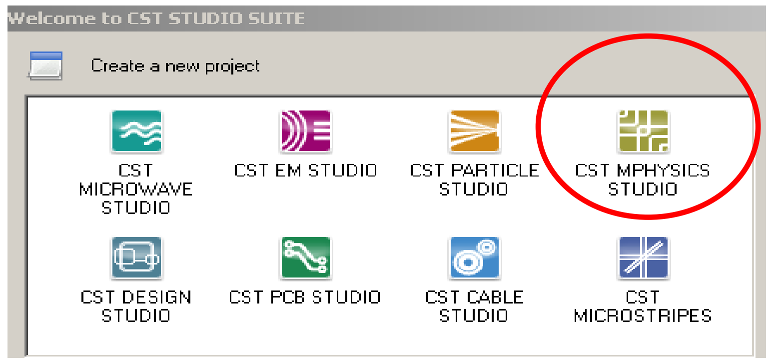
Accounting for thermal heating effects and mechanical deformation in the electrical design

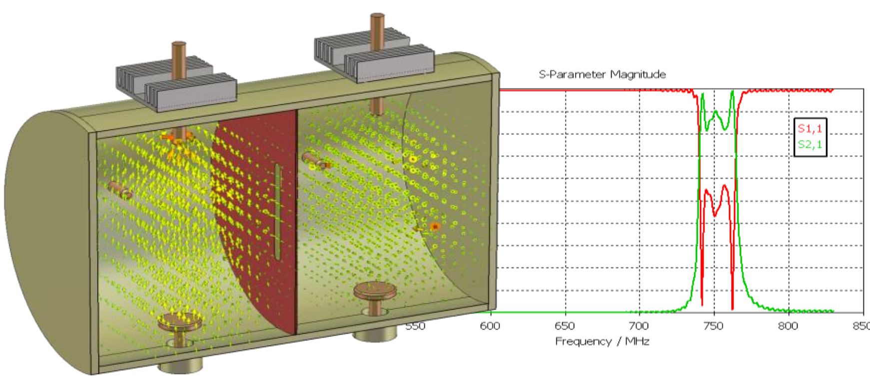
The Motivation …

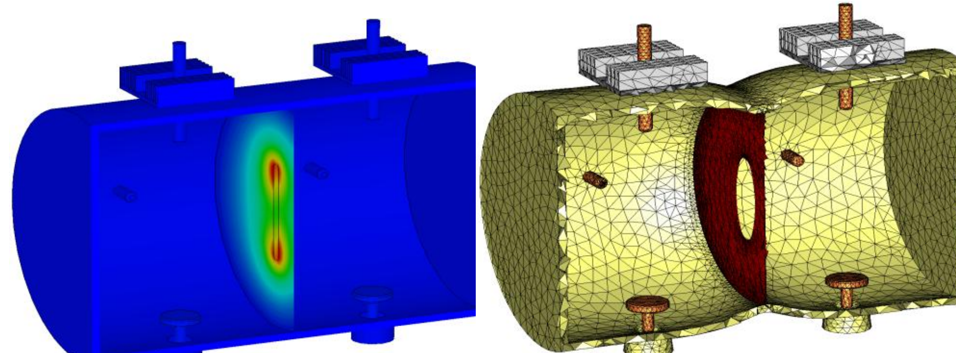


CST MPHYSICS STUDIO™

- Thermal Simulation
- Mechanical Stress Simulation



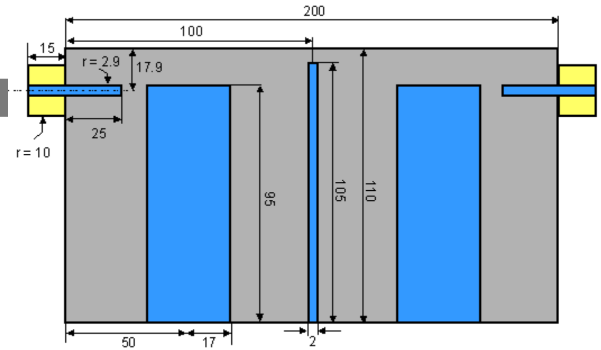


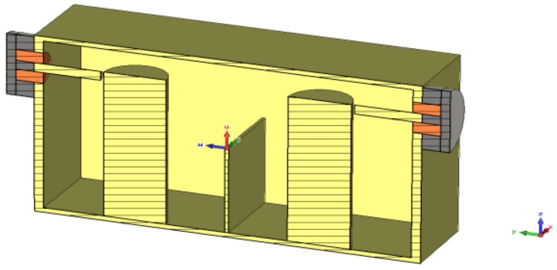


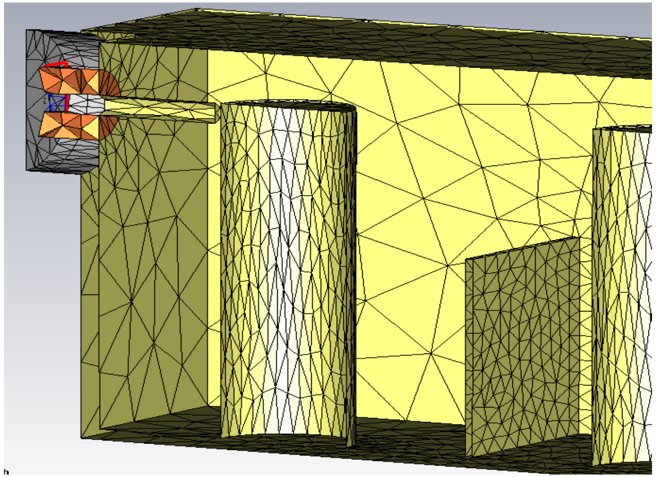
Courtesy of Spinner GmbH, Germany

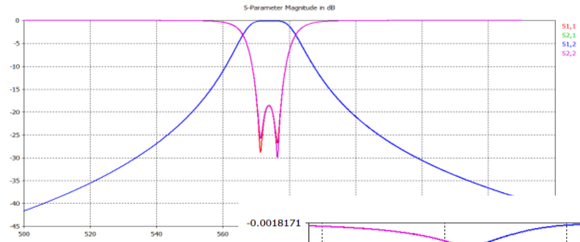
Online Demo

Example : 2-Post Bandpass Filter

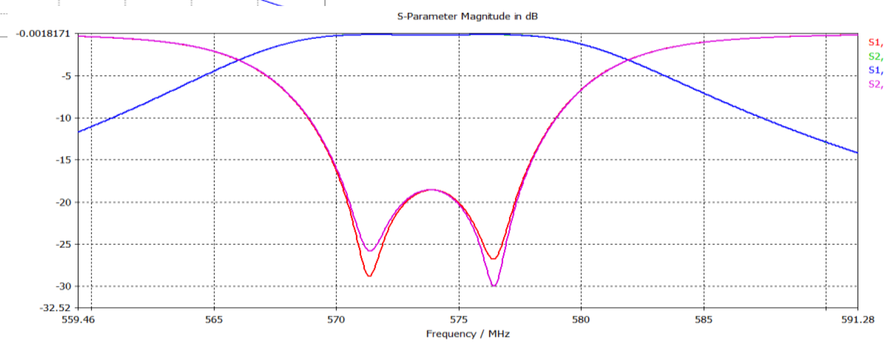




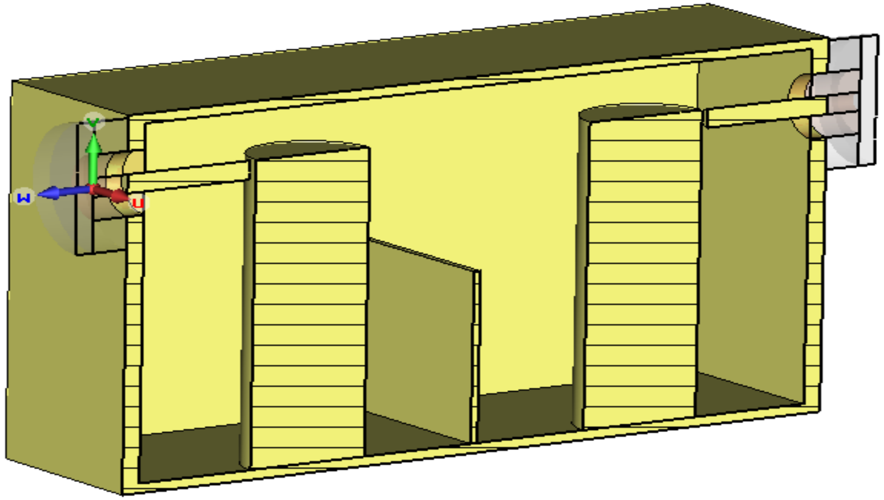




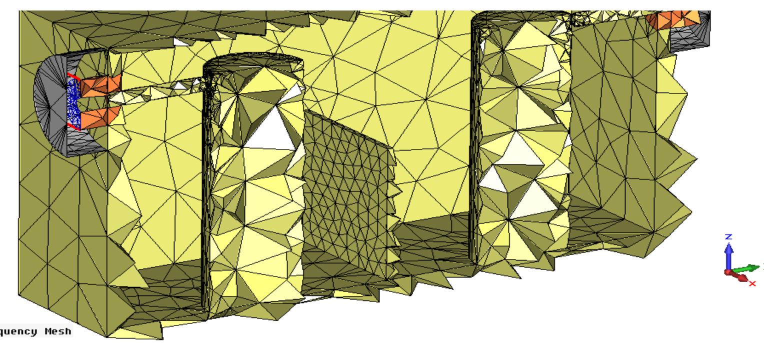
Rel Bandwidth:0.9 %



1) EM (FD tet)



Material	brass
Type	Normal
Epsilon	1
Mue	1
El. cond.	1e+007 [S/m]
Therm.cond.	30 [W/K/m]
Young's Mod.	100 [kN/mm^2]
Poiss.Ratio	0.34
Thermal Exp.	15 [1e-6/K]



Type High Frequency Mesh

1D Results > |S| dB

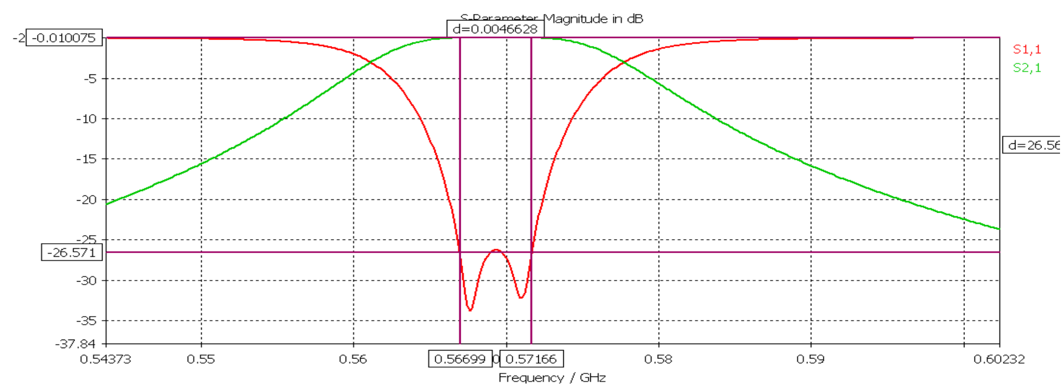
Tchebychev Filter
====================

Order = 2
Bandwidth = 5 MHz
Center Frequency = 570 MHz
Passband ripple = 0,01 dB (1,100747 VSWR)
Return loss = -26,3828 dB

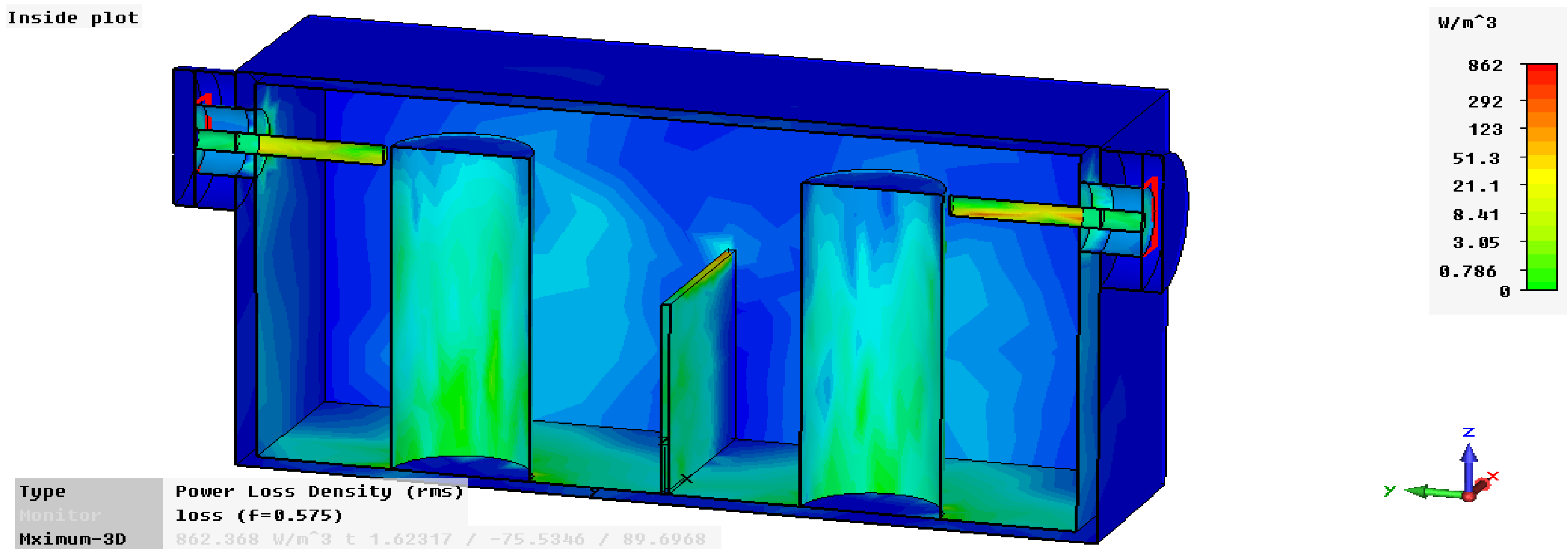
Normed g values:
----
g1 = 0,4489
g2 = 0,4078
g3 = 1,1008

Corresponding coupling coefficients in MHz / (rel):
----
k_E = 11,14 (0,0195413)
k1_2 = 11,69 (0,0205021)
k_out = 11,14 (0,0195413)

Group Delay Time
----
t_d1 = 57,153 ns
t_d2 = 51,922 ns
t_d3 = 0, ns

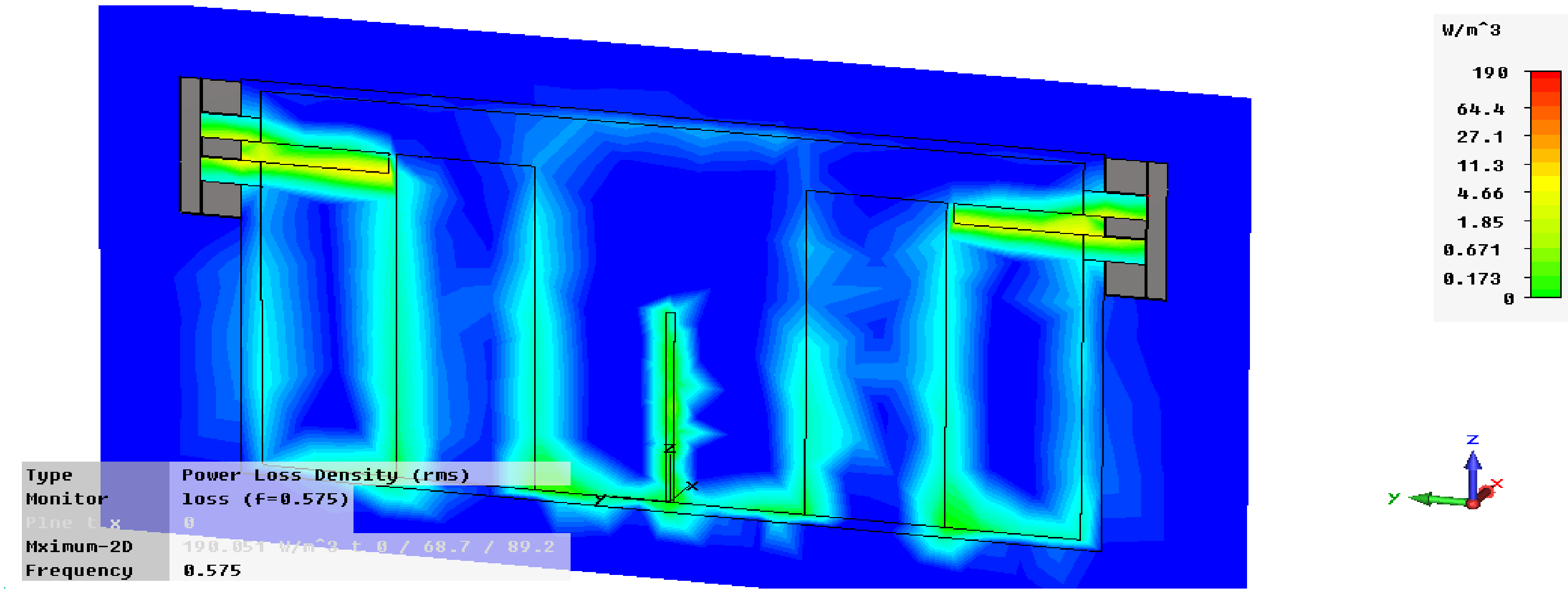


Power Loss Dens. > loss (f=0.575)

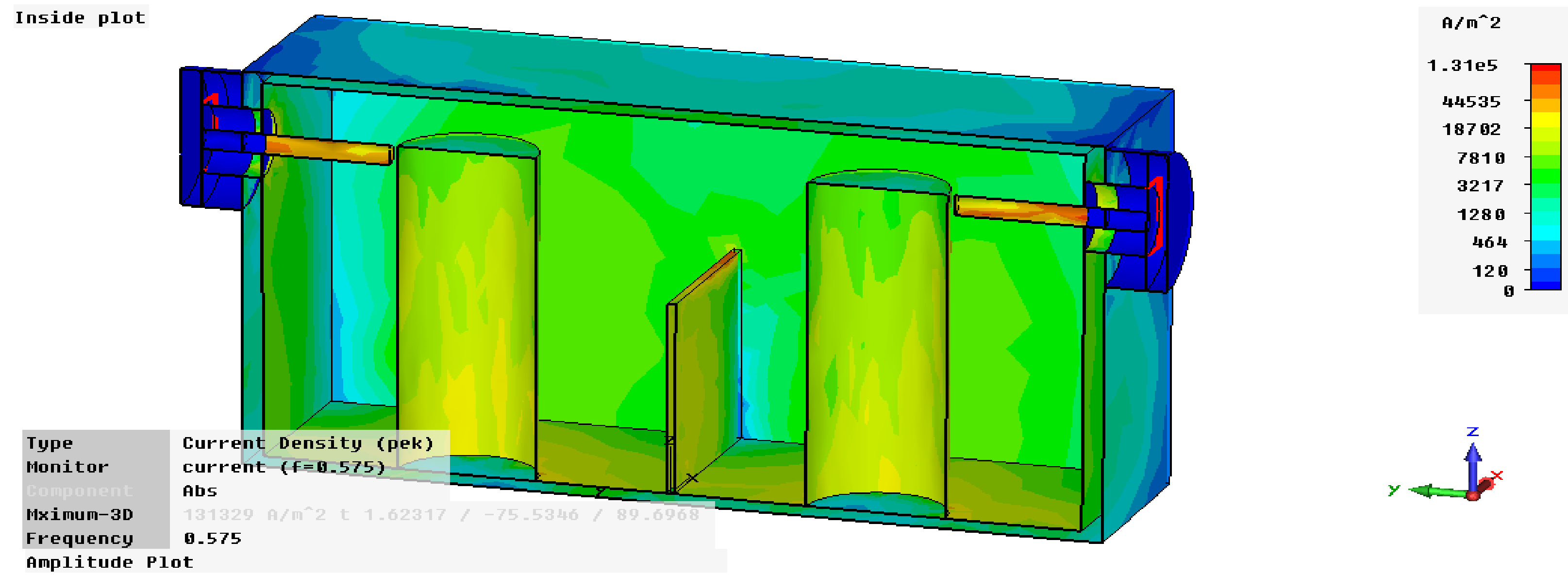


Type	Power Loss Density (rms)
Monitor	loss (f=0.575)
Mximum-3D	862.368 W/m^3 t 1.62317 / -75.5346 / 89.6968
Frequency	0.575

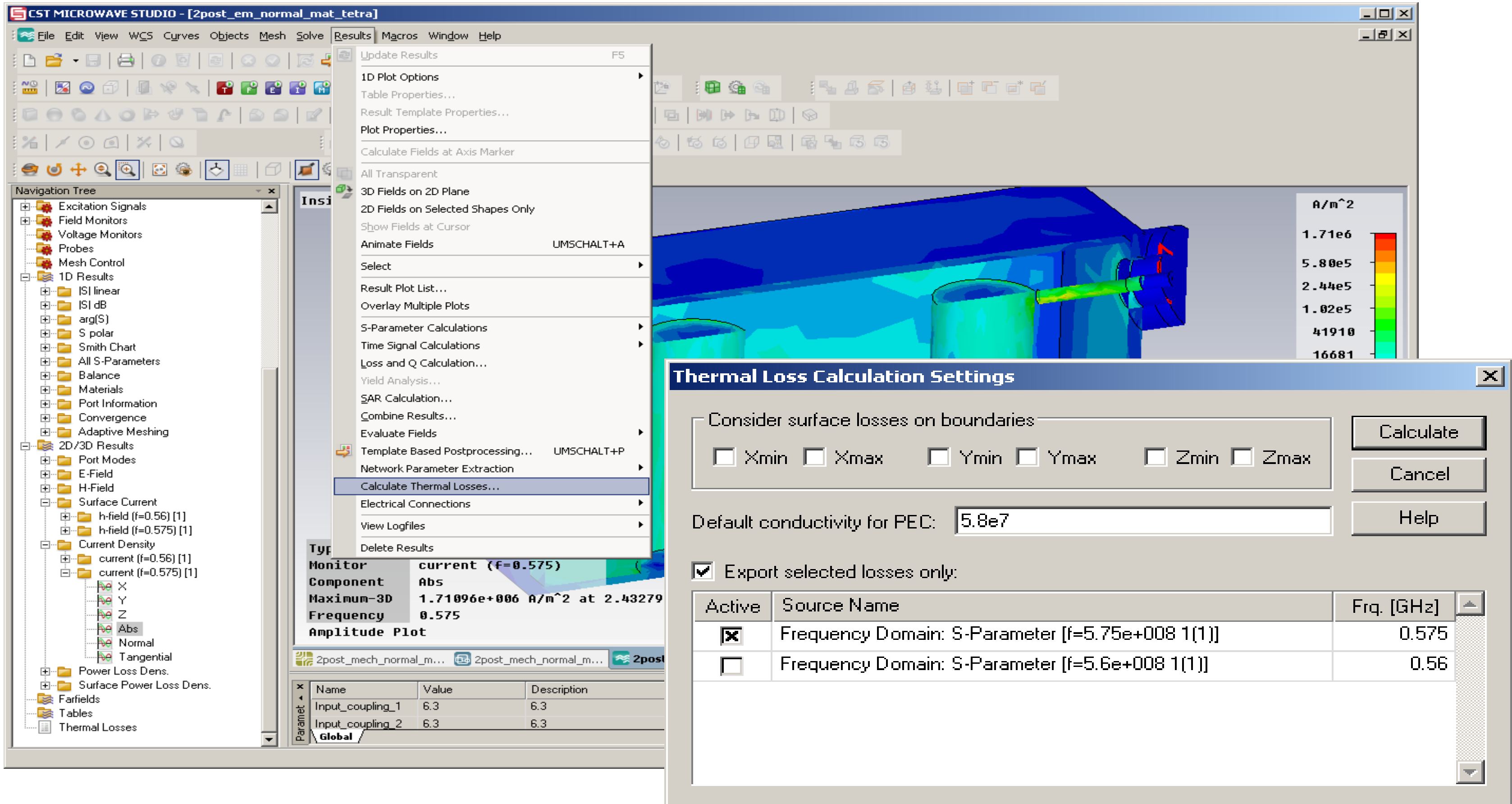
Power Loss Dens. > loss (f=0.575)



Current Density (f=0.575)

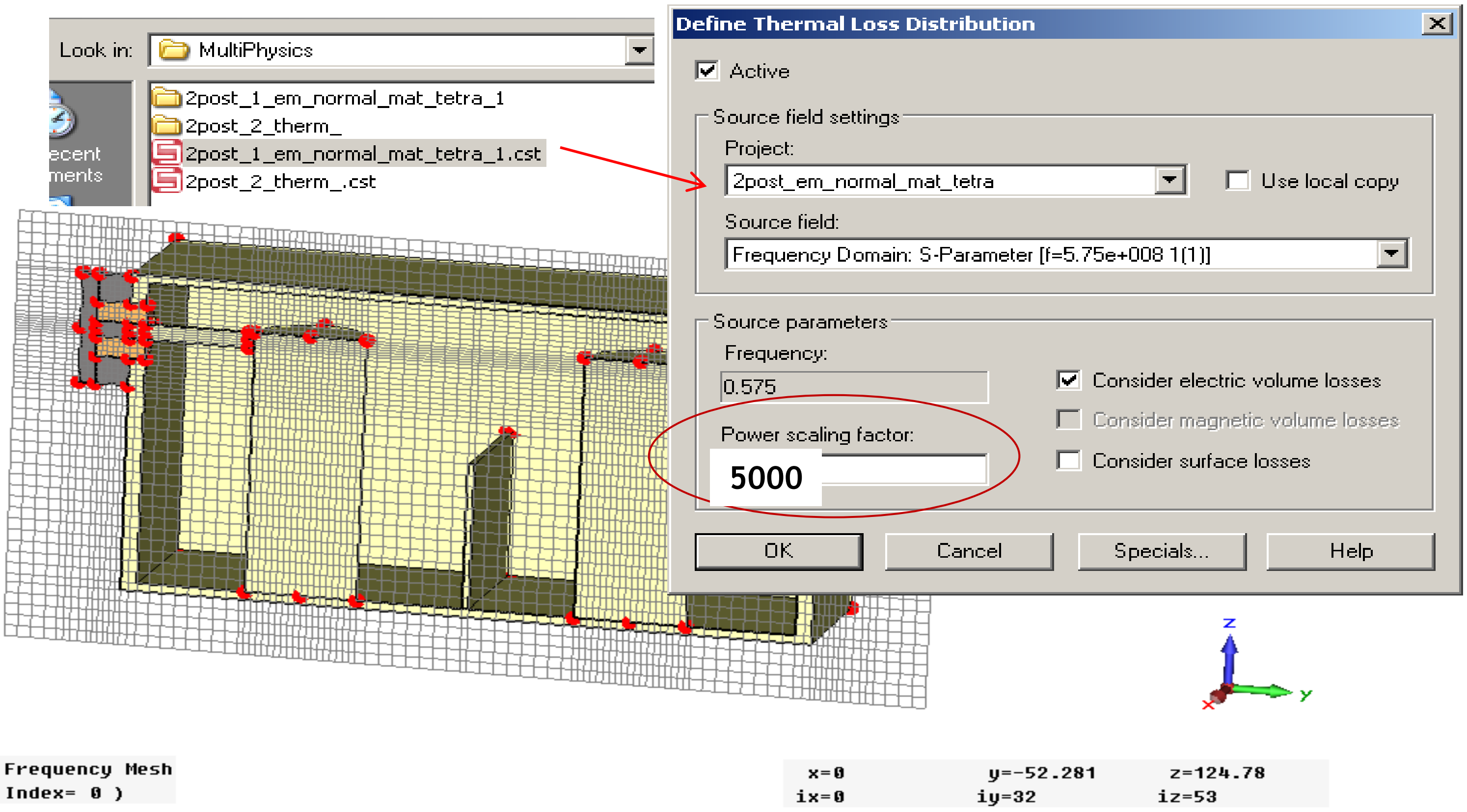


Export the Thermal losses



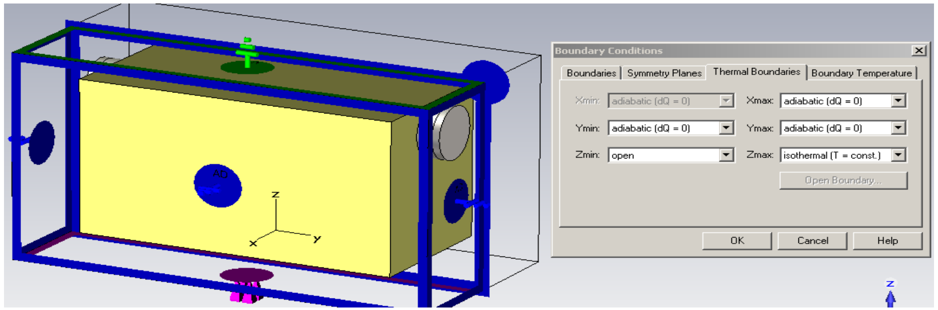
2) Thermal Solver

Import the losses from EM FD

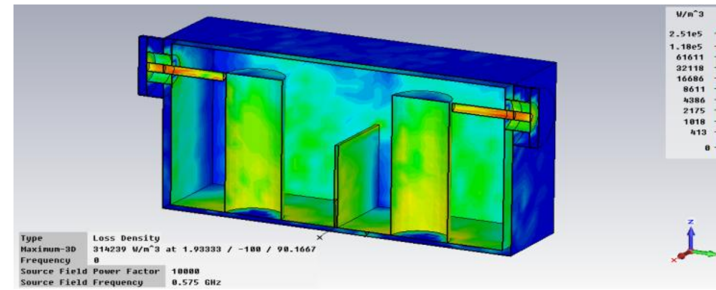


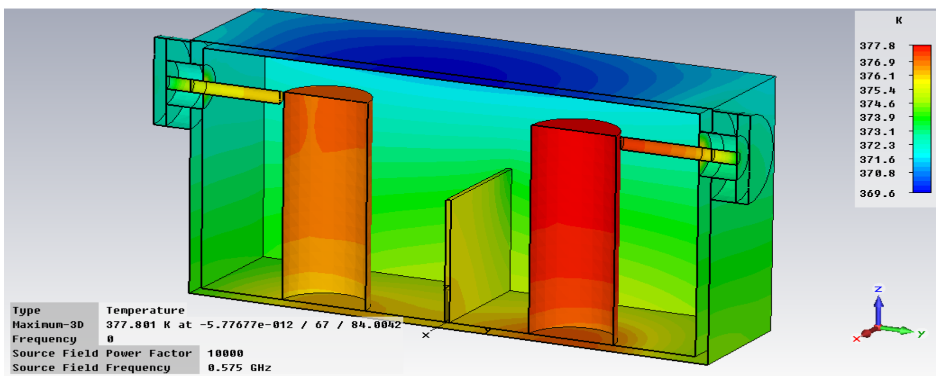
Thermal boundaries

Thermal boundaries

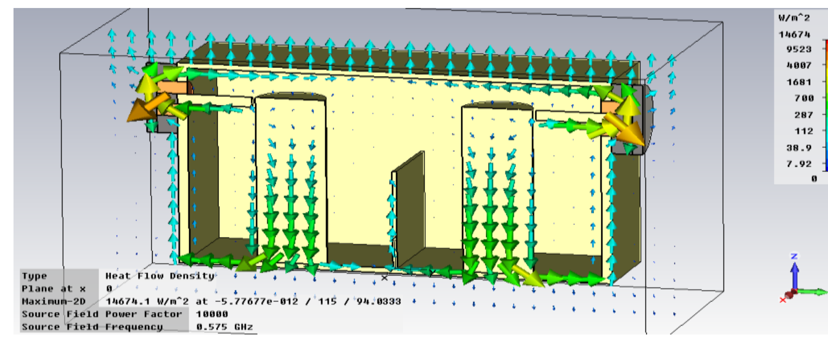


Thermal volume losses as source





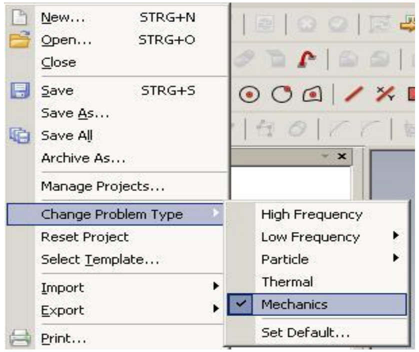
Temperature

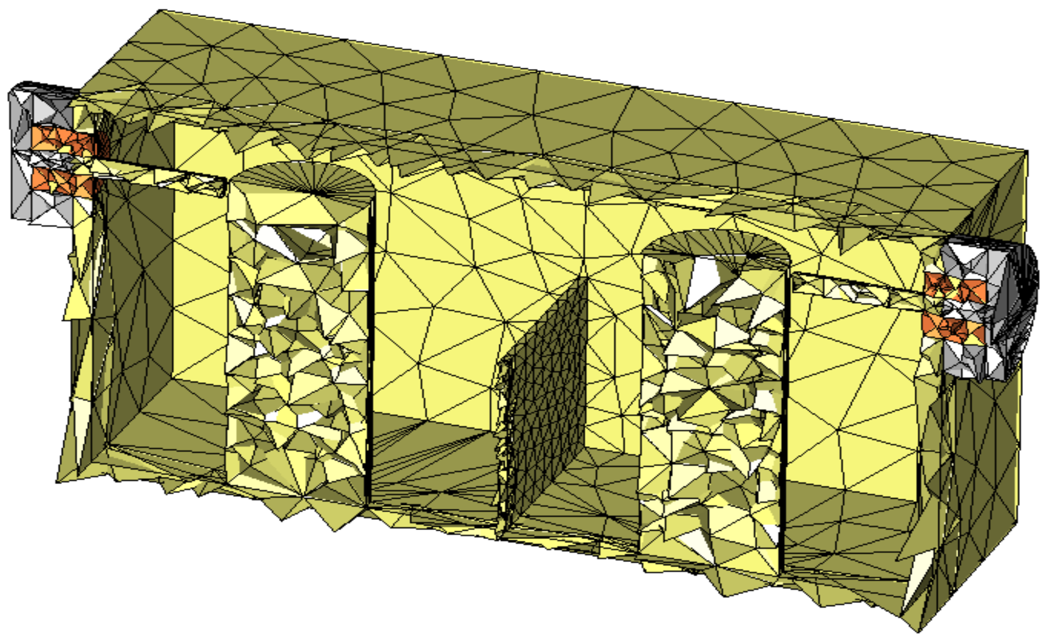


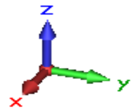
Heat flow

3) Mechanical Solver

$$\cancel{[M][\ddot{x}]}+\cancel{[B][\dot{x}]}+[K][x]=[F]$$







Type Mechanics Mesh

http://www.engineeringtoolbox.com/young-modulus-d_417.html

Strain

Strain can be expressed as

strain = dL / L (1)

where

strain = (m/m) (in/in)

dL = elongation or compression (offset) of the object (m) (in)

L = length of the object (m) (in)

Stress

Stress can be expressed as

stress = F / A (2)

where

stress = (N/m^2) $(lb/in^2, psi)$

F = force (N) (lb)

A = area of object (m^2) (in^2)

Young's Modulus (Tensile Modulus)

Young's modulus or Tensile modulus can be expressed as

E = stress / strain = (F / A) / (dL / L) (3)

where

E = Young's modulus (N/m^2) $(lb/in^2, psi)$

$\sigma = \varepsilon . E$

To describe elastic properties of linear objects like wires, rods, or columns which are stretched or compressed, a convenient parameter is the ratio of the stress to the strain, a parameter called the "*Young's modulus*" or "*Modulus of Elasticity*" of the material. Young's modulus can be used to predict the elongation or compression of an object as long as the stress is less than the yield strength of the material.

Material	Young's Modulus (Modulus of Elasticity) - *E* - $(10^6$ psi)	Young's Modulus (Modulus of Elasticity) - *E* - $(10^9$ N/m^2, GPa)	Ultimate Tensile Strength - S_u - $(10^6$ N/m^2, MPa)	Yield Strength - S_y - $(10^6$ N/m^2, MPa)
ABS plastics		2.3	40	
Acrylic		3.2	70	
Aluminum	10.0	69	110	95
Antimony	11.3			
Beryllium	42			
Bismuth	4.6			
Bone		9	170 (compression)	
Boron				3100
Brasses		100 - 125	250	
Bronzes		100 - 125		
Cadmium	4.6			
Carbon Fiber Reinforced Plastic		150		
Cast Iron 4.5% C, ASTM A-48			170	
Chromium	36			
Cobalt	30			
Concrete, High Strength (compression)		30	40 (compression)	
Copper	17		220	70
Diamond		1,050 - 1,200		
Douglas fir Wood		13	50 (compression)	
Steel, Structural ASTM-A36		200		

1 GPa = 1kN/mm2

- $1\ N/m^2 = 1 \times 10^{-6}\ N/mm^2 = 1\ Pa = 1.4504 \times 10^{-4}\ psi$
- $1\ psi\ (lb/in^2) = 144\ psf\ (lb_f/ft^2) = 6{,}894.8\ Pa\ (N/m^2) = 6.895 \times 10^{-3}\ N/mm^2$

Poisson's ratio

From Wikipedia, the free encyclopedia

Poisson's ratio (***ν***), named after Siméon Poisson, is the ratio, when a sample object is stretched, of the contraction or transverse strain (perpendicular to the applied load), to the extension or axial strain (in the direction of the applied load).

When a sample cube of a material is stretched in one direction, it tends to contract (or occasionally, expand) in the other two directions perpendicular to the direction of stretch. Conversely, when a sample of material is compressed in one direction, it tends to expand (or rarely, contract) in the other two directions. This phenomenon is called the **Poisson effect**. Poisson's ratio *ν* (nu) is a measure of the Poisson effect.

The Poisson's ratio of a stable, isotropic, linear elastic material cannot be less than −1.0 nor greater than 0.5 due to the requirement that the elastic modulus, the shear modulus and bulk modulus have positive values [1]. Most materials have Poisson's ratio values ranging between 0.0 and 0.5. A perfectly incompressible material deformed elastically at small strains would have a Poisson's ratio of exactly 0.5. Most steels and rigid polymers when used within their design limits (before yield) exhibit values of about 0.3, increasing to 0.5 for post-yield deformation (which occurs largely at constant volume.) Rubber has a Poisson ratio of nearly 0.5. Cork's Poisson ratio is close to 0: showing very little lateral expansion when compressed. Some materials, mostly polymer foams, have a negative Poisson's ratio; if these auxetic materials are stretched in one direction, they become thicker in perpendicular directions. While anisotropic materials can as well have Poisson ratios in some directions above 0.5.

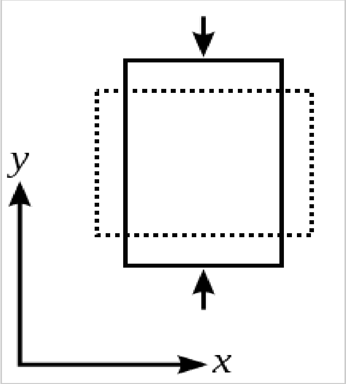


Figure 1: Rectangular specimen subject to compression, with Poisson's ratio circa 0.5

Assuming that the material is compressed along the axial direction:

$$\nu = -\frac{\varepsilon_{\mathrm{trans}}}{\varepsilon_{\mathrm{axial}}} = -\frac{\varepsilon_{\mathrm{x}}}{\varepsilon_{\mathrm{y}}}$$

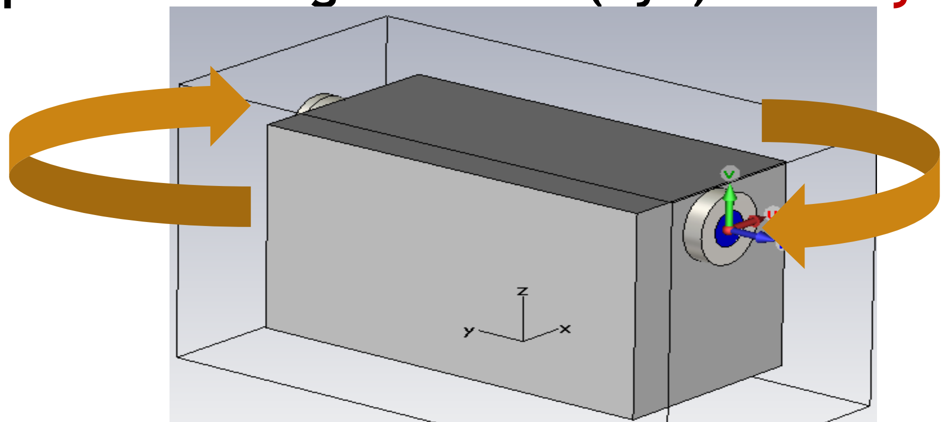
where

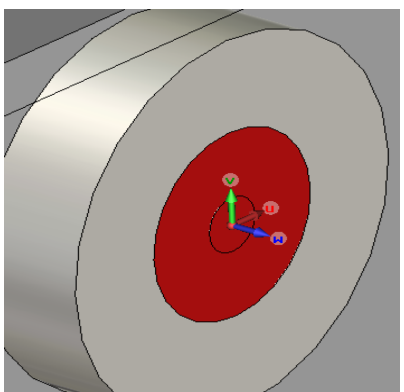
- ν is the resulting Poisson's ratio,
- $\varepsilon_{\mathrm{trans}}$ is transverse strain (negative for axial tension, positive for axial compression)
- $\varepsilon_{\mathrm{axial}}$ is axial strain (positive for axial tension, negative for axial compression).

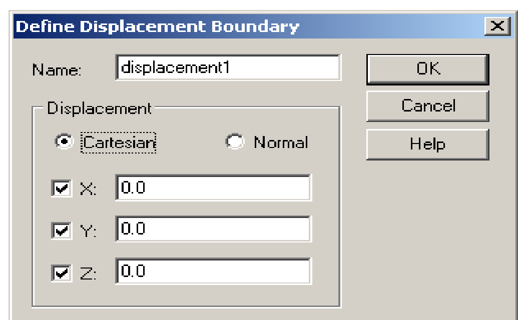
material	poisson's ratio
rubber	~ 0.50
gold	0.42
saturated clay	0.40-0.50
magnesium	0.35
titanium	0.34
copper	0.33
aluminium-alloy	0.33
clay	0.30-0.45
stainless steel	0.30-0.31
steel	0.27-0.30
cast iron	0.21-0.26
sand	0.20-0.45
concrete	0.20
glass	0.18-0.3
foam	0.10 to 0.40
cork	~ 0.00

Displacements > displacement1

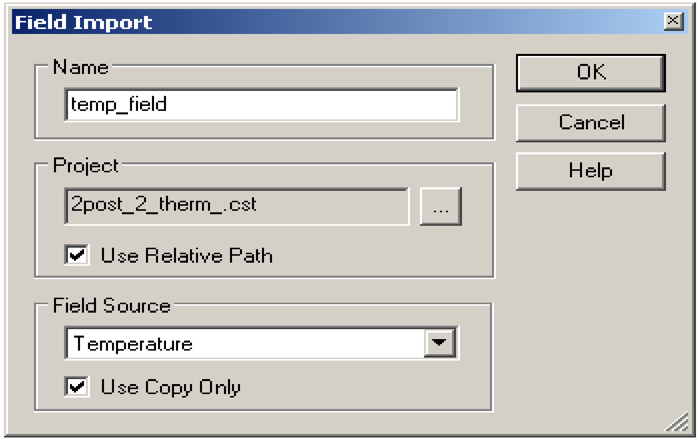
Define a displacement eg at a face (xyz) directly at the WG-Port

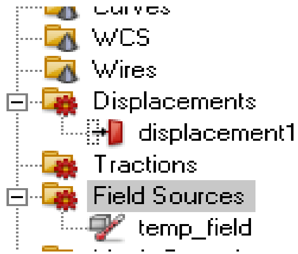


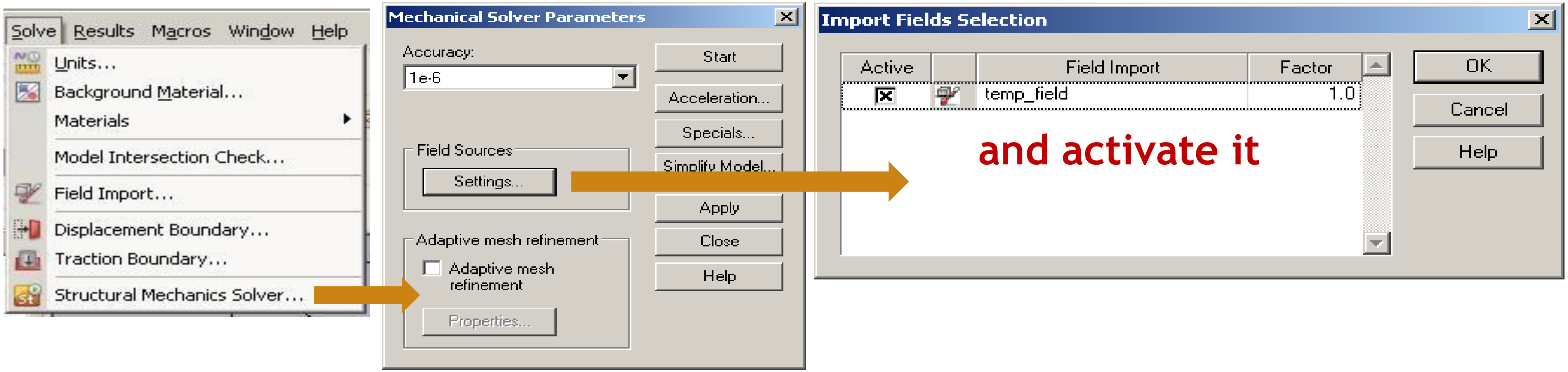




Import a field source (from therm),

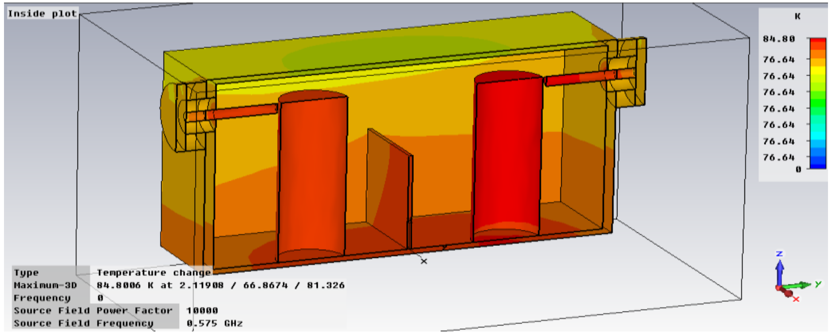




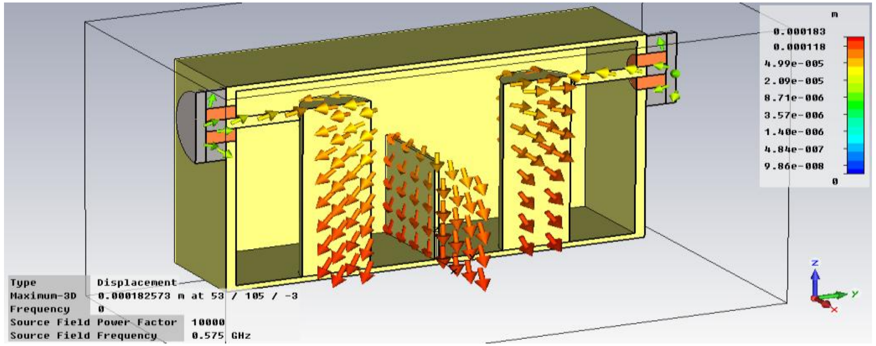


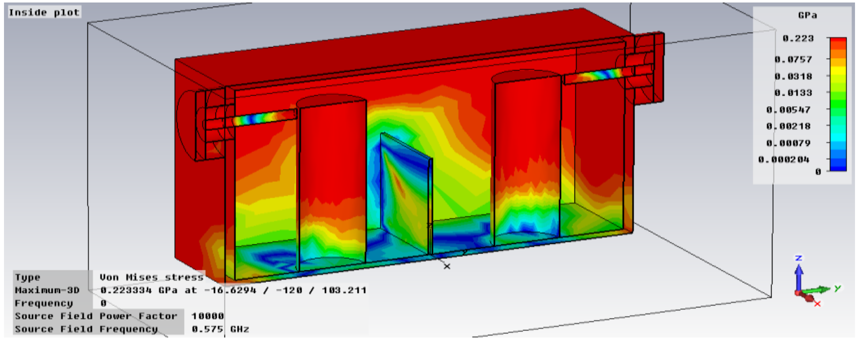
2D/3D Results > Displacement

Temperature change as source

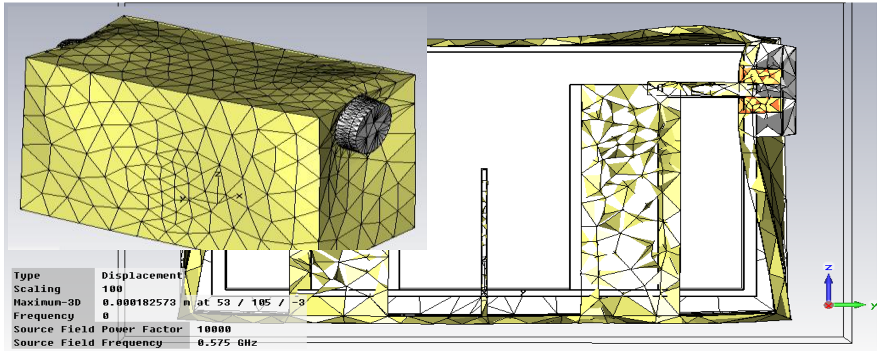


Mech. Displacements





Von Mises Stress

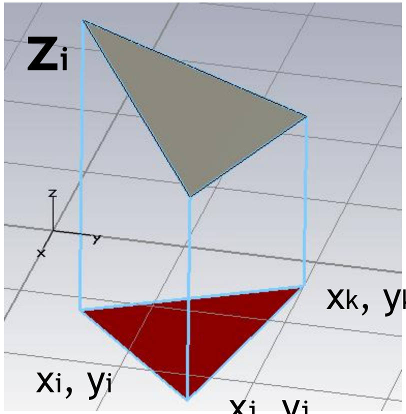


Deformed Mesh

4) Sensitivity (Introduction)

Matrix to solve: $[K]\{E\}=\{Q\}$

[K]: symmetric, complex, contains geometry, material, frequency



Example: Linear Shape functions for a 2D element in xy

$$[N]=-\frac{1}{2\Delta}[1,x,y]\begin{bmatrix} a_i & a_j & a_k \\ b_i & b_j & b_k \\ c_i & c_j & c_k \end{bmatrix}; a_{ijk}=x_j y_k - y_j x_k; b_{ijk}=y_j-y_k; c_{ijk}=x_k-x_j$$

$$z=[N_i,N_j,N_k]\begin{Bmatrix} z_i \\ z_j \\ z_k \end{Bmatrix}$$

Example: electrostatic

$$k_{m,n}=\iint_{xy}(\varepsilon_x \frac{\partial N_m}{\partial x}\frac{\partial N_n}{\partial x}+\varepsilon_y \frac{\partial N_m}{\partial x}\frac{\partial N_n}{\partial x})dxdy; m,n=i,j,k$$

[E]: unkowns z

[Q]: Sources

Introduction to Sensitivity

S-Parameters:

3D Fieldsolution

$$S(\omega, p) = \frac{1}{-j\omega\mu_0} E^T(\omega, p) K^T(\omega, p) E(\omega, p)$$

[K] …left hand side, E (Fields at ports, p… any parameter

Sensitivity of S-parameter vs. parameter change:

$$-j\omega\mu_0 \frac{\partial S}{\partial p} = E^T \frac{\partial K}{\partial p} E$$

Same 3D Fieldsolution

Direct analytical derivation of K-matrix elements via e.g. [N]

Introduction to Sensitivity

Numerical calculation of gradients is expensive and unstable

Here: Sensitivity of S-parameter vs. parameter change

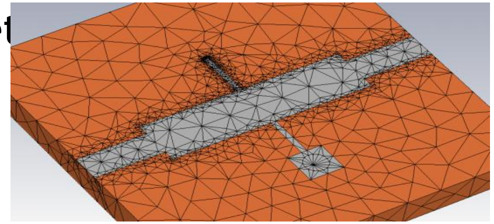
$$-j\omega\mu_0 \boxed{\frac{\partial S}{\partial p}} = E^T \frac{\partial K}{\partial p} E$$

no additional 3D solution required (only another S-Parameter computation)

Very efficient computation of sensitivities

Result: S-parameter ranges for tolerant paramet

Currently available for FD-Tet solver



Introduction to Sensitivity

What is it good for?

- The sensitivity helps estimate „new“ S-parameters due to the (small) change of the parameter, at no extra cost

  Suppose the parameter *p* changes by a quantity Δ*p* :

$$S(x+\Delta p) \approx S(x) + \sum_p \frac{\partial S}{\partial p} . \Delta p$$

exact computation of the Sensitivity

(Approximated by 1st order Taylor expansion)

- The various sensitivities are used in an optimizer to solve for Δp as variables to best fit the S-parameter goals.

$$S_{nm} \Leftarrow S_{nm(3D-MWS)} + \sum_p \frac{\partial S}{\partial p} . \Delta p$$

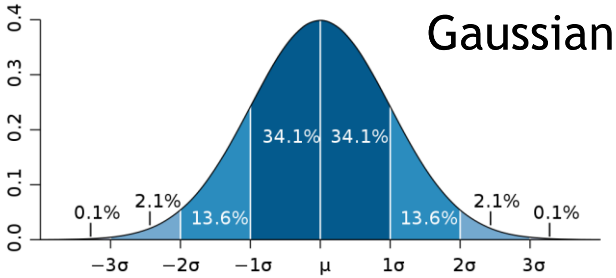
Δp … face constraints

What is the Yield Analysis

For every product, there are:

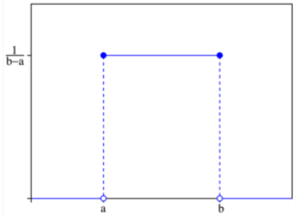
- Technical specifications
- Fabrication tolerances

Gaussian

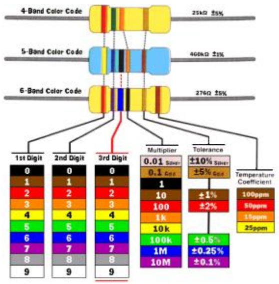


The fabrication tolerances will lead to some products not fulfilling the specifications

Uniform



Yield: $$yield = \frac{\#Passed}{\#Total}$$



Typical Approach vs. CST Approach

How is yield calculated typically?

- Parameters vary according to a known probability curve
- Repeat
  - Change the value of all parameters
  - Simulate
  - Check if specification (in our case for S-params.) is met
- Until the number of simulations is statistically relevant

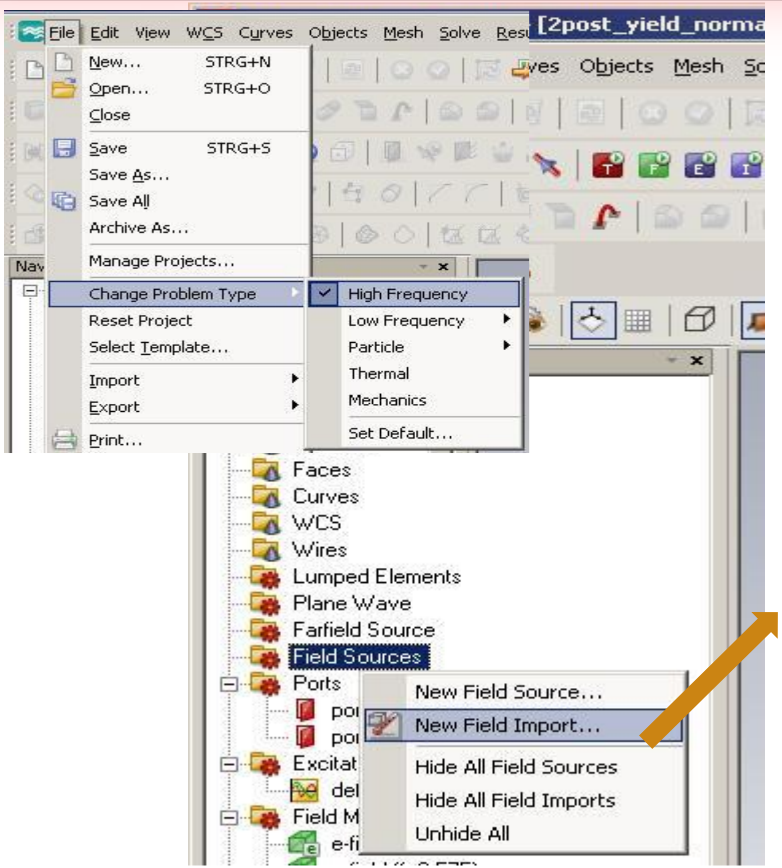
This is a large number of EM simulations - typicaly hundreds or thousands!!!

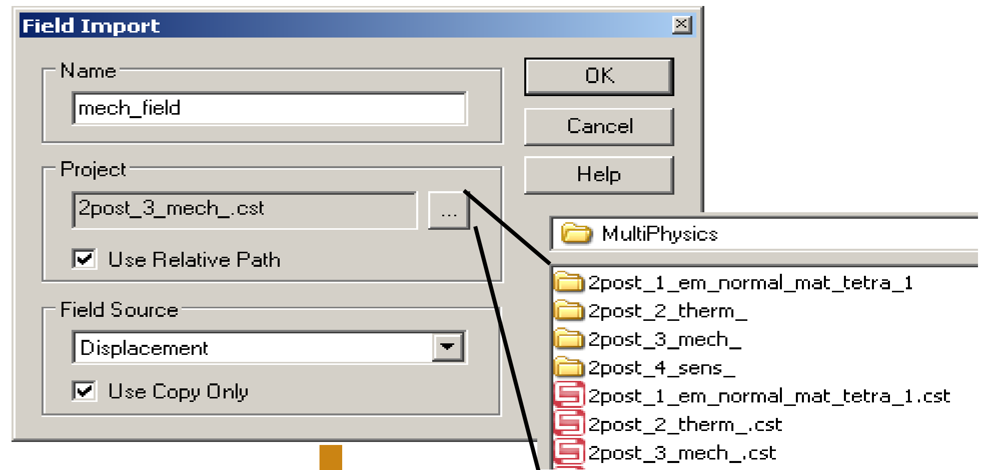
Knowing the sensitivity, there is no need to perform 3D simulations, at least if the parameters vary in a small range.

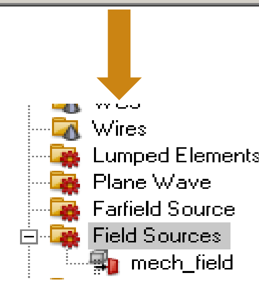
The efficiency of this new sensitivity analysis approach makes Monte-Carlo based yield analysis feasible even for complex multi-parametrical three-dimensional structures

4) Sensitivity (based on mech. Displacements)

Import the displacements

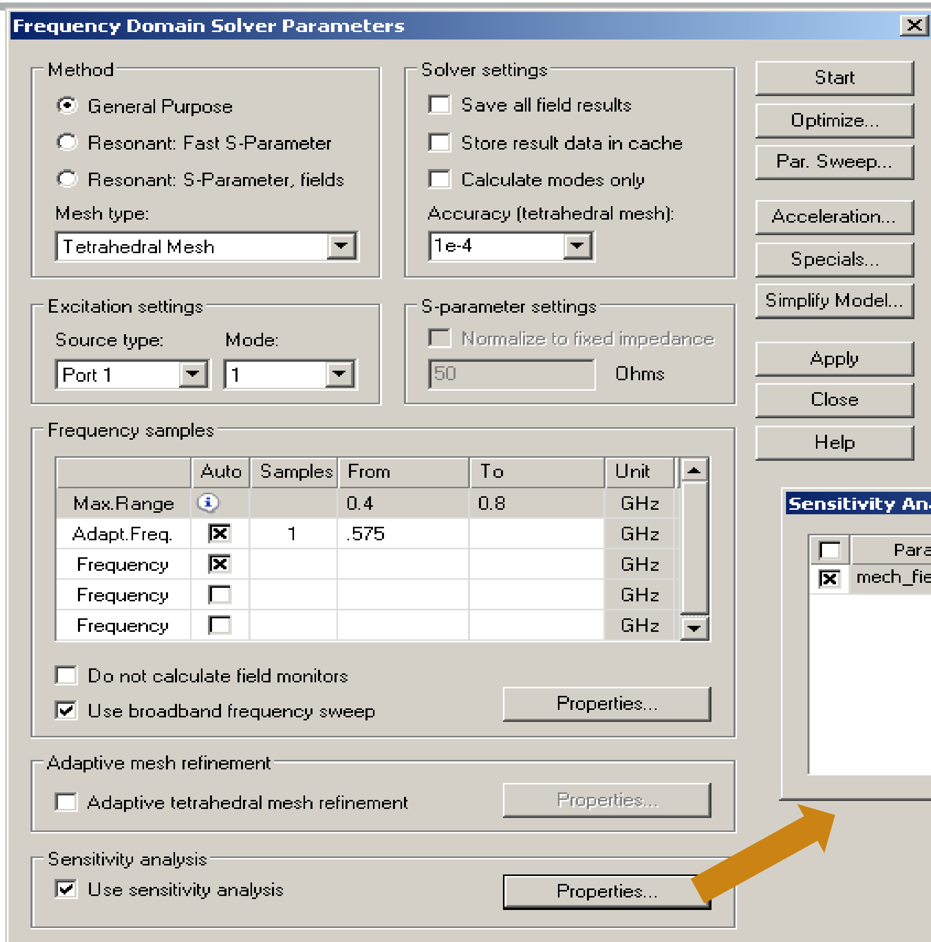


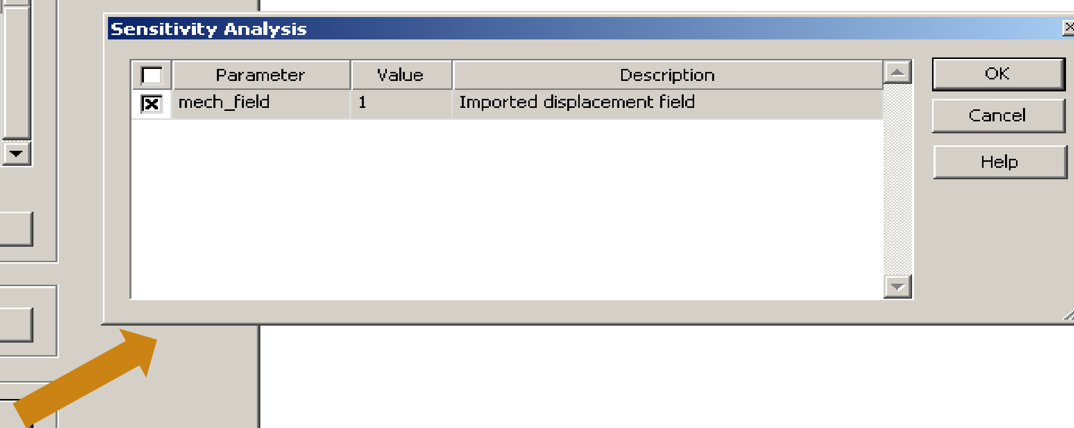




4) Sensitivity

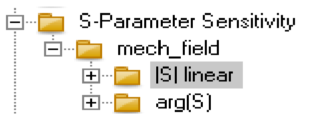
Setup Sensitivity Analysis

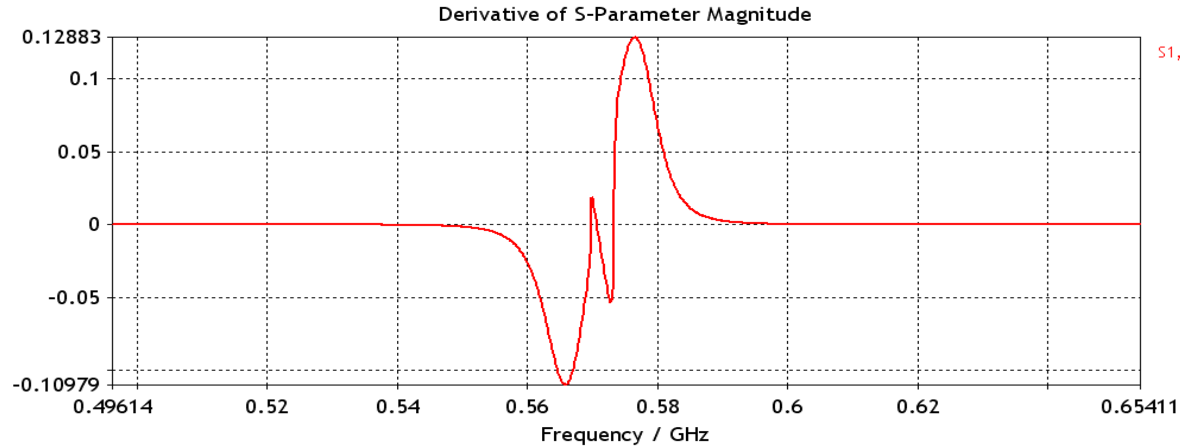


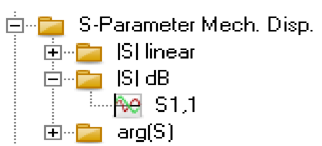


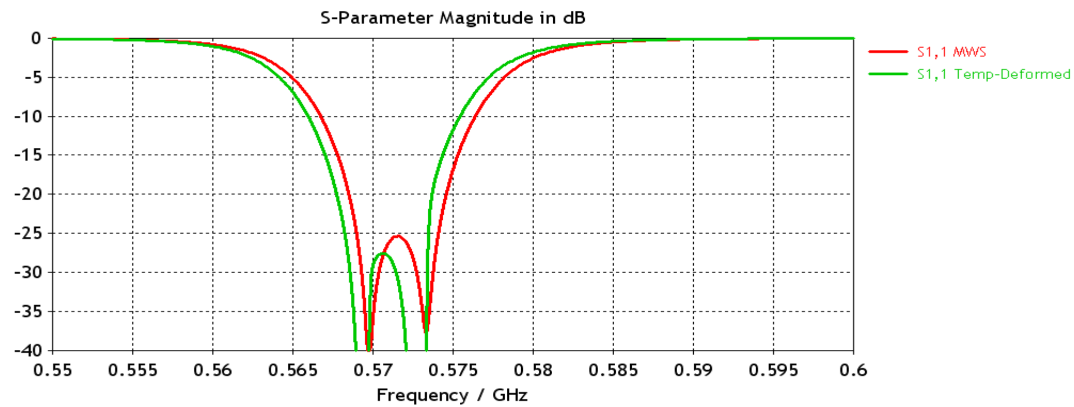
4) Sensitivity

Display S-parameter Sensitivity



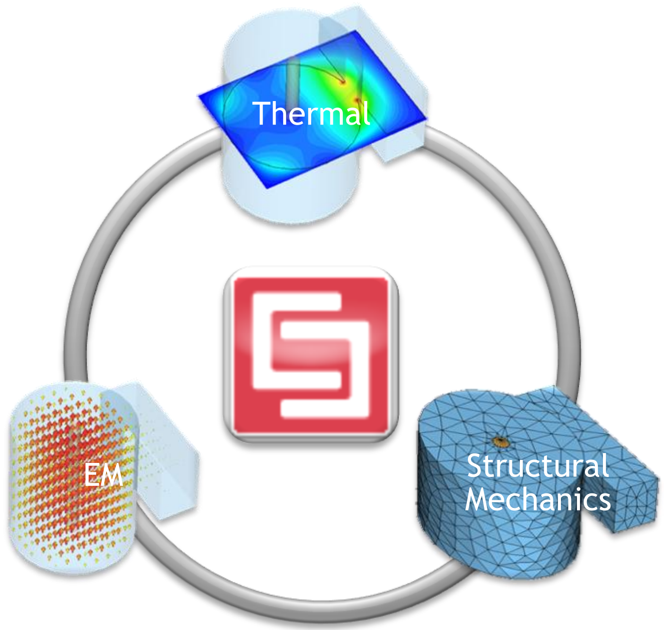






Summary

- Integrated workflow with CST MPHYSICS STUDIO™
- Ease-of-use: New solvers within well known frontend
- Accuracy of integrated solution and solver technology
- Wide application range due to tight integration within CST STUDIO SUITE™



Thank you for your attention!