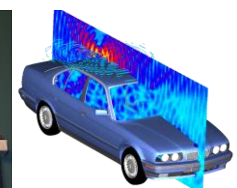
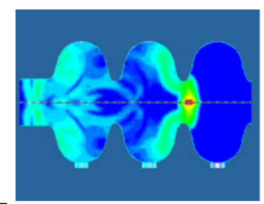
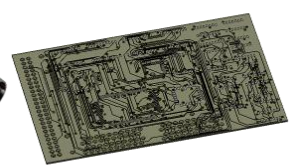
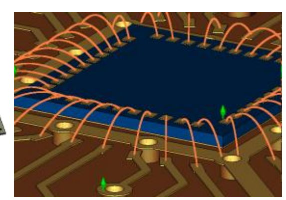
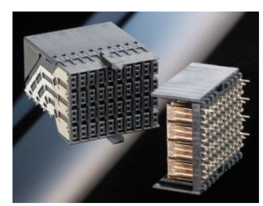
Problemangepaßte volumen- und oberflächenbasierte Lösungstechnologien in CST STUDIO SUITE™

Franz Hirtenfelder, Ralf Ehmann



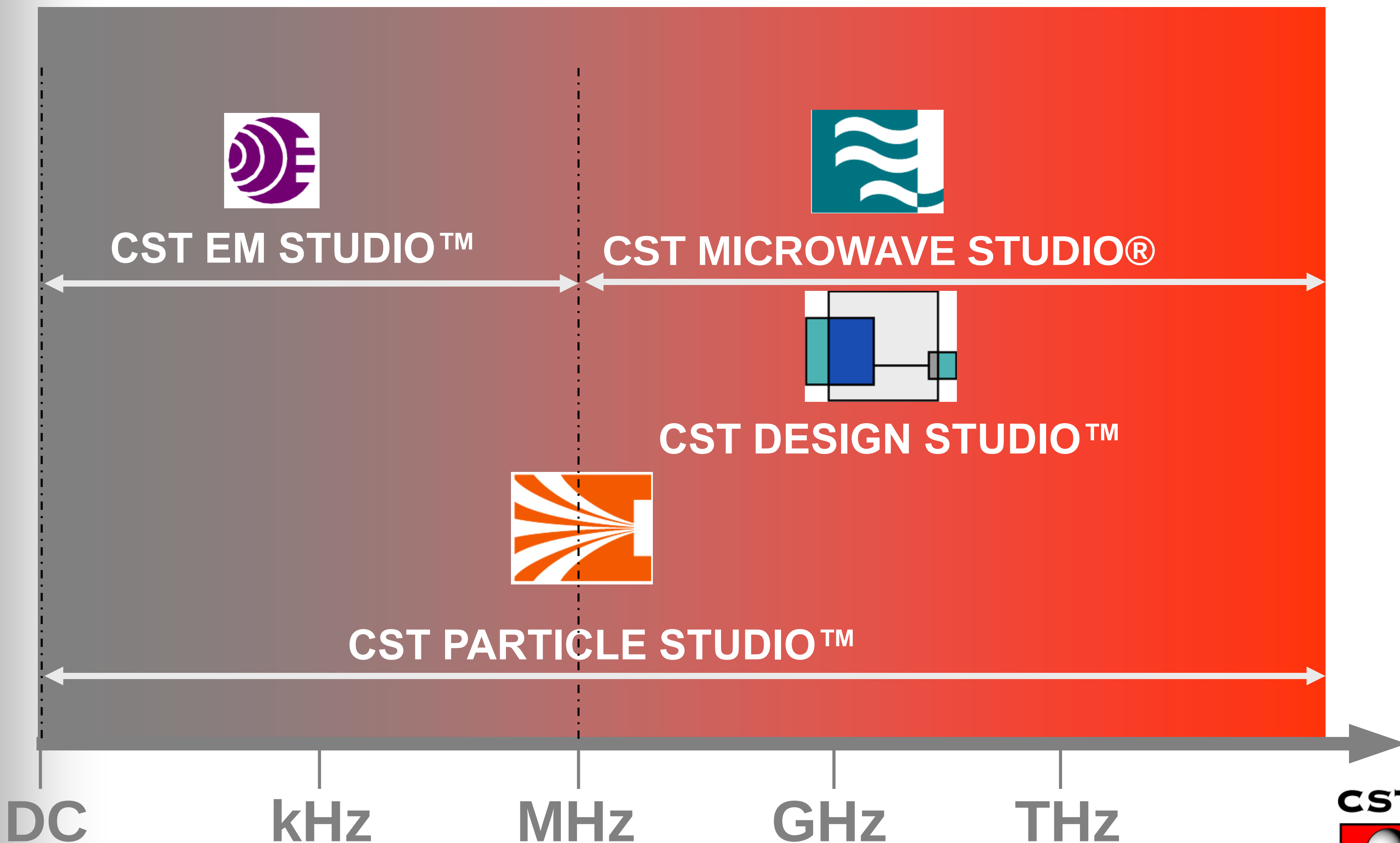





CST - Computer Simulation Technology

Schedule

- Introduction:
  Solver in CST MICROWAVE STUDIO®
- Periodic Structures in MWS
- Filter Analysis in MWS
- Large Structures in MWS
- Summary

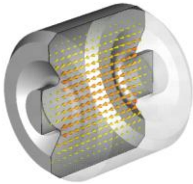
CST STUDIO SUITE™
Products Inside

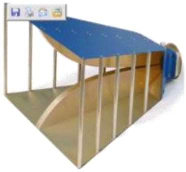


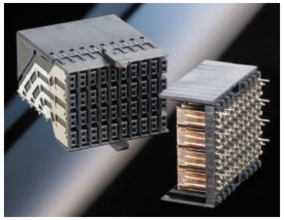
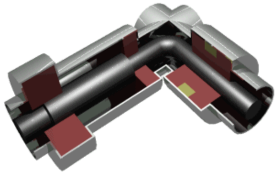
CST MICROWAVE STUDIO®

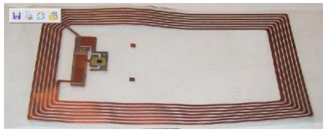
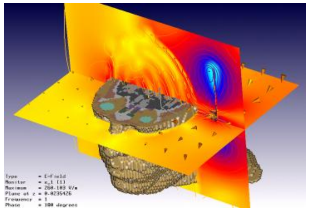
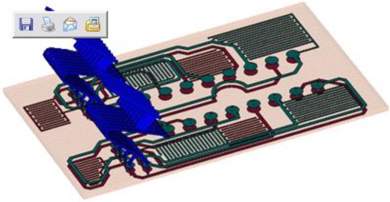
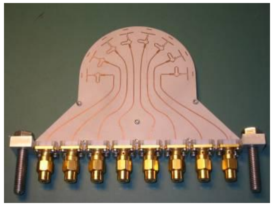
Some selected Application Areas

- Classical MW
  - Waveguide, Antenna, Filter, Coupler, Balun, Splitter, Cavity, Connector
- EMC/EMI
- SI
- FSS, RCS





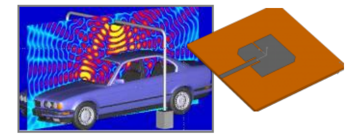



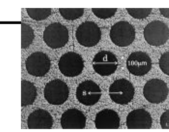





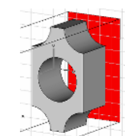
CST MICROWAVE STUDIO®

Solver

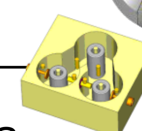
General Purpose Solver 3D-Volume	
Transient	• Large problems • Broadband • Arbitrary time signals
Frequency Domain	• Narrow band / single frequency • Small problems • Periodic structures with Floquet port modes







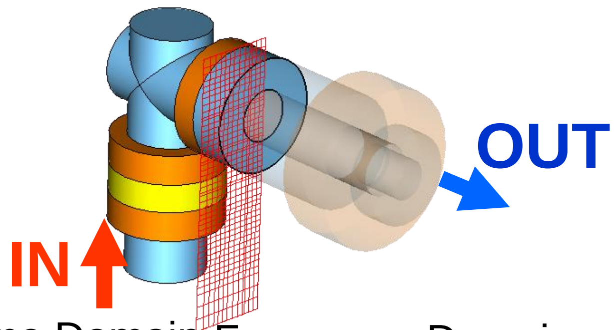
Special Solver 3D-Volume: Closed Resonant Structures	
Eigenmode	• Strongly resonant structures, narrow band • Cavities
Resonant **FD Resonant**	• Strongly resonant, closed structures



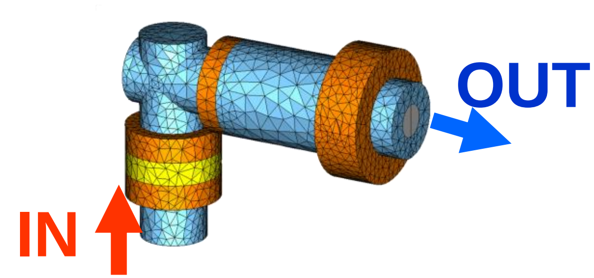
Special Solver 3D-Surface: Large open metalic structures	
Multi-**L**evel **F**ast **M**ethod of **M**oments	• Large Structures • Dominated by metal

General Purpose Solvers

Time Domain – Frequency Domain

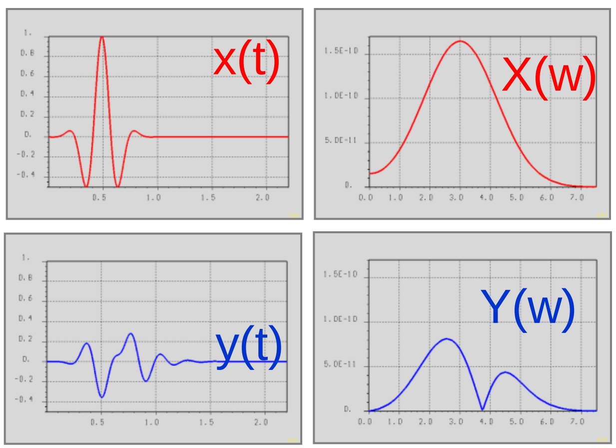


Time Domain Frequency Domain



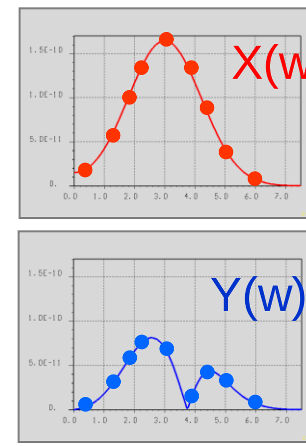
Frequency Domain calculation

IN

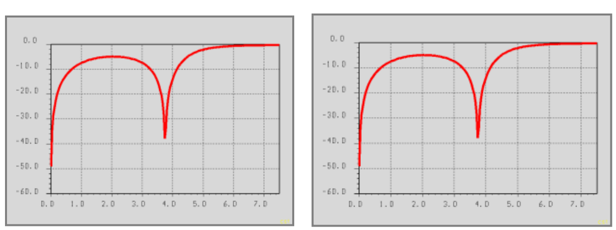


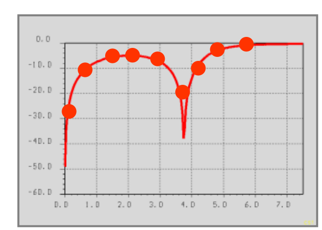
OUT

IN



OUT





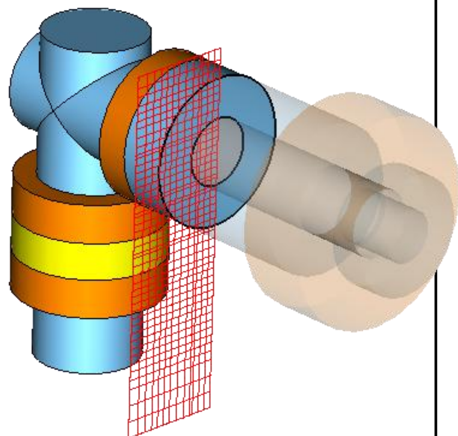
Transfer (TDR) S-Parameter

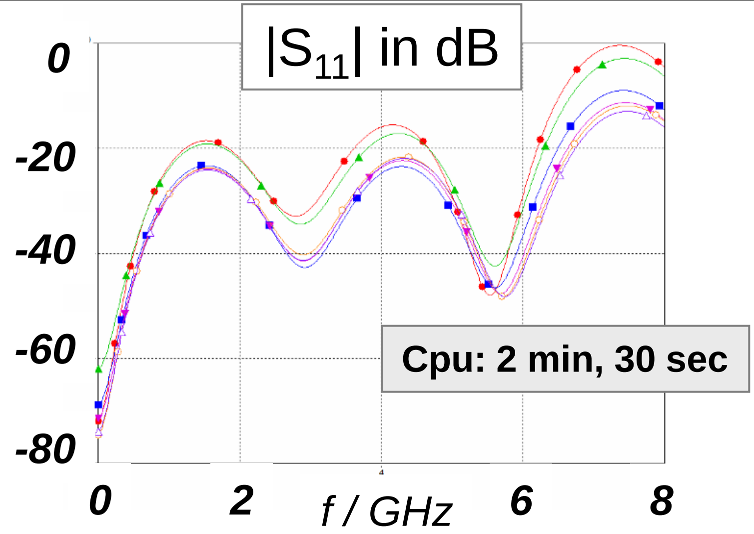
Transfer S-Parameter

Transient Analysis

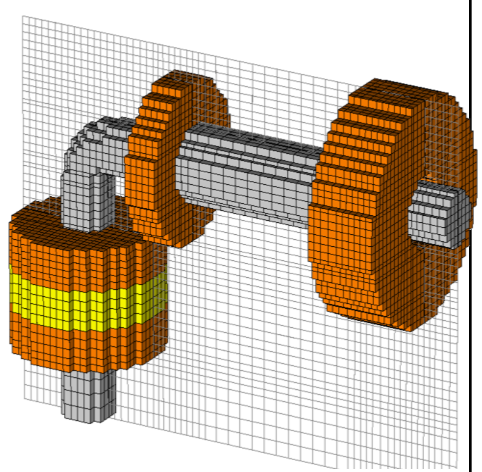
Comparison: PBA - Staircase

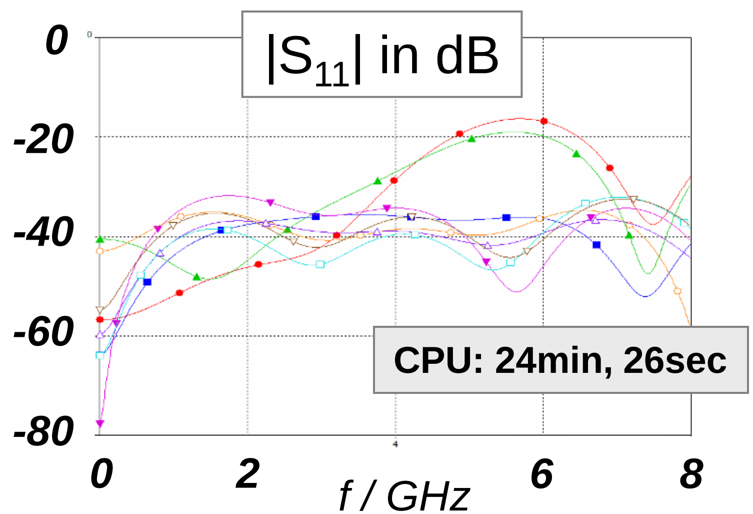
PBA





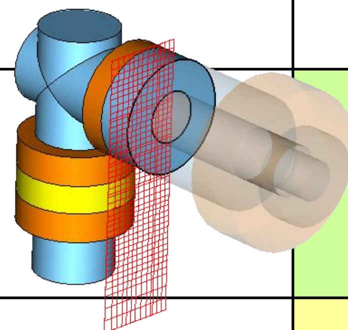
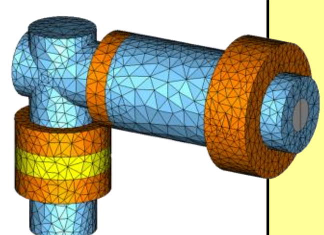
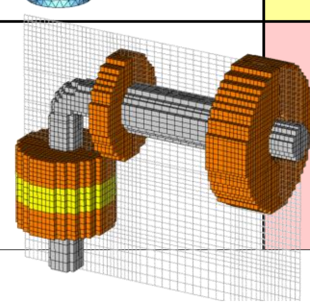
Staircase





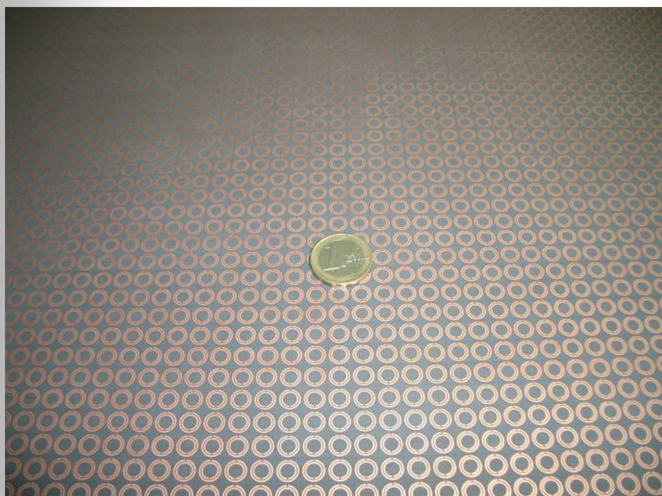
Comparison

Transient-PBA, Transient-Staircase, Frequency Domain

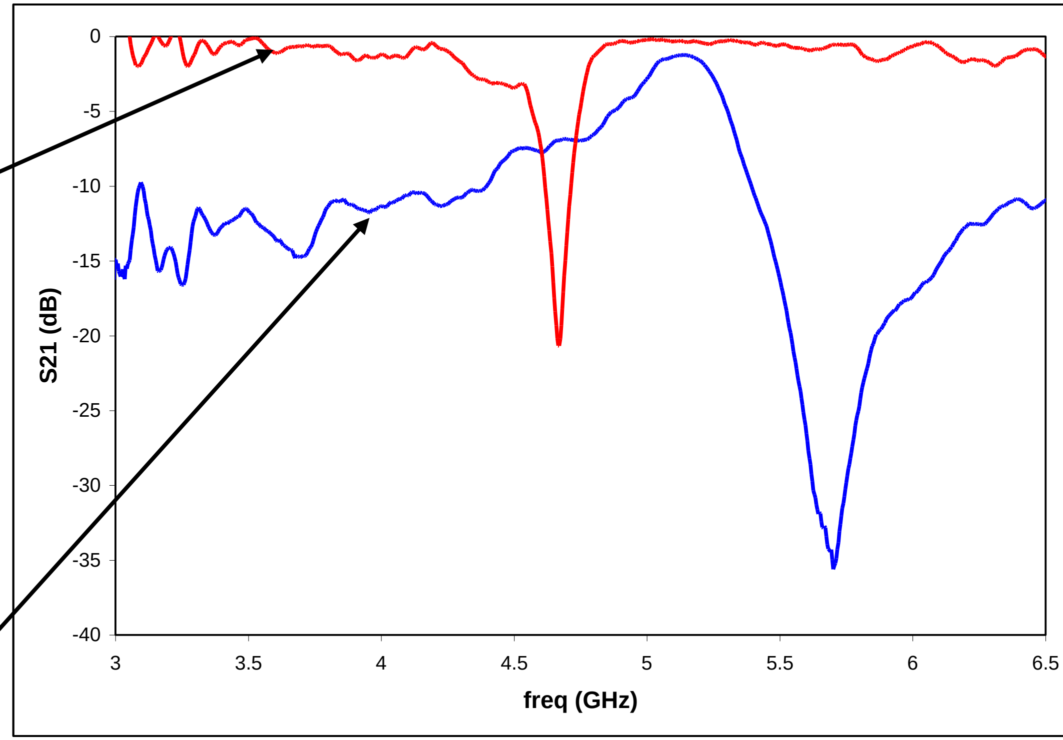
Solution Technique	CPU - Time
Transient PBA 	2 minutes, 30s
Frequency Domain 	3 minutes, 36s Slower than PBA: 1.44
Transient Staircase 	24 minutes, 26s Slower than PBA: ~10

Periodic Structures

Typical application for Frequency Domain Solver



FSS-Surfaces



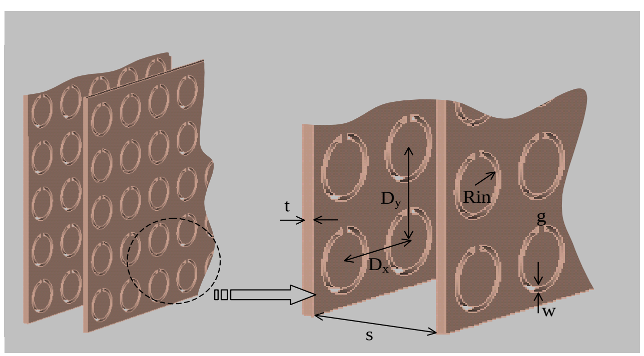
Bandpass- / Bandstop Behaviour

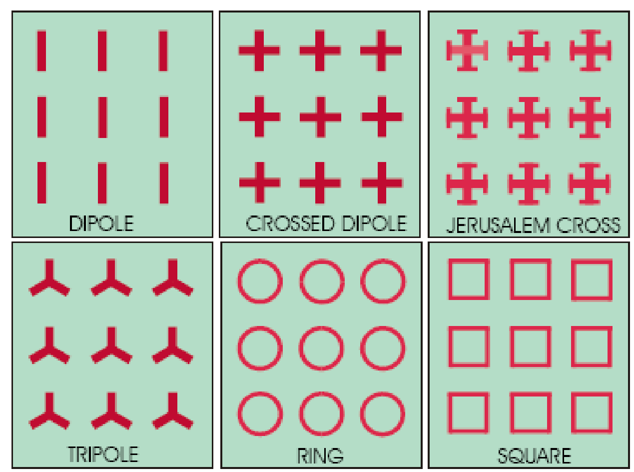
Periodic Arrays

Frequency Selective Surfaces (FSS)?

Periodic assemblies of identical elements arranged in a one- or two-dimensional array.

These periodic structures are either an array of apertures in a thin metallic sheet or metallic patches on a dielectric substrate





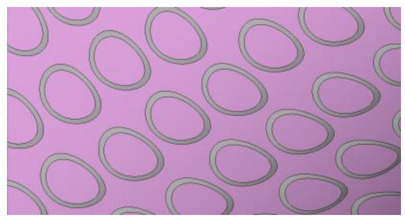
Applications

(Photo by Kockums AB).

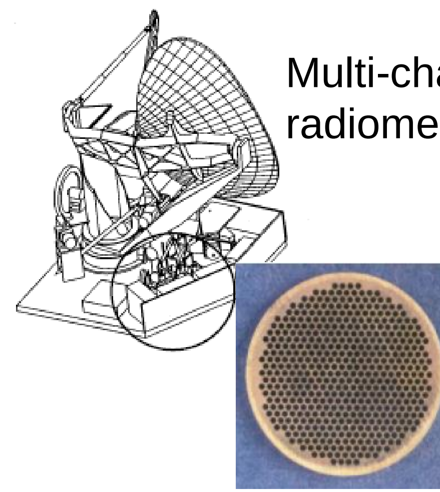
Ghost ships

Rapidly retractable antennas, some of which are concealed behind frequency selective surfaces (FSS)

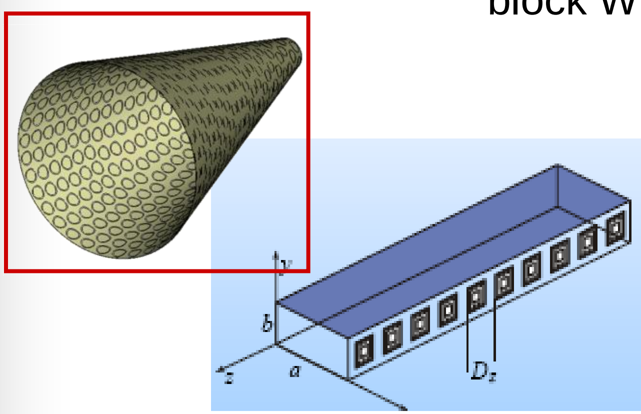
FSS Radomes



Stealthy wallpaper to block Wi-Fi signals



Multi-channel radiometer filters



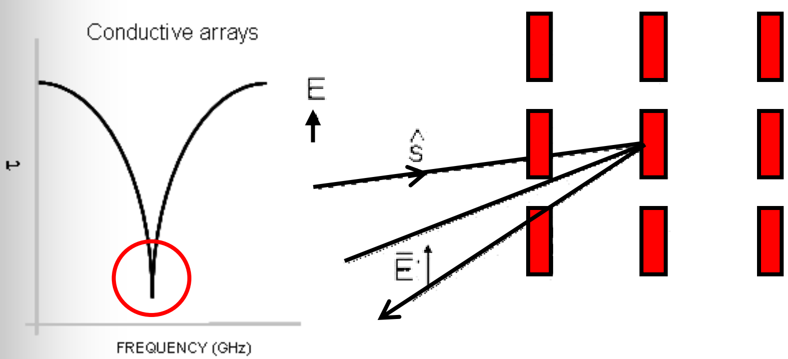
FSS horns and waveguides and reflector antennas

Optically tunable FSS arrays on Si

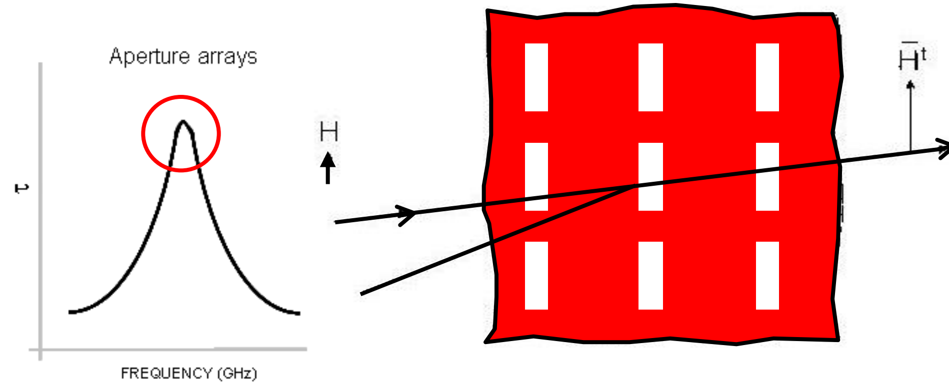
Conducting and Aperture arrays

Complimentary Arrays

Combination of conducting and aperture arrays of similar shape when put one on top of each other forms a “complete” perfectly conducting plane



Band Stop



Band Pass

Passive and Active arrays

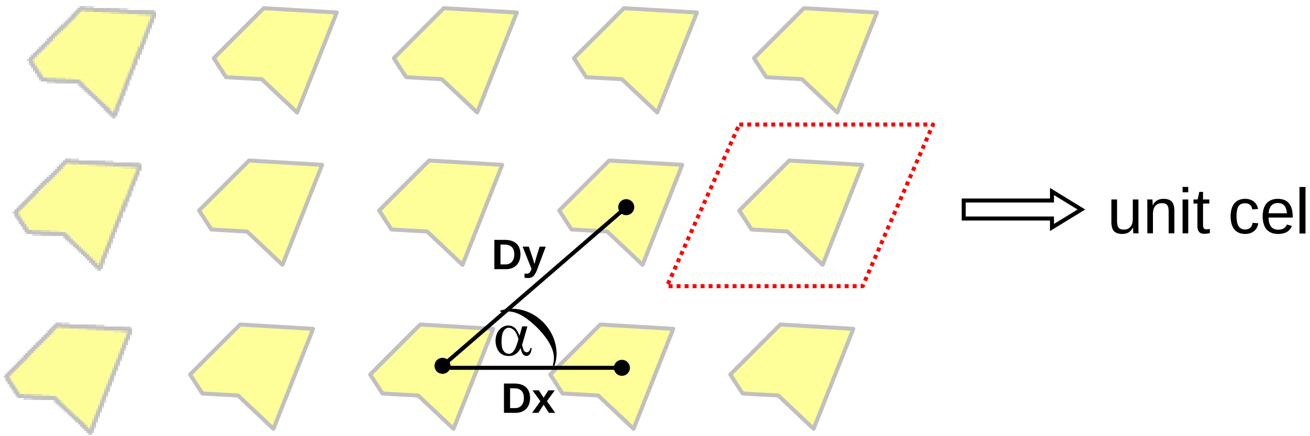
Methods of Excitation

Fundamentally any periodic array can be excited in two ways:

- Incident Plane wave $\bar{E}_i$ *(passive array)*
- Individual Generators connected to each elements (active array)

For an active array the voltage generators must have the same amplitude and a linear phase variation across the active array in order to qualify as a periodic array

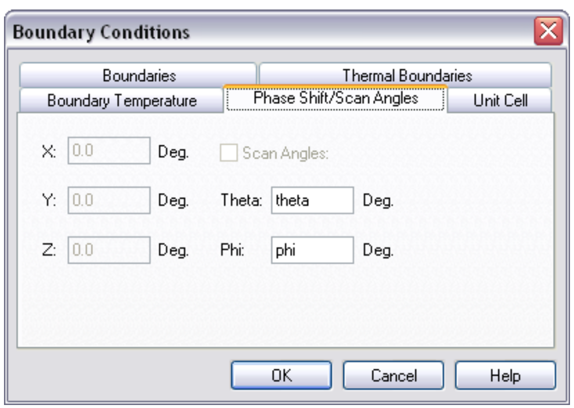
The unit cell



The unit cell can be defined as the basic building block (can be an arbitrary resonant shape) of the array that repeats itself infinitely defined by the periodicity Dx, Dy and the angle in-between α

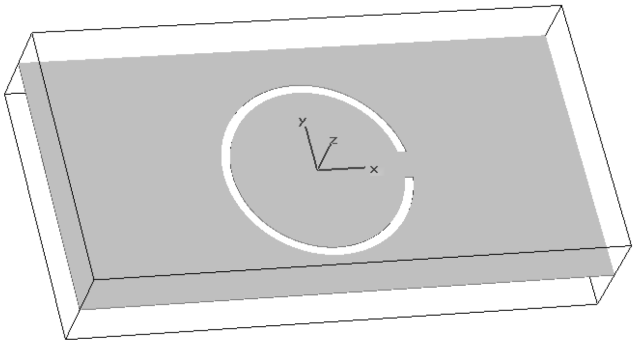
CST STUDIO SUITE™
Solvers

- Time Domain
  - – 0 phase between elements
- Frequency Domain
  - – Arbitrary phase between elements

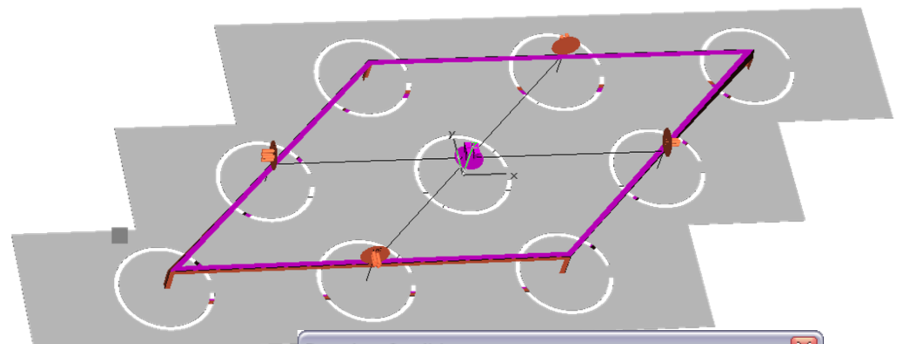


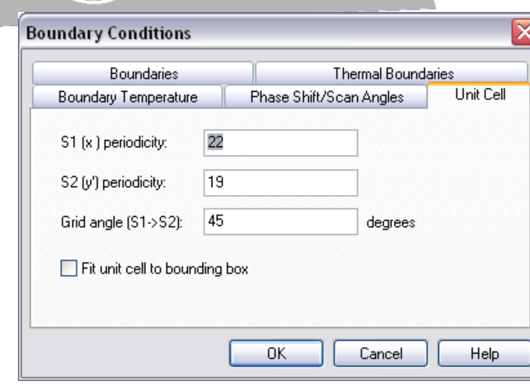
Periodic Setup in MWS

Single Element modelled in MWS

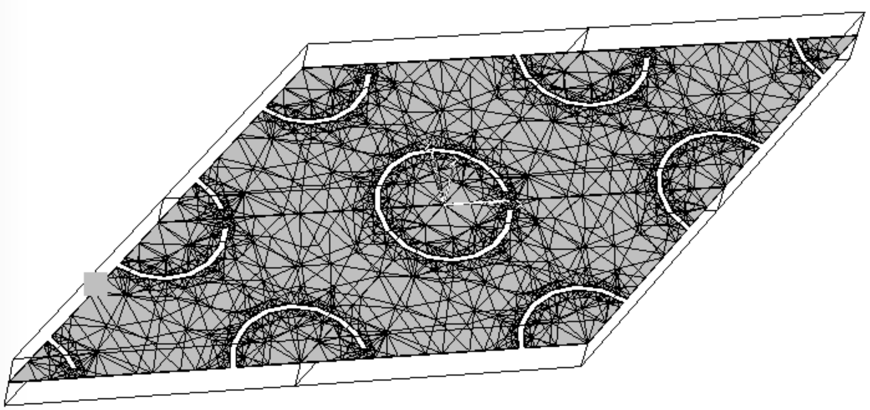


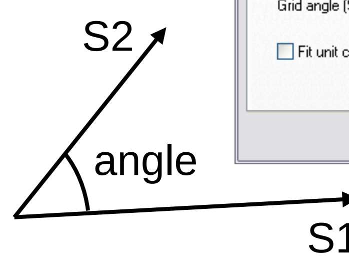
Periodic Unit Cell boundaries in MWS



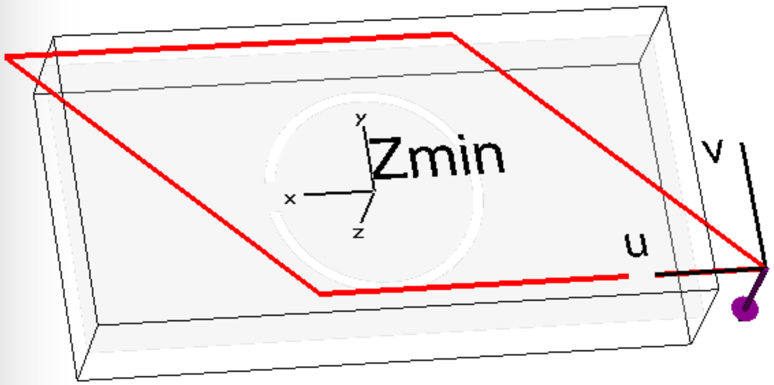


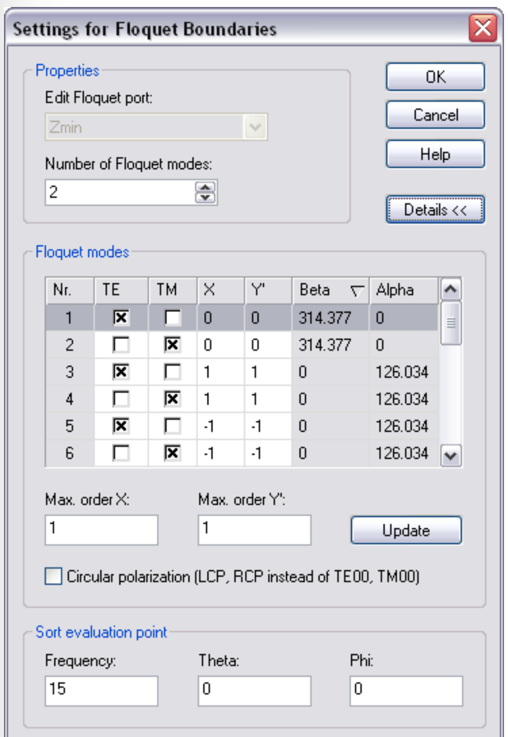
Tetrahedral mesh for the F-Solver in MWS





Excitation Ports: Floquet Mode Setup




Settings for Floquet Boundaries

Properties

Edit Floquet port:

Zmin

Number of Floquet modes:

2

OK

Cancel

Help

Details <<

Floquet modes

Nr.	TE	TM	X	Y'	Beta	Alpha
1	☒	☐	0	0	314.377	0
2	☐	☒	0	0	314.377	0
3	☒	☐	1	1	0	126.034
4	☐	☒	1	1	0	126.034
5	☒	☐	-1	-1	0	126.034
6	☐	☒	-1	-1	0	126.034

Max. order X: 1

Max. order Y': 1

Update

☐ Circular polarization (LCP, RCP instead of TE00, TM00)

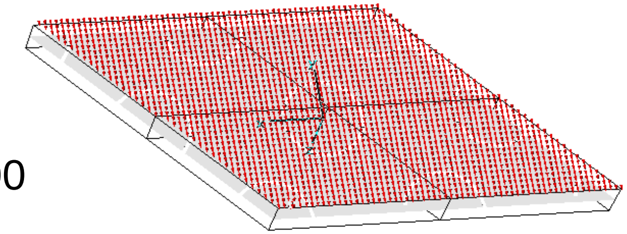
Sort evaluation point

Frequency: 15

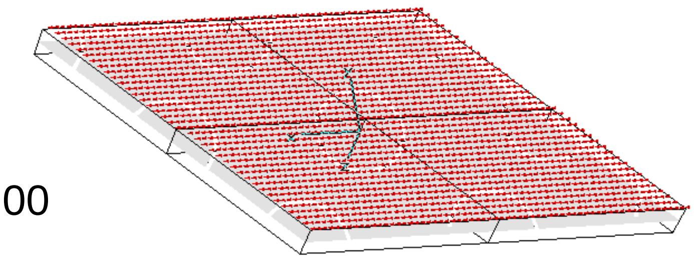
Theta: 0

Phi: 0

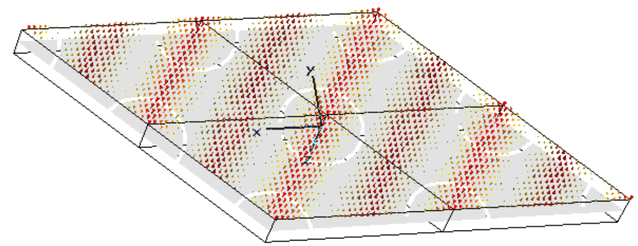
TE_{00}



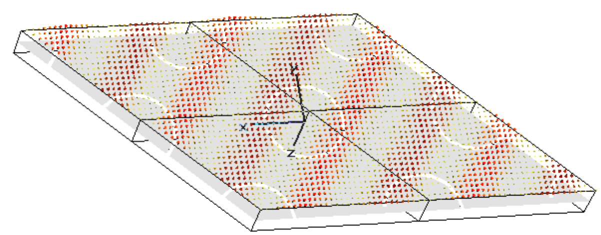
TM_{00}



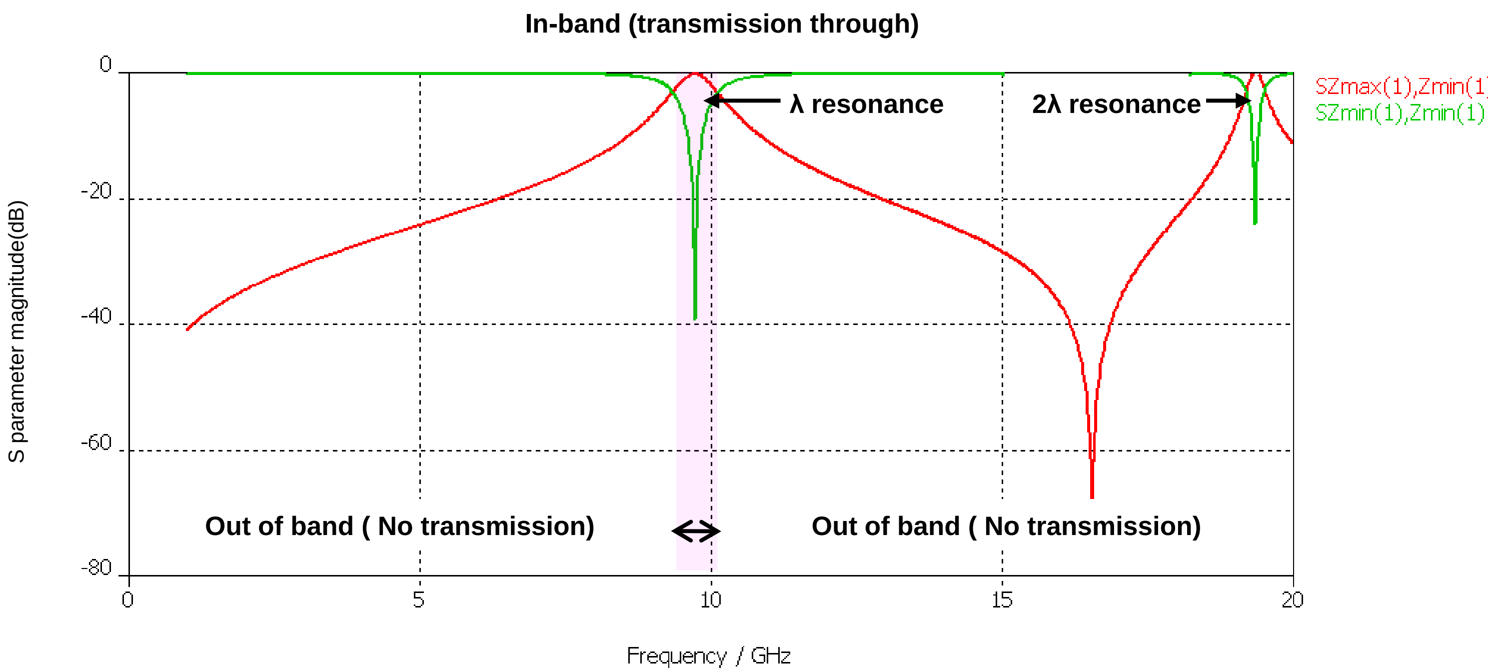
TE_{11}

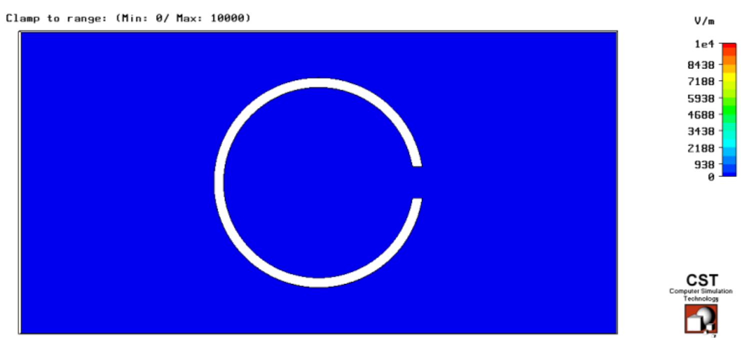


TM_{11}

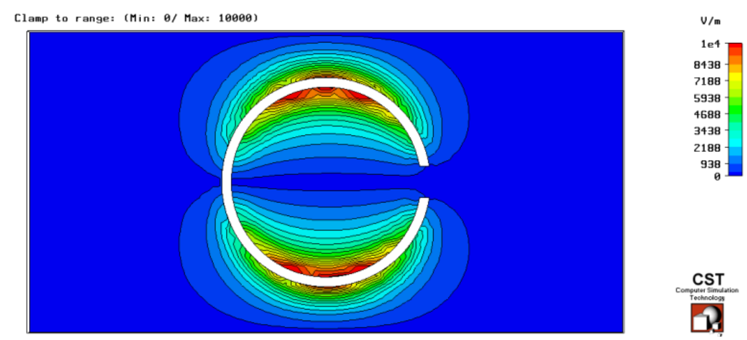


Transmission coefficient





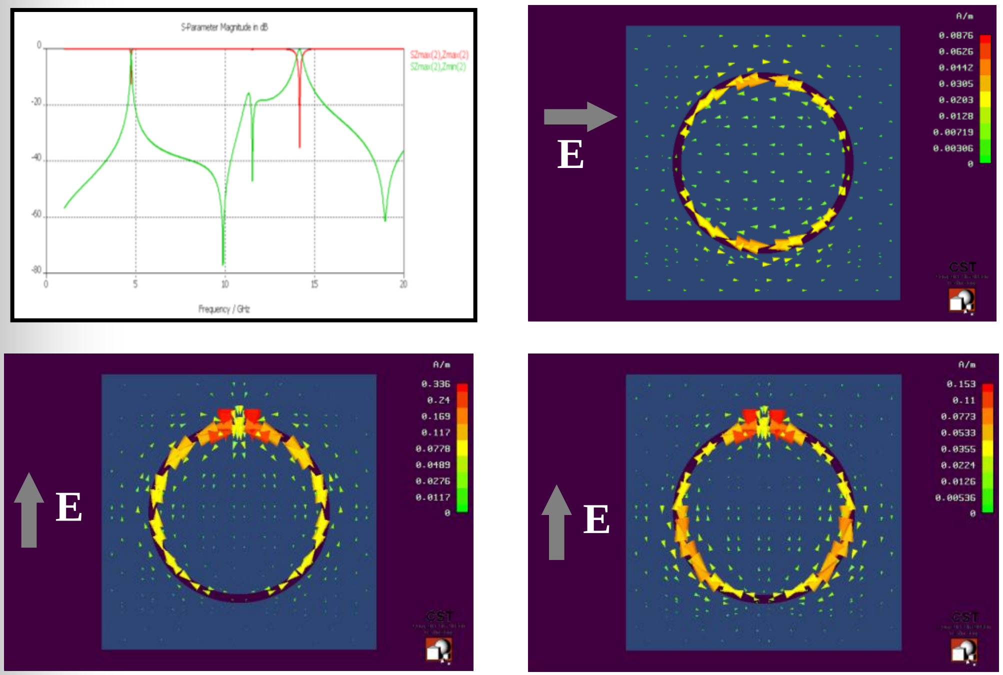
E field animation at 1GHz



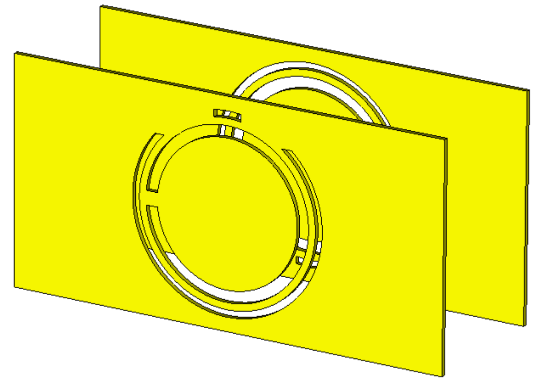
E field animation at 10GHz

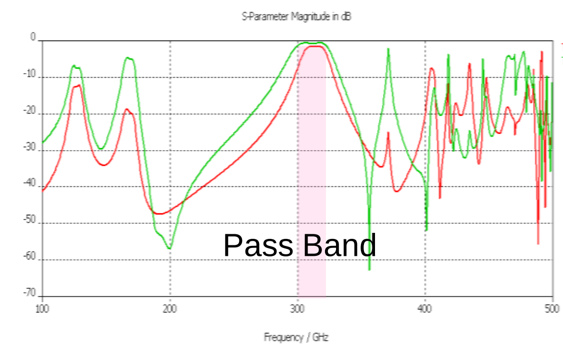
ring fd_01.zip

Coupling modes & Casacaded arrays



Coupling TE and TM modes by nesting rings allow for dual polar dual frequency filters to be designed

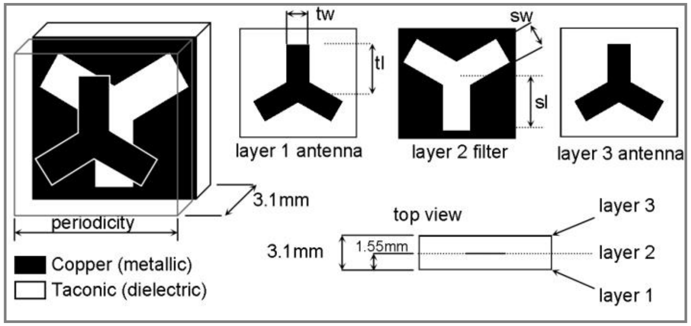


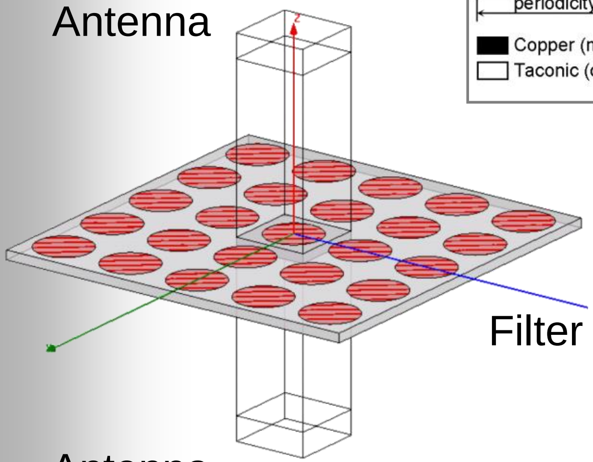


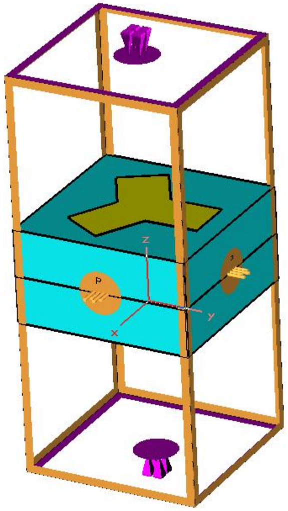
Cascaded arrays give higher BW and the separation allows to control the roll-off rate

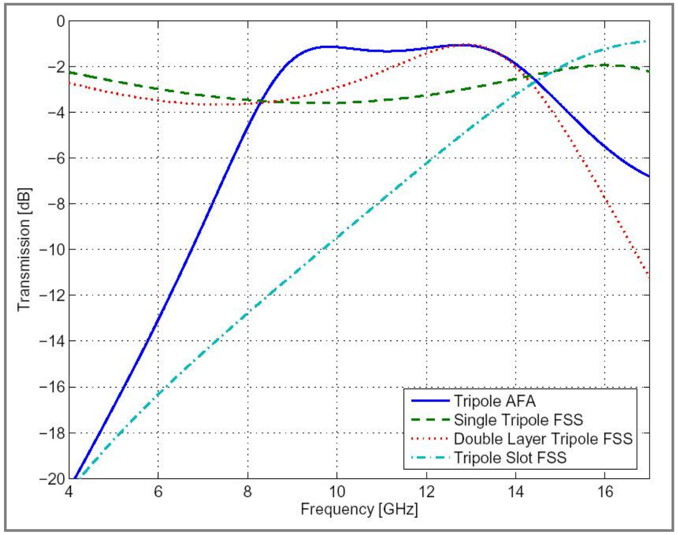
Example: Wideband Tripole AFA

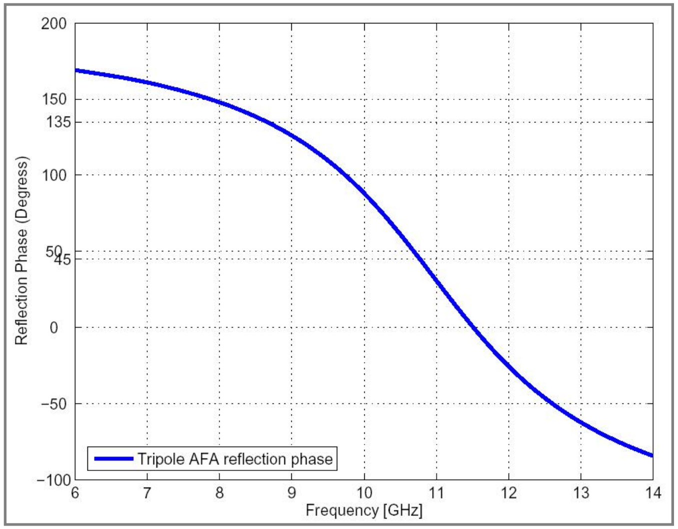
3 layer FSS setup



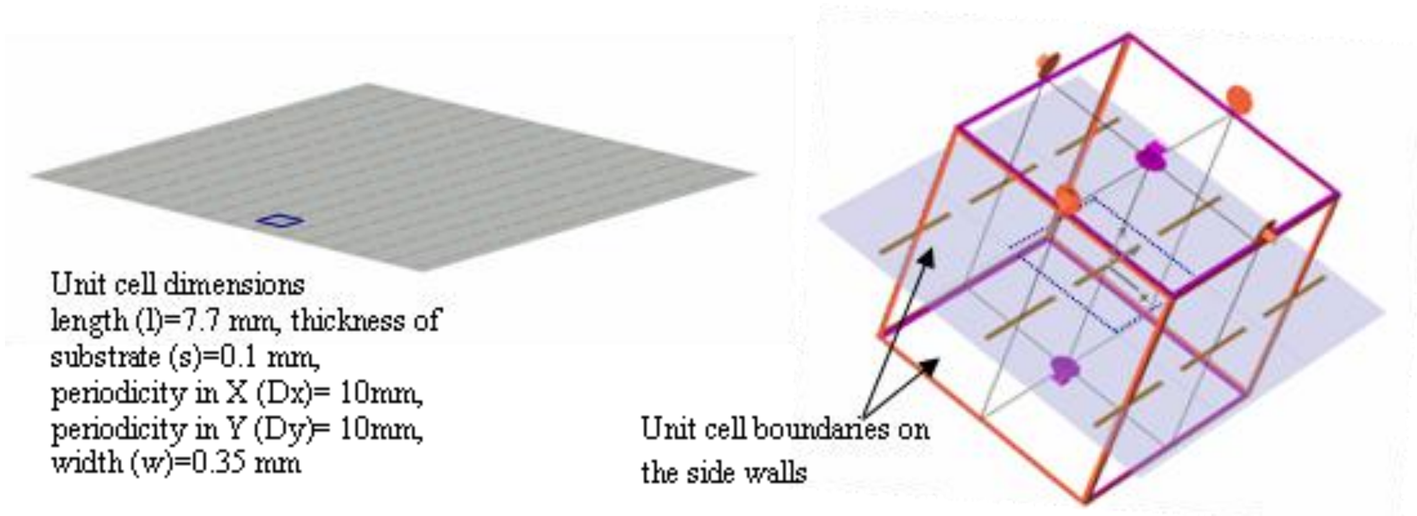


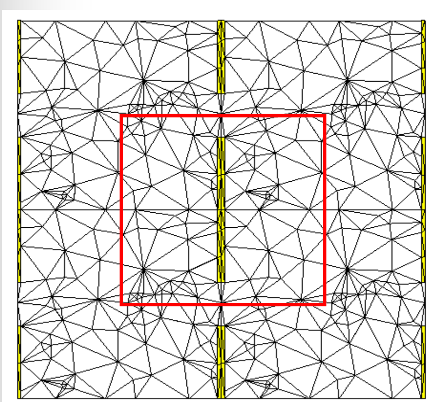






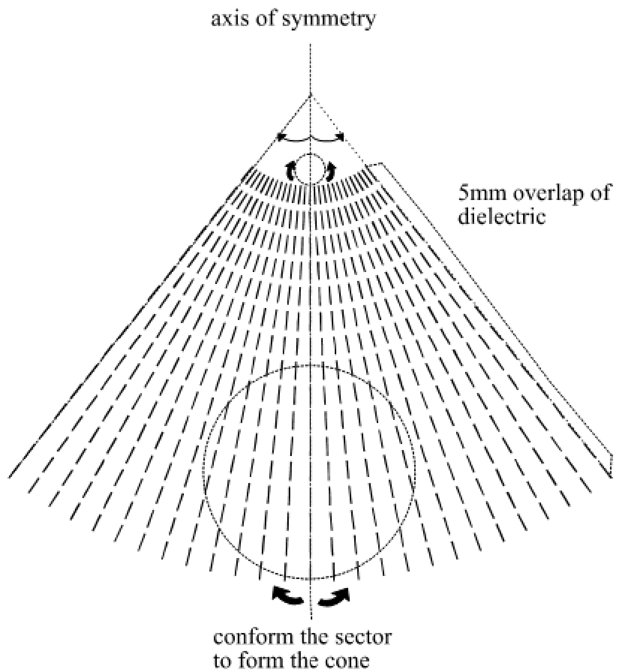
Infinite Dipole Array

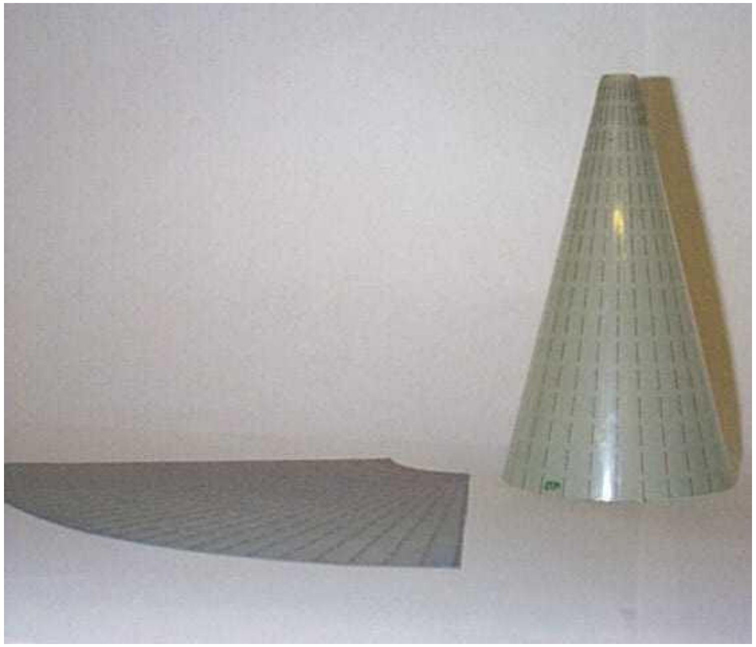




- **converged after 3 adaptive passes – 6480 tetrahedral mesh cells**
- **Total run time - broadband frequency sweep with 10 frequency samples 23 mins.**

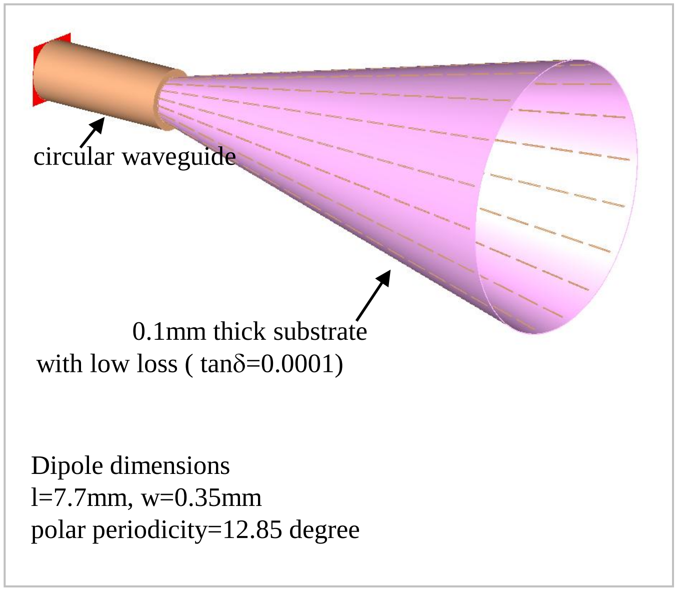
Conical finite array

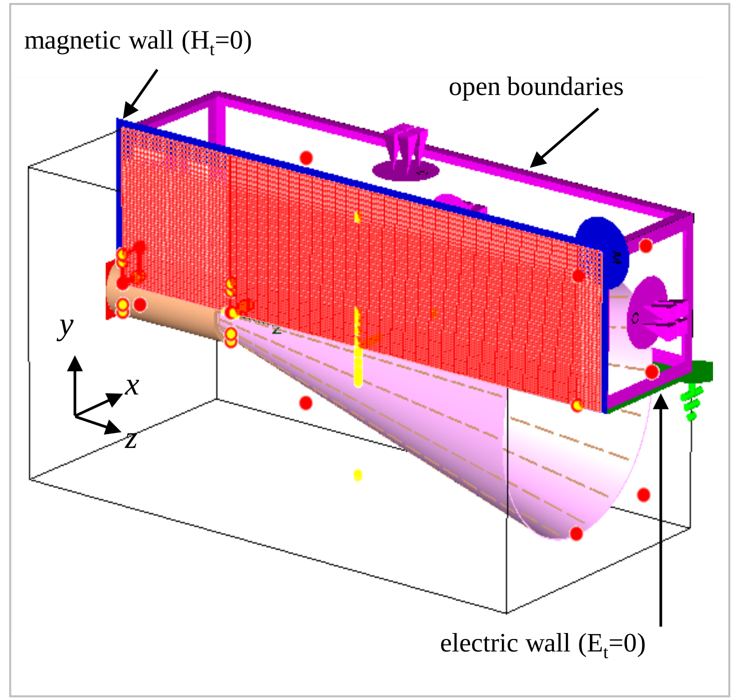




Printed dipole elements on a sector with polar periodicity of 12.85°

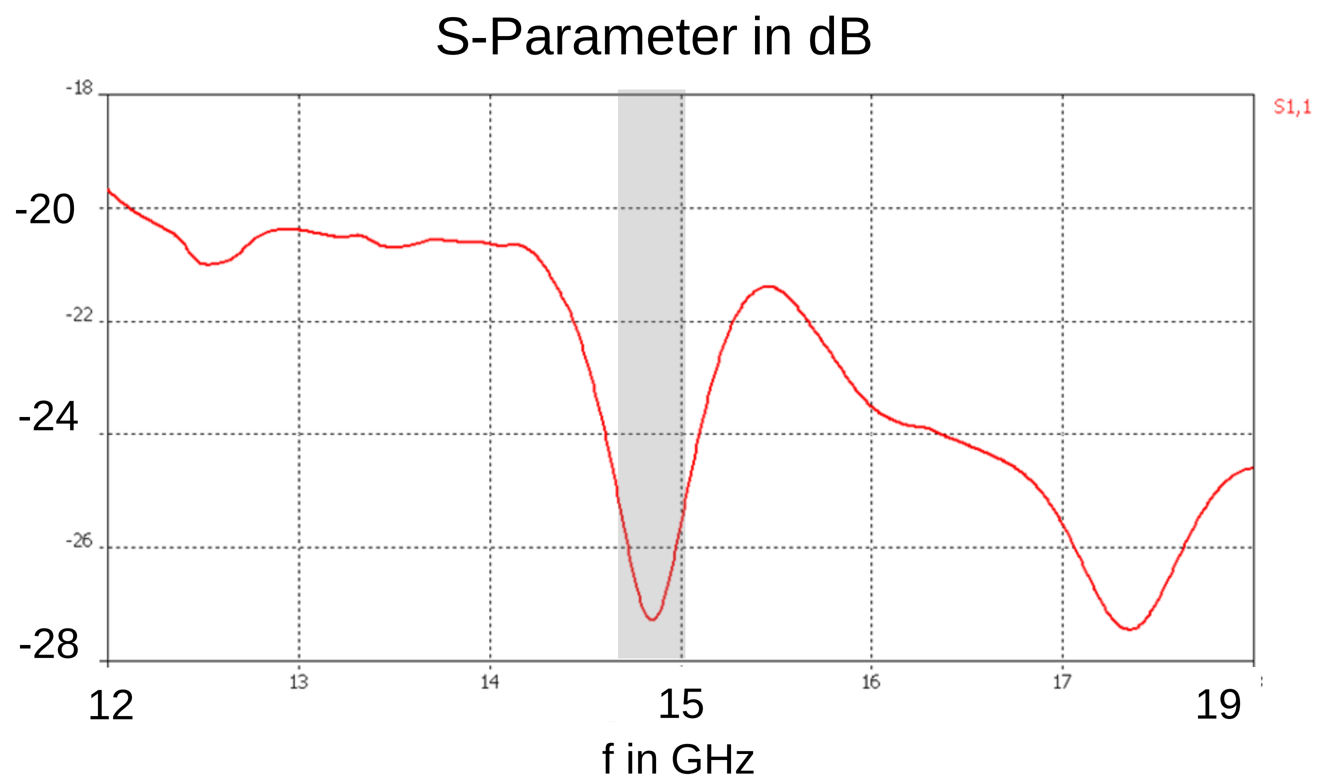
Conical finite array modelling



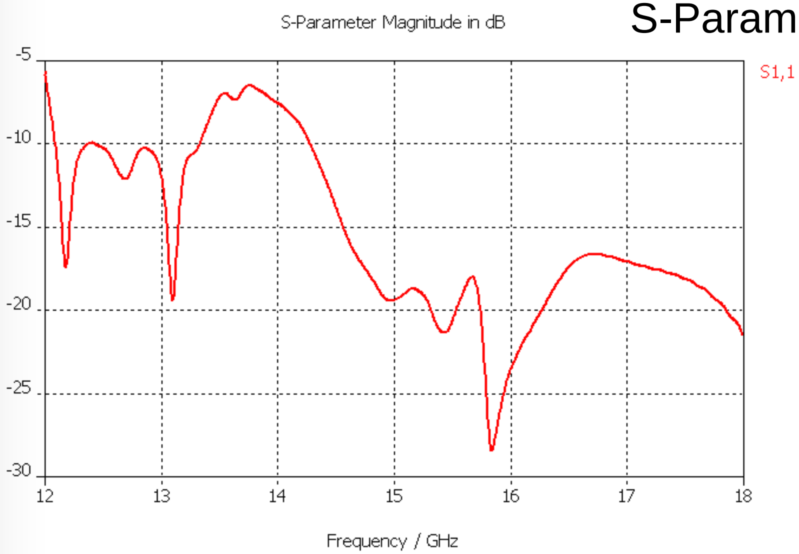


- **Computational effort greatly reduced by symmetry boundary conditions/PBA (total of 2 million mesh cells)**

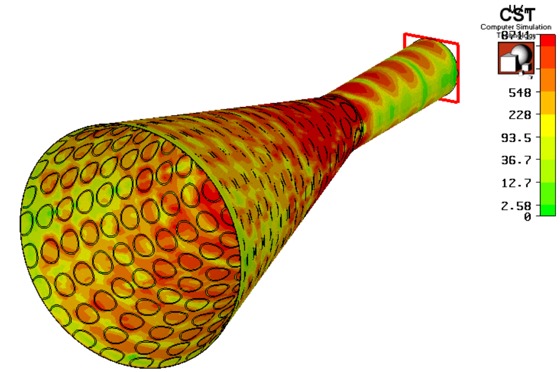
Conical finite array modelling



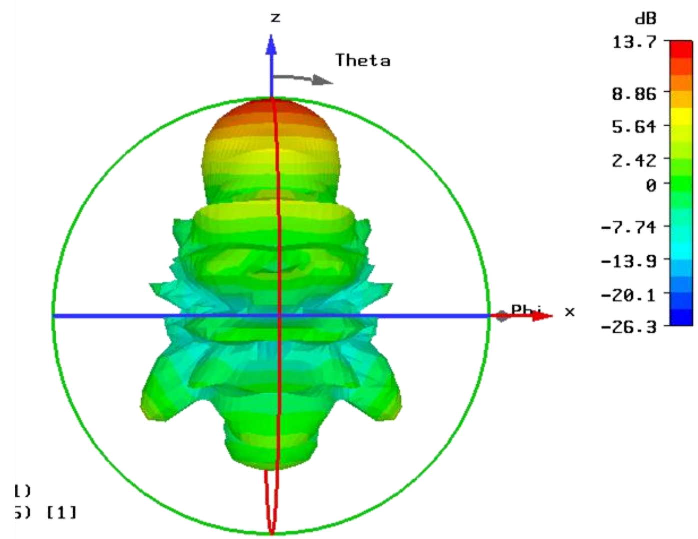
Small horn with ring elements



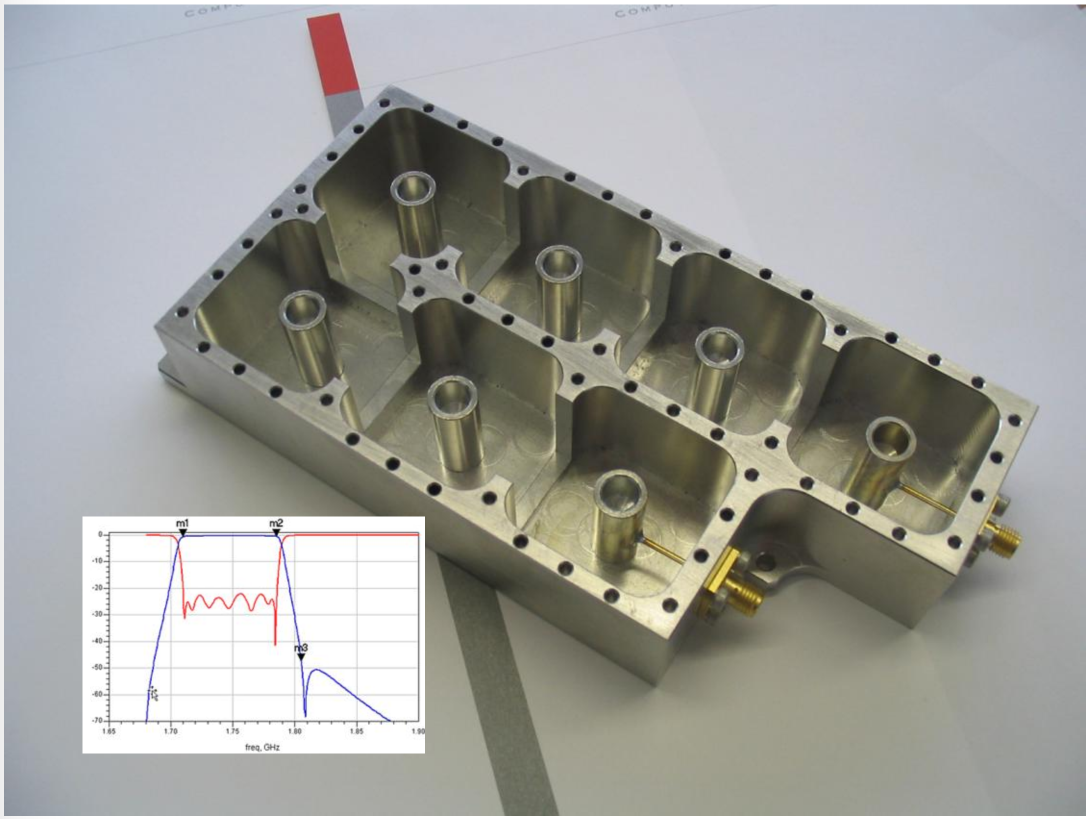
S-Parameter in dB



FSH ring elements give higher gain values for a horn aperture much smaller than of the dipole array presented earlier

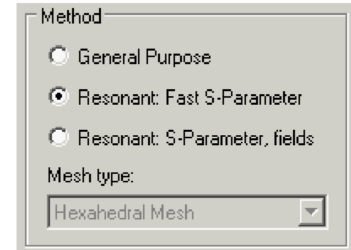


Filter Simulation

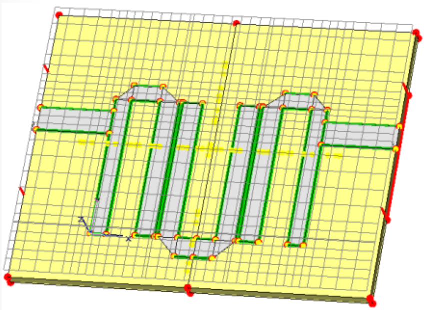


Solver Selection
Meshing Techniques
Accuracy
Tuning Hints
Examples

Solver Selection

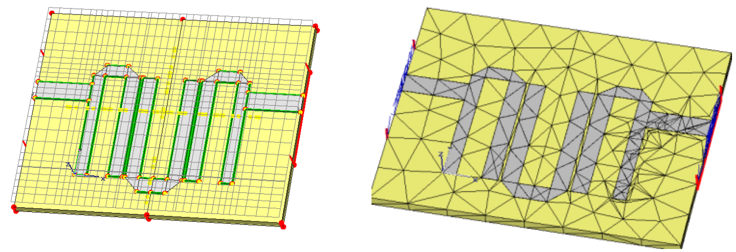


Time Domain (TD)

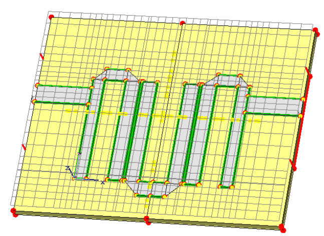


Frequency Domain (FD)

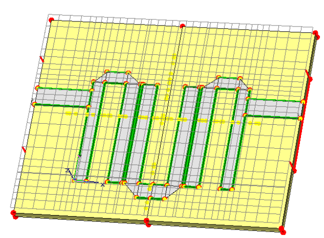
General Purpose



Resonant: Fast S-parameter (MOR)

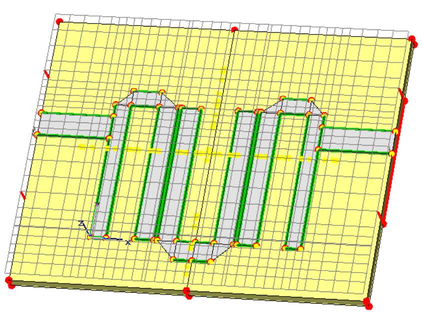


Resonant: S-Parameter, Fields (Modal Analysis)

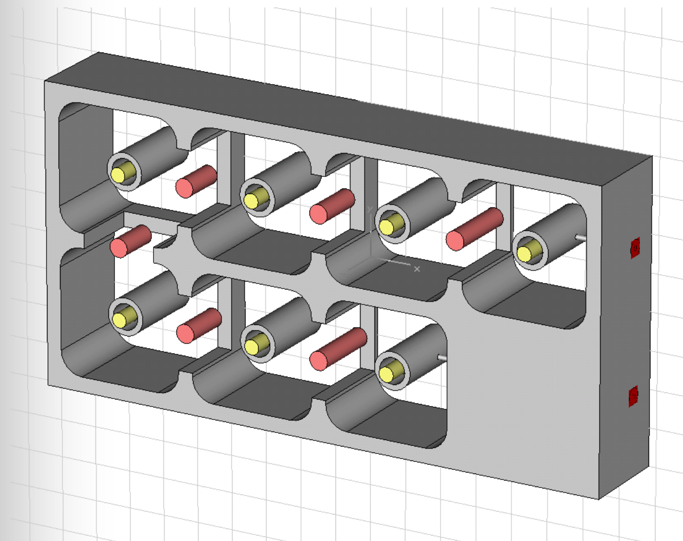


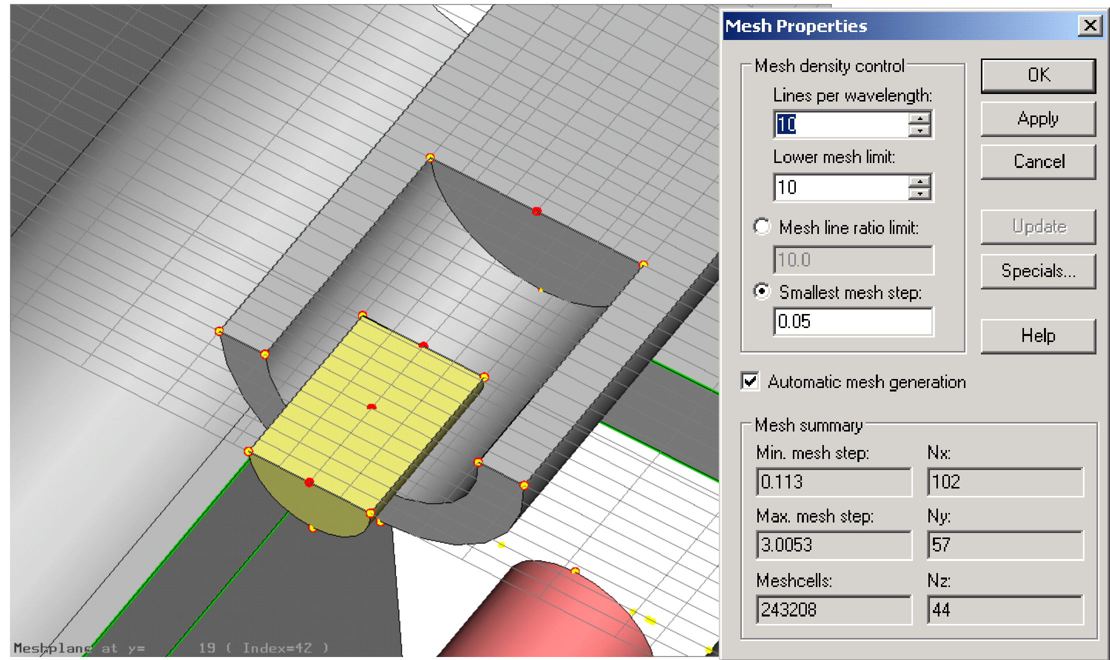
Eigenmode (E)

Modal (Resonant Fields)
Lossy/Lossless

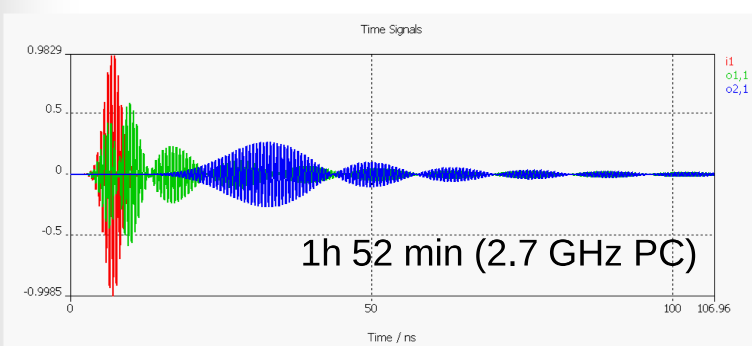


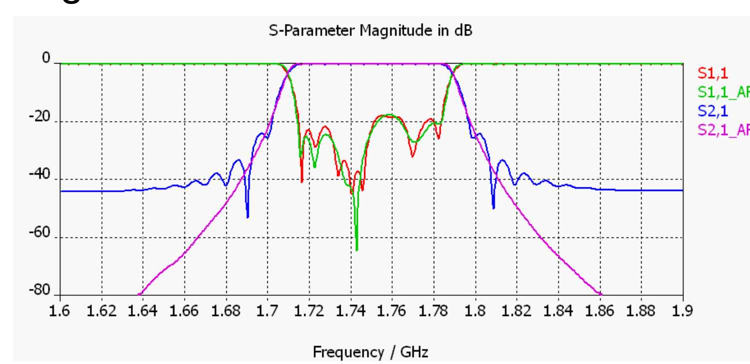
Solver Selection: Time Domain



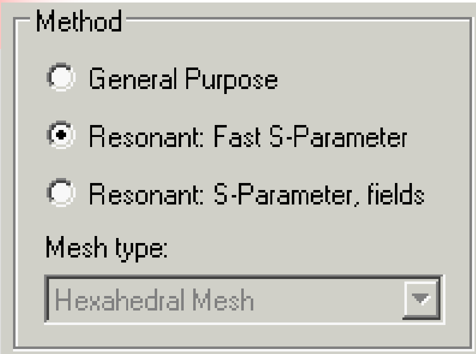


Extremly small variations of tuning elements: require small mesh steps and thus long run times
PBA helps greatly to keep number of mesh cells low,
Resonances requires long run times, AR Filter settings critical

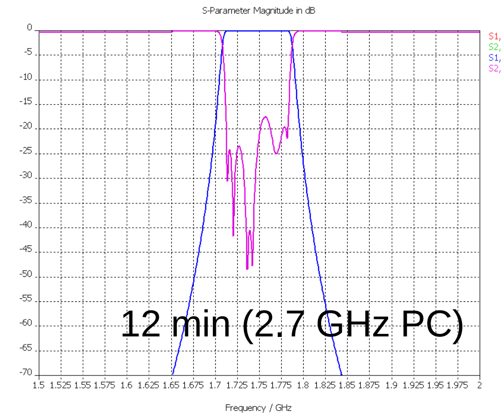




Solver Selection: Resonant Fast S-Param.

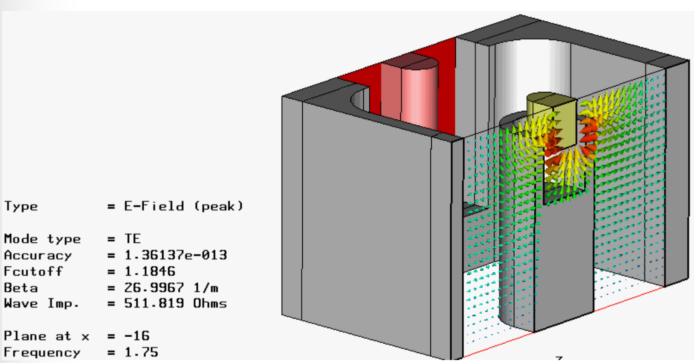


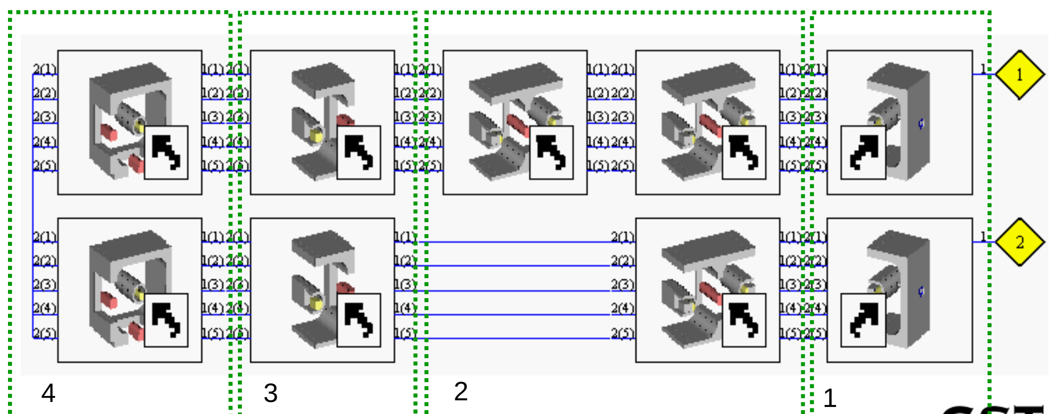
Robust and fast solver
for filters and
highly resonant structures



Resonant Fast S-Parameter Solver Advantages:

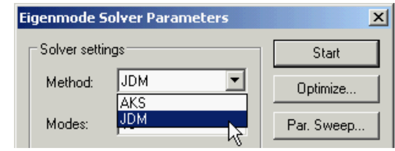
- PBA inside
- lossy dielectrics
- insensible to high mesh ratios, small mesh steps
- handle S-parameters for port modes under cutoff (required for submodeling in CST DS)



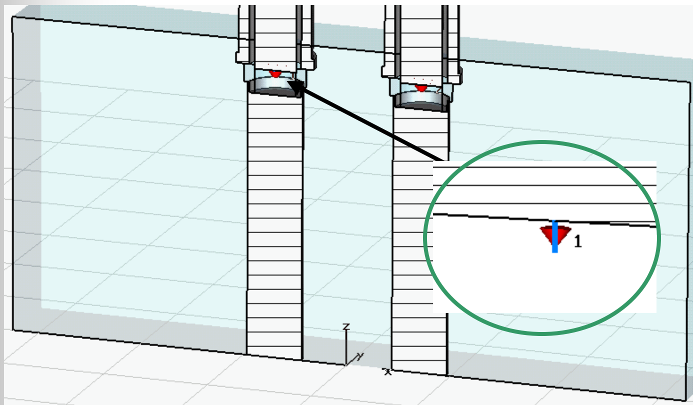


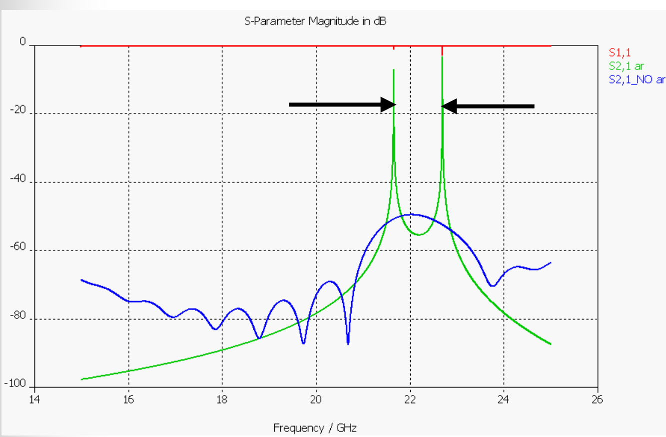
Solver Selection: Eigenmode

Terminology: Coupling Bandwidth

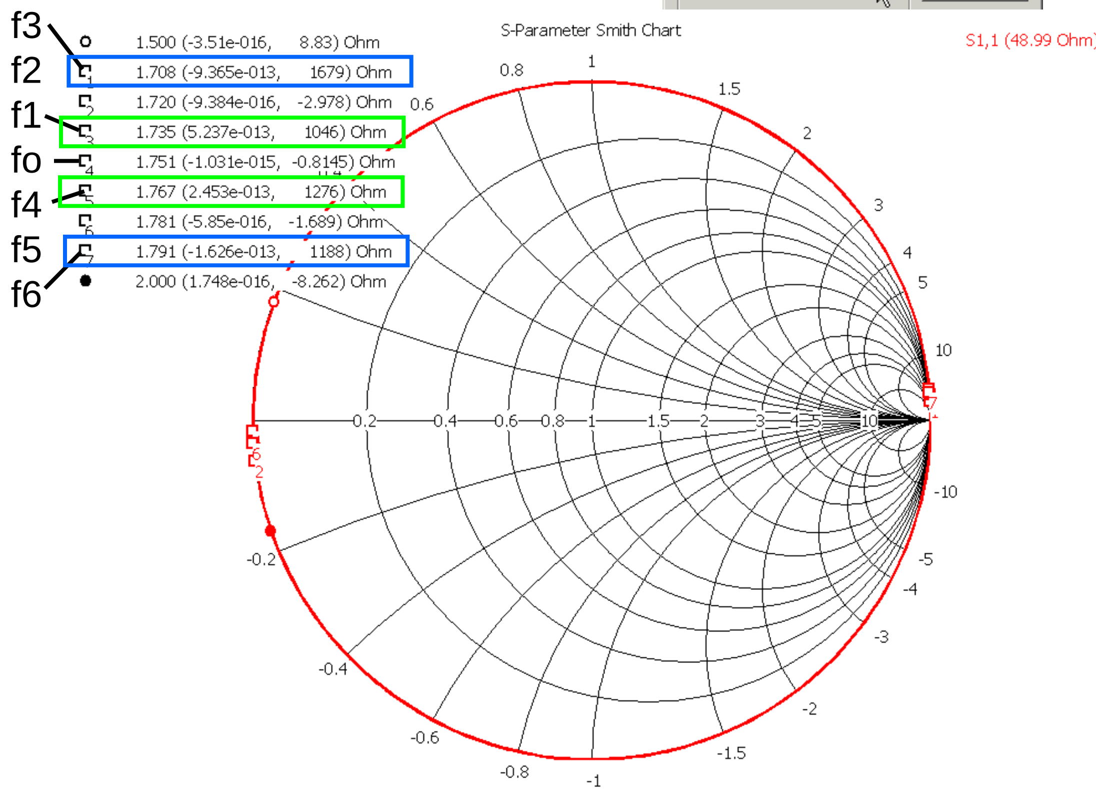


Even/Odd Mode



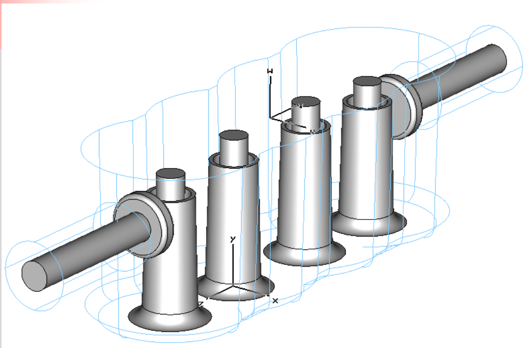


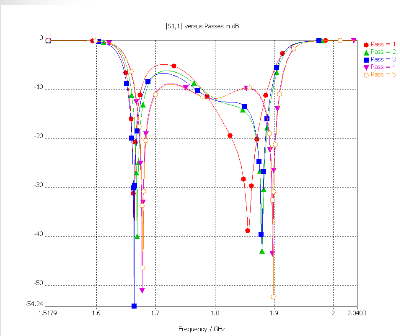
Multi Eigenmode



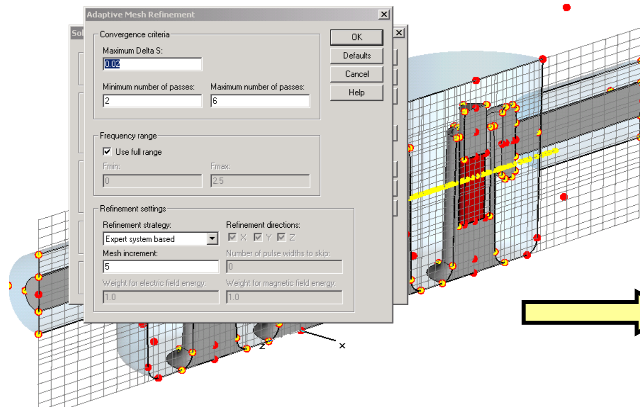
K34= (f4-f1)(f6-f3)/K12=
=(1767-1735)(1791-1708)/66= 40.24MHz

Accuracy: PBA





1. Adaptive mesh refinement of untuned filter

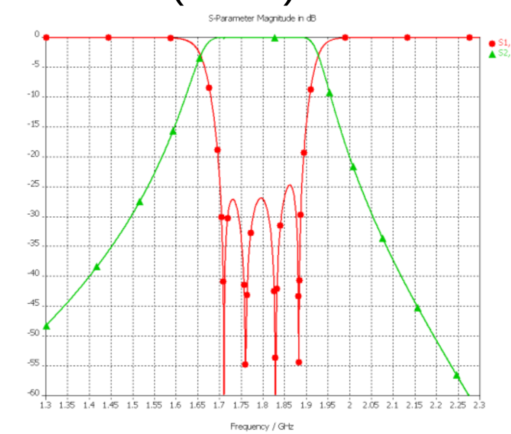


2. Tuning Step

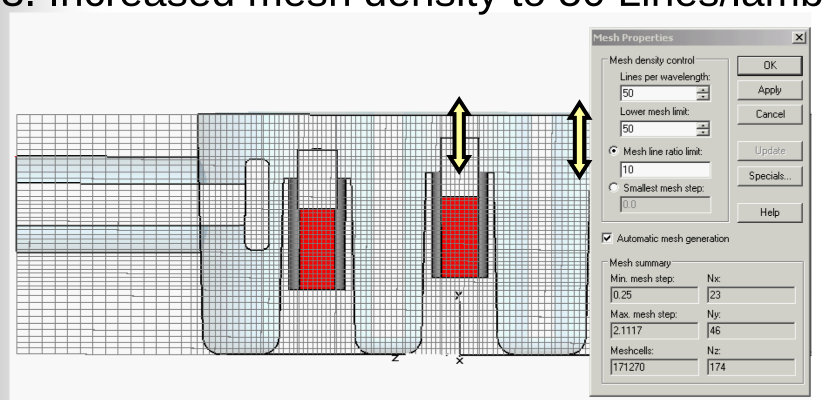
30 Lines/Lambda = 51000 cells

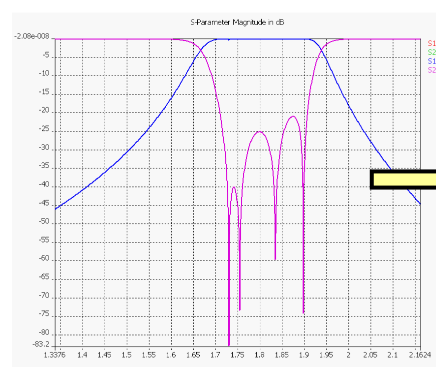
TD (AR) Solver time: 256 s

Resonant (MOR) Solver 91 s



3. Increased mesh density to 50 Lines/lambda



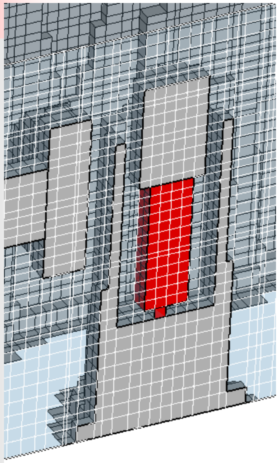


slight readjustedment of only one parameter by 0.0125mm!!

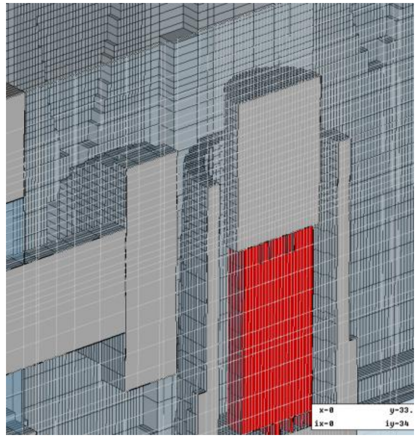
Resonant (MOR) Solver 414 s

Accuracy: Staircase

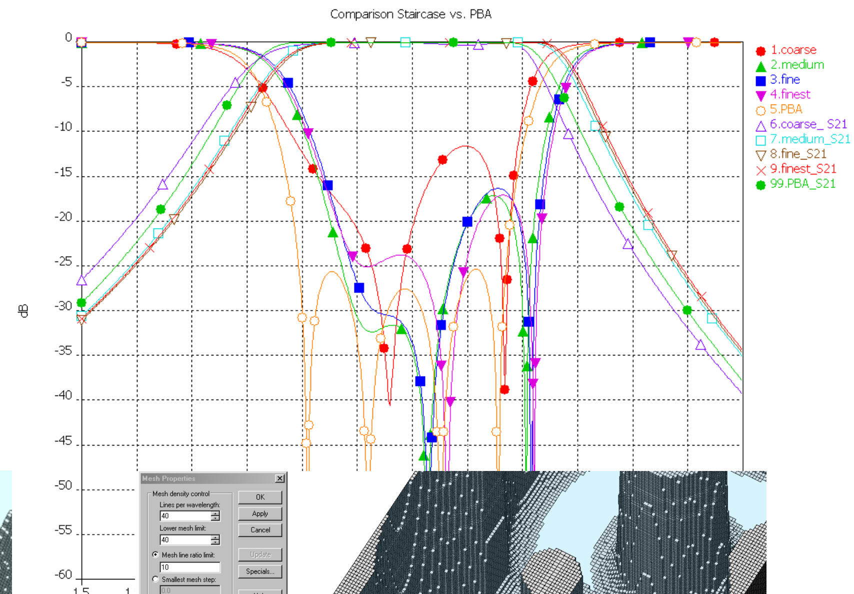
Mesh density was increased:
Results did not converge to the PBA-results

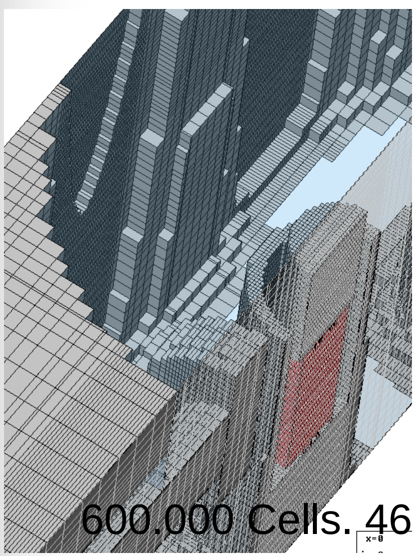


89.000 Cells. 2.5 min
(1.7 GHz Laptop)

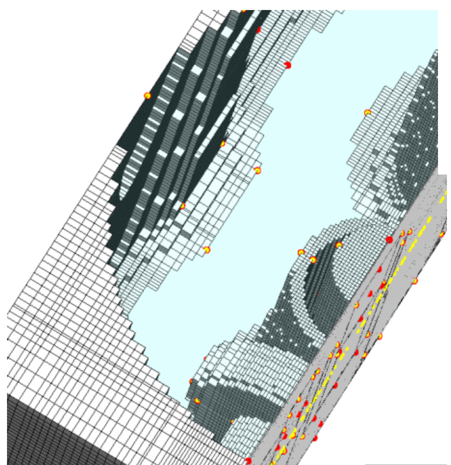


384.000 Cells. 27 min

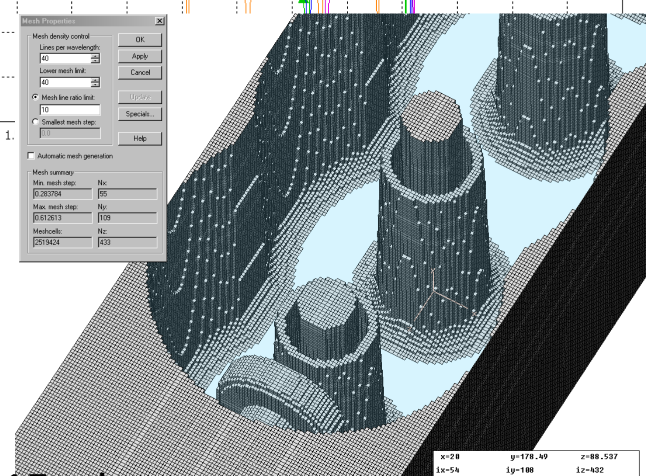




600.000 Cells. 46 min



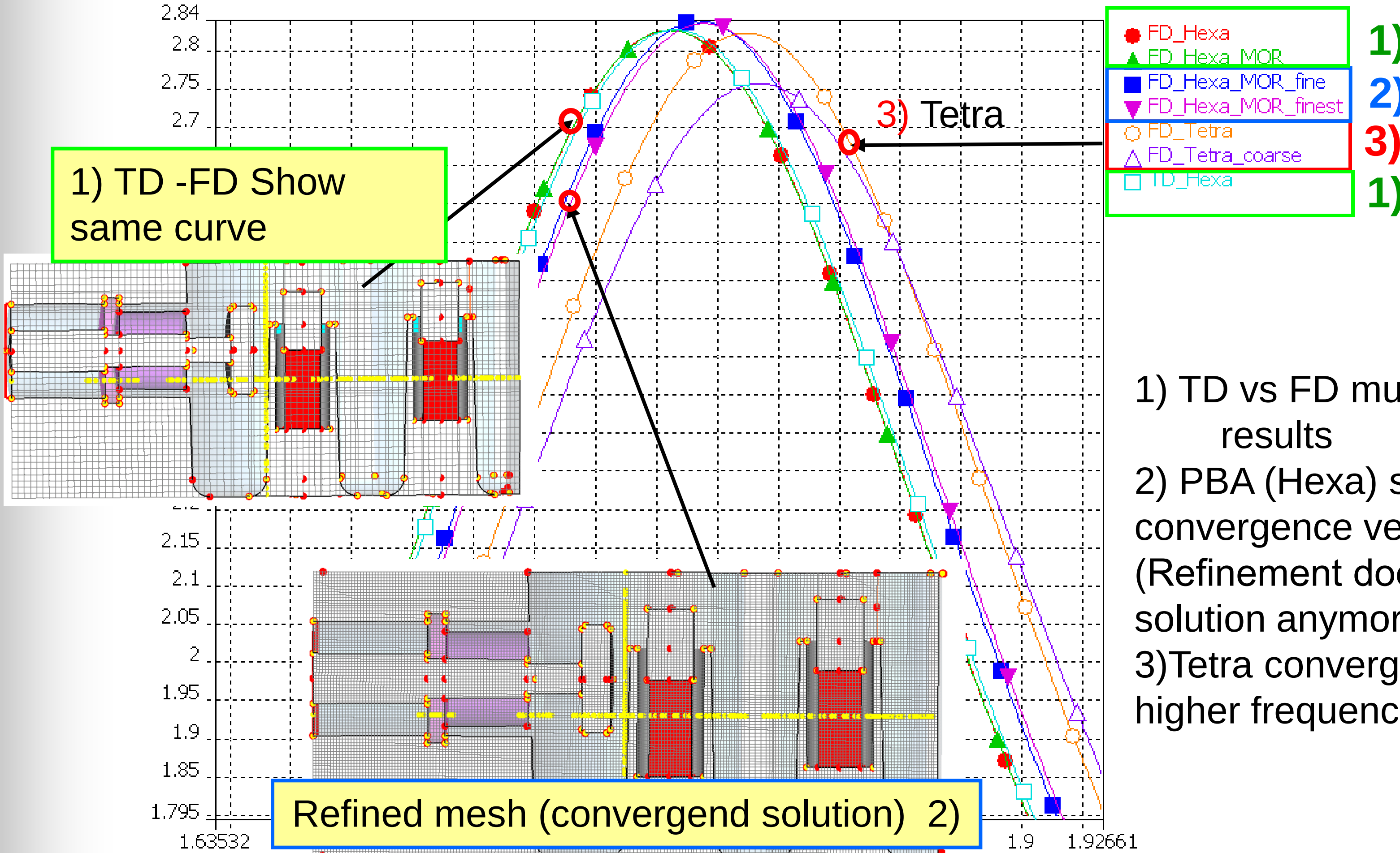
1.050.000 Cells. 1h 15 min
(all MOR Solver, 1.7 GHz Laptop)



5Mio , 2.5 h

Accuracy: Hexa-Mesh vs. Tetra-Mesh

Convergence using different Mesh types and Solvers

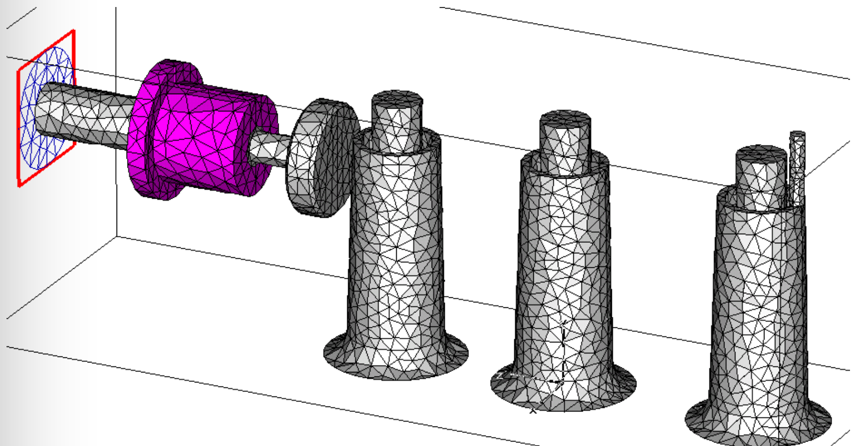


1) TD vs FD must show same results
2) PBA (Hexa) shows convergence very early. (Refinement doesn‘t change solution anymore).
3)Tetra converges towards higher frequencies.

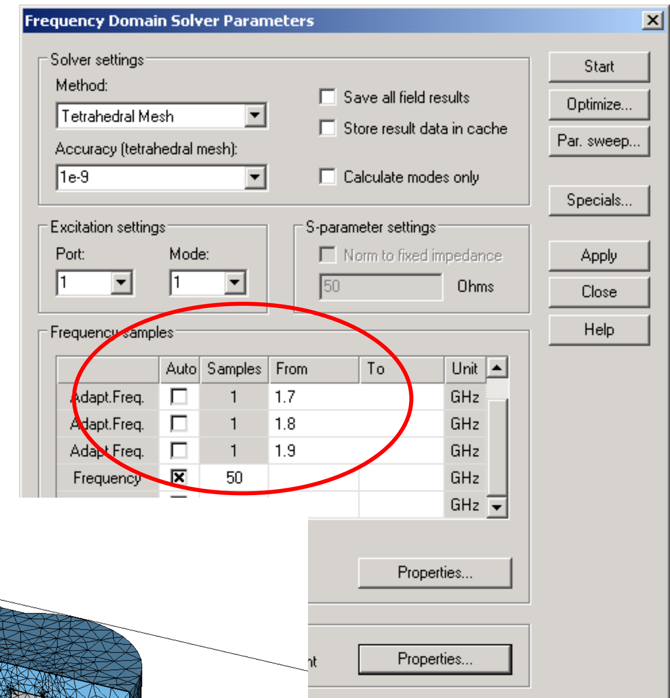
Accuracy: Hexa-Mesh vs. Tetra-Mesh

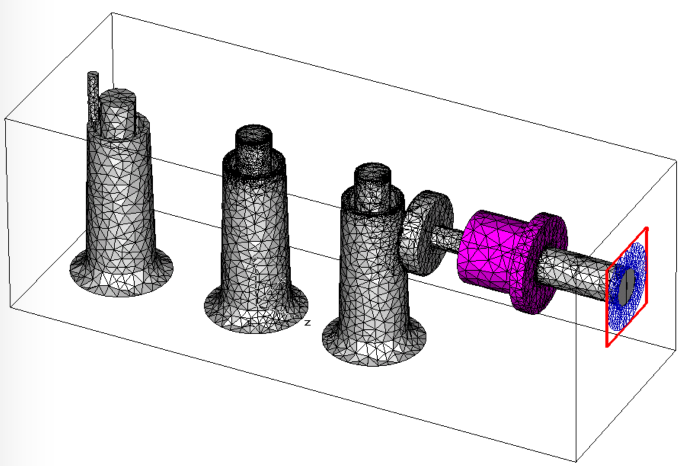
Convergence check using Tetra Mesh

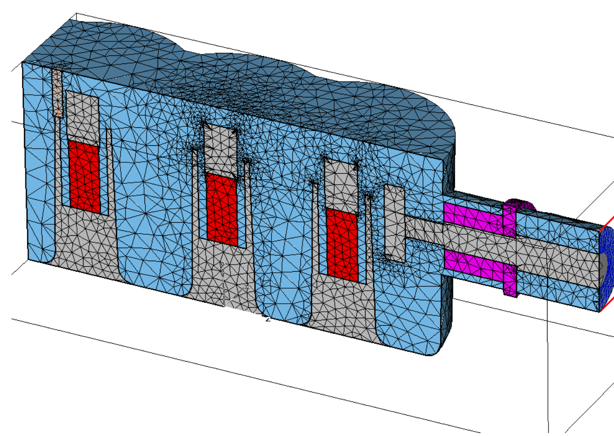
3 adaptive points to generate a refined mesh according to the appearance of the various modes!



Inital and final mesh after 5 passes

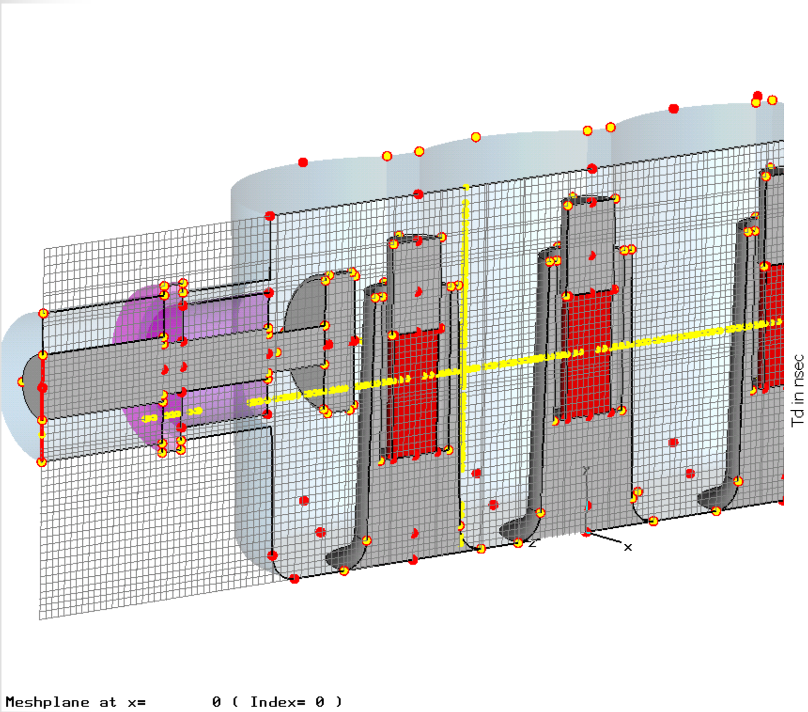


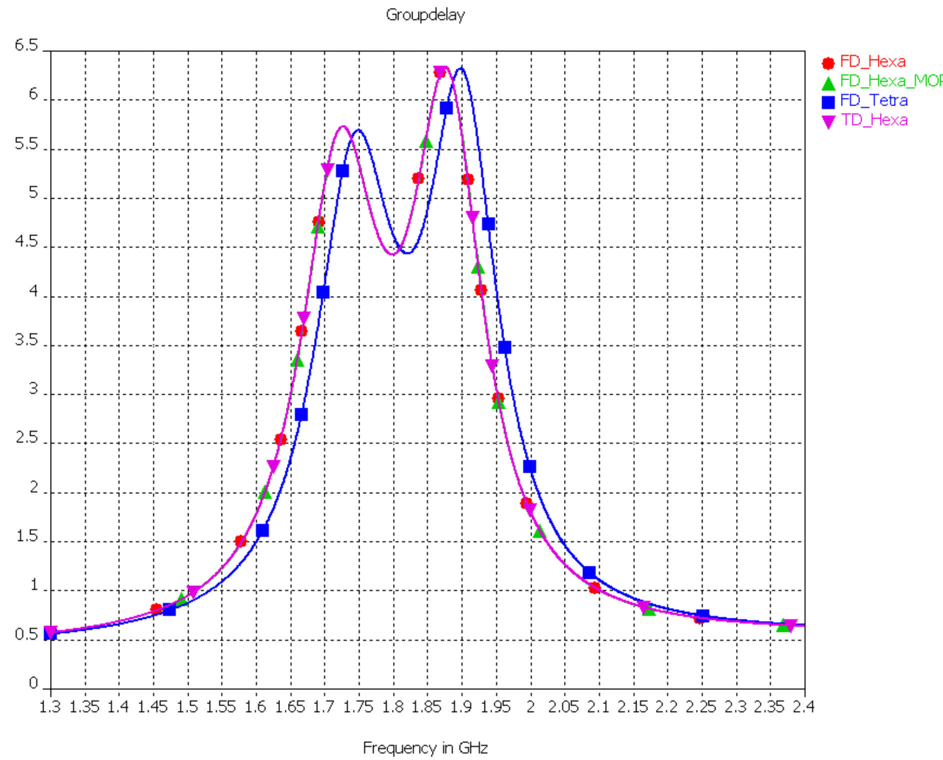




Accuracy: Hexa-Mesh vs. Tetra-Mesh

Check of Groupdelay Hexa vs. Tetra Mesh

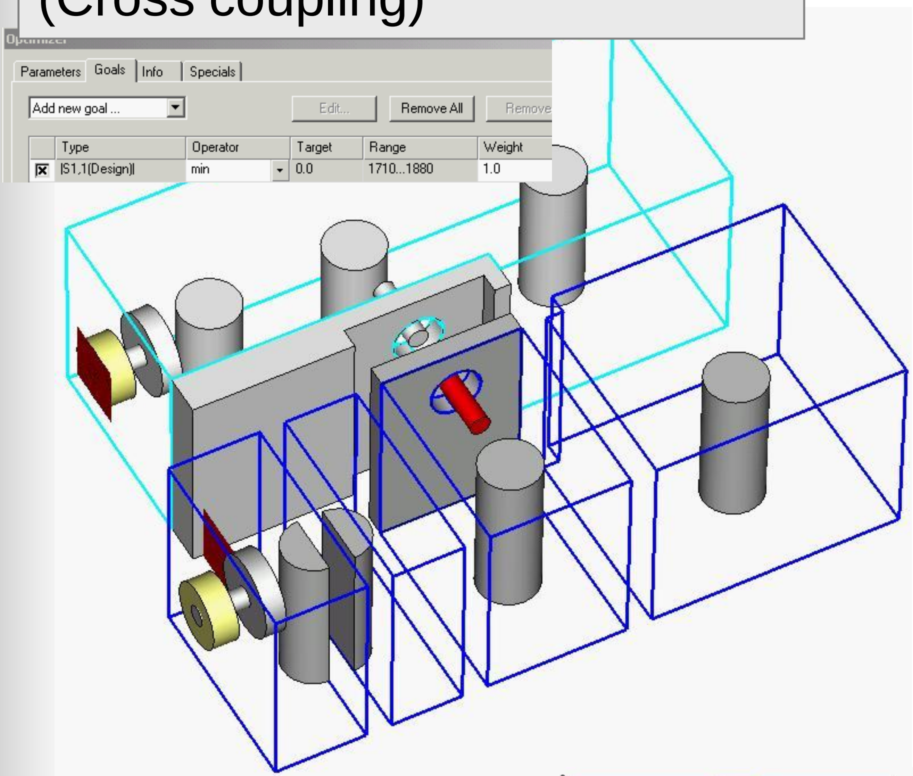


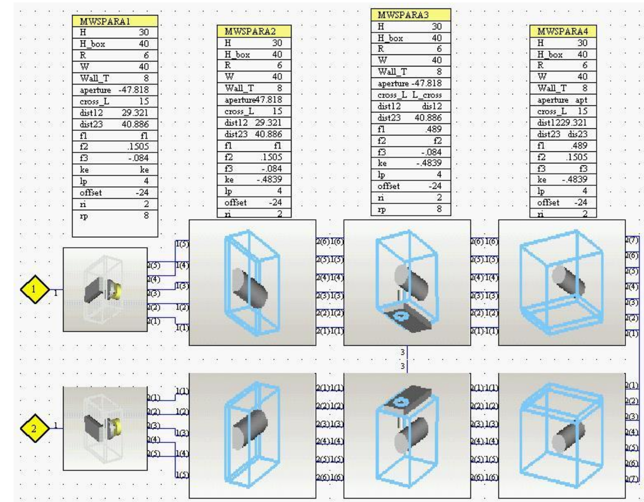


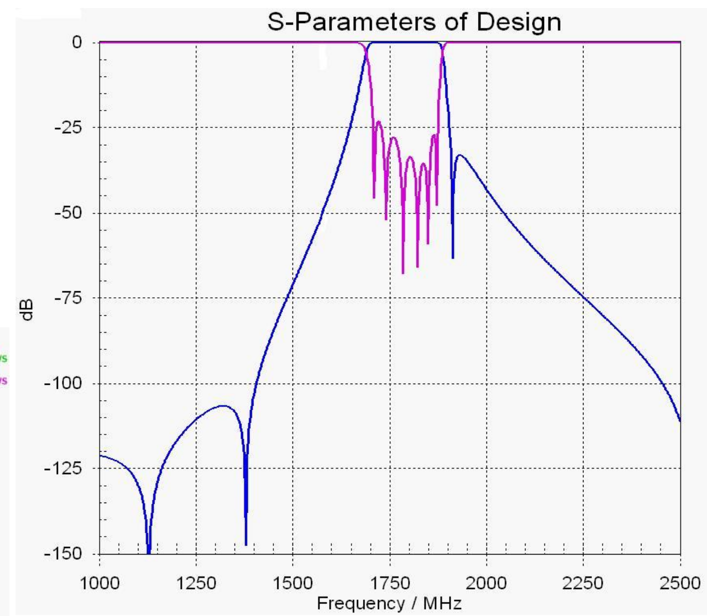
Shape of groupdelay practically identical between Hexa and Tetra mesh. Deviation of Tetra results due to facetting: the resonators appear smaller in size and thus shifts groupdelay towards higher frequencies

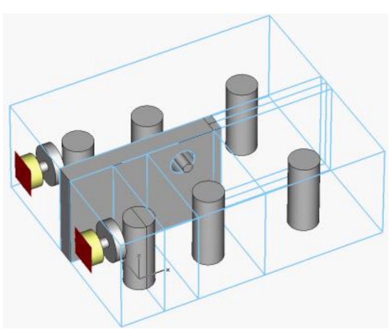
Filter Tuning: Submodels

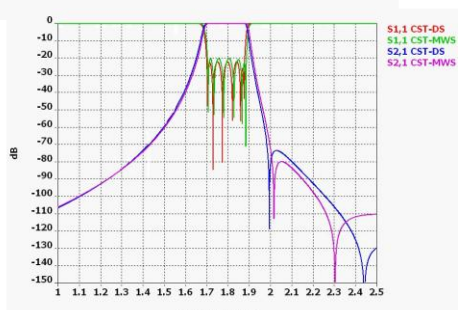
Tuning of a Combline Filter
(Cross coupling)











Filter Tuning: Submodels

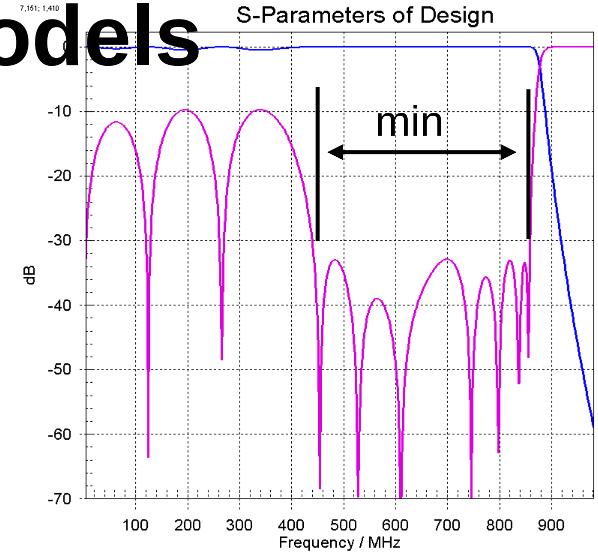
Lowpass filter

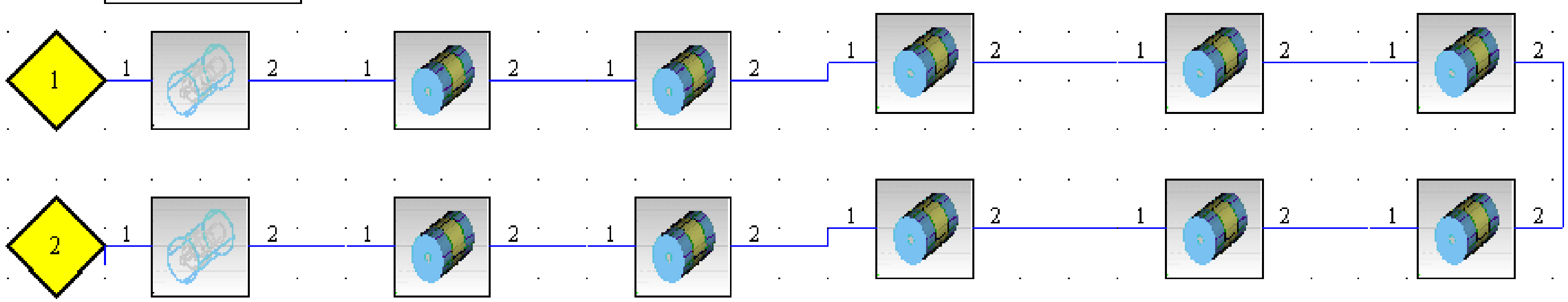
MWSPARA1	
C1_1	C1
L2_1	L2
r50	6.485
r_L	2.7
r_a	14.9
r_c1	10.75

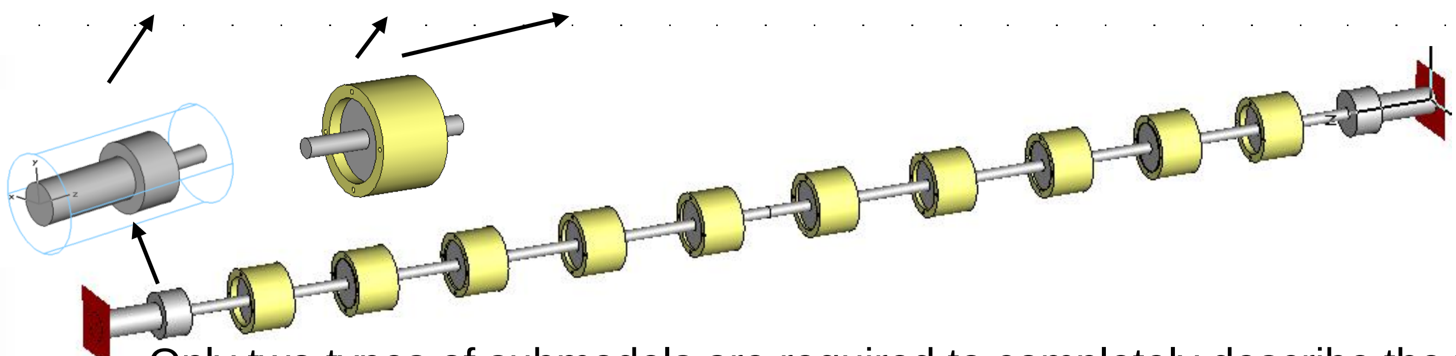
MWSPARA2	
C3_1	C3
L2_1	L2
L4_1	L4
L_tef	20
b_kerb2	0.55
d_loch	1.3
epsilon_r	2.1
r_L	2.7
r_a	14.9
r_c	11.42
t_kerb	0.7

MWSPARA3	
C3_1	C5
L2_1	L4
L4_1	L6
L_tef	20
b_kerb2	0.55
d_loch	1.3
epsilon_r	2.1
r_L	2.7
r_a	14.9
r_c	11.42
t_kerb	0.7

MWSPARA2_2	
C3_1	C7
L2_1	L6
L4_1	L8
L_tef	20
b_kerb2	0.55
d_loch	1.3
epsilon_r	2.1
r_L	2.7
r_a	14.9
r_c	11.42
t_kerb	0.7



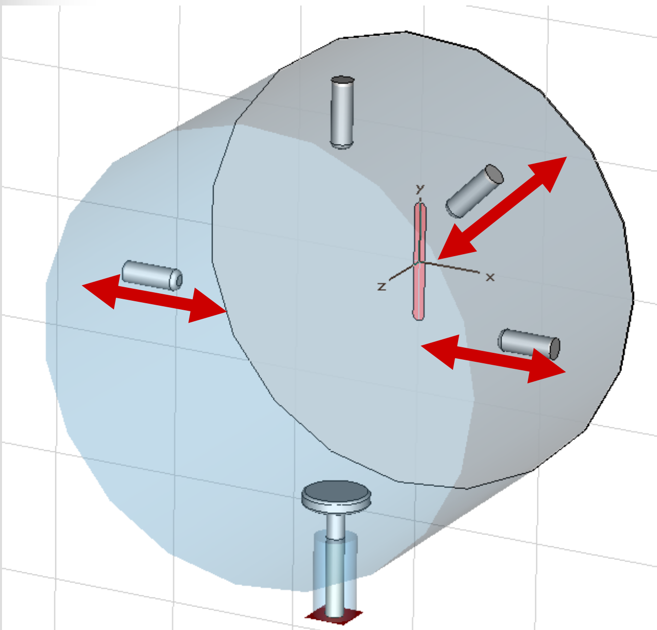


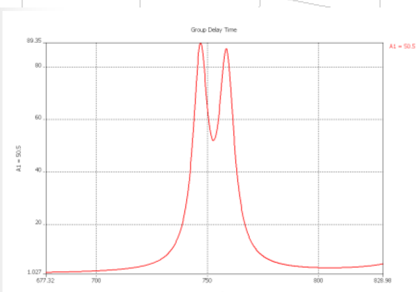


Only two types of submodels are required to completely describe the filter

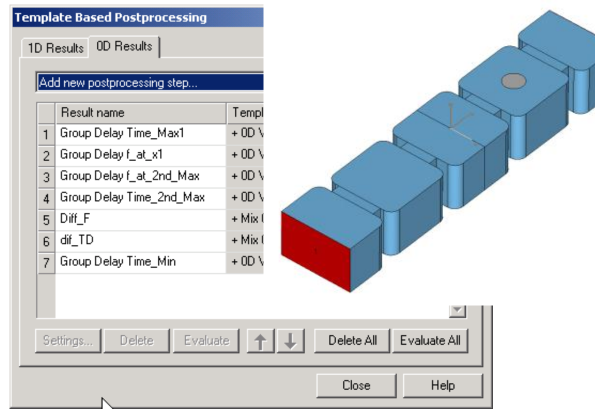
Filter Tuning: Groupdelay, Examples

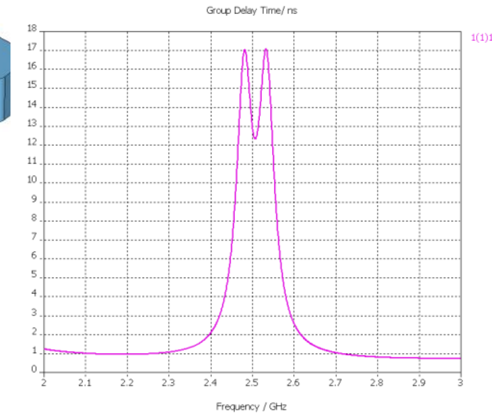
Tuning of a Dual Mode Filter



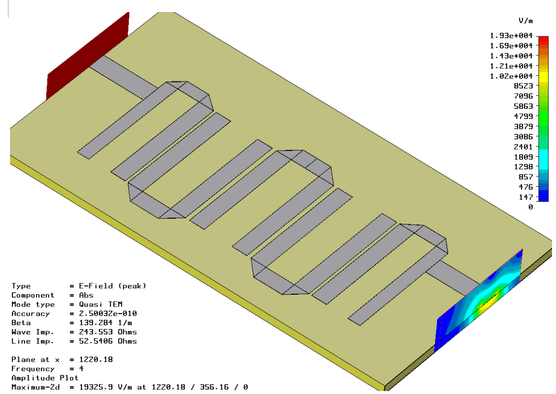


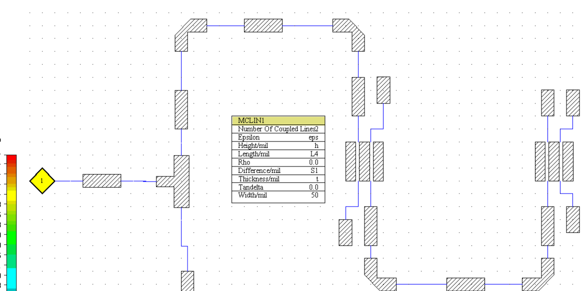
Iris Coupled Cavity Filter

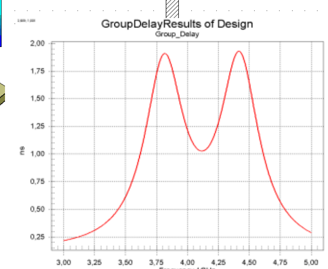




Hairpin Filter



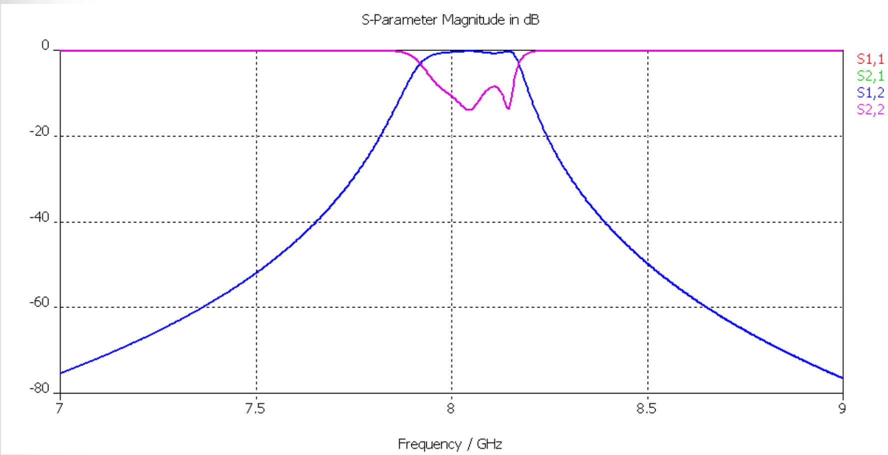




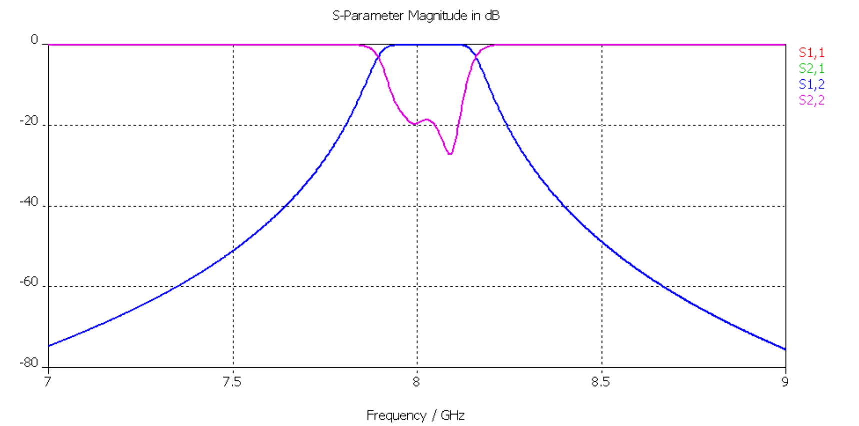
Filter Tuning: Inverse Chirp-Z

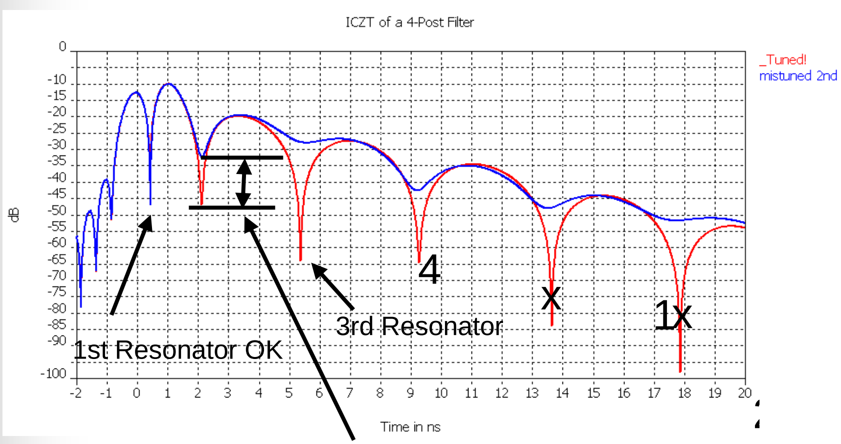
The Inverse Chirp-Z Transformation

Mistuned 2nd Resonator

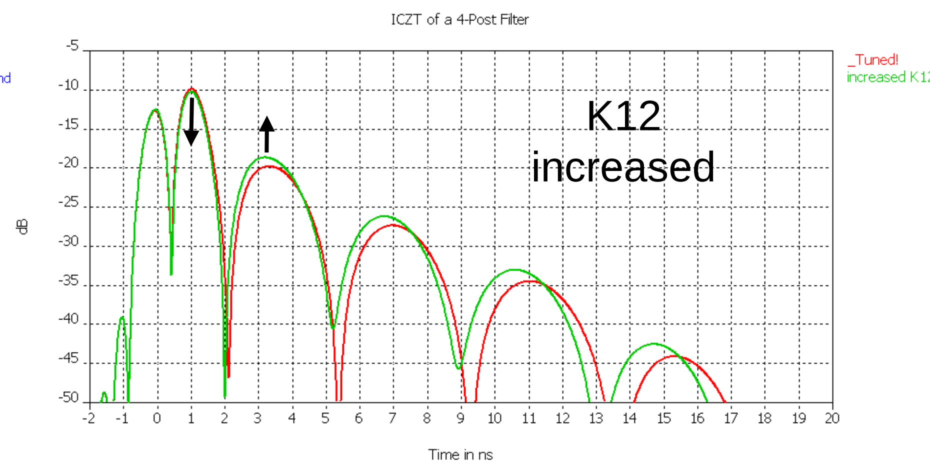


Mistuned Coupling K12
(between Resonator 1 and 2)





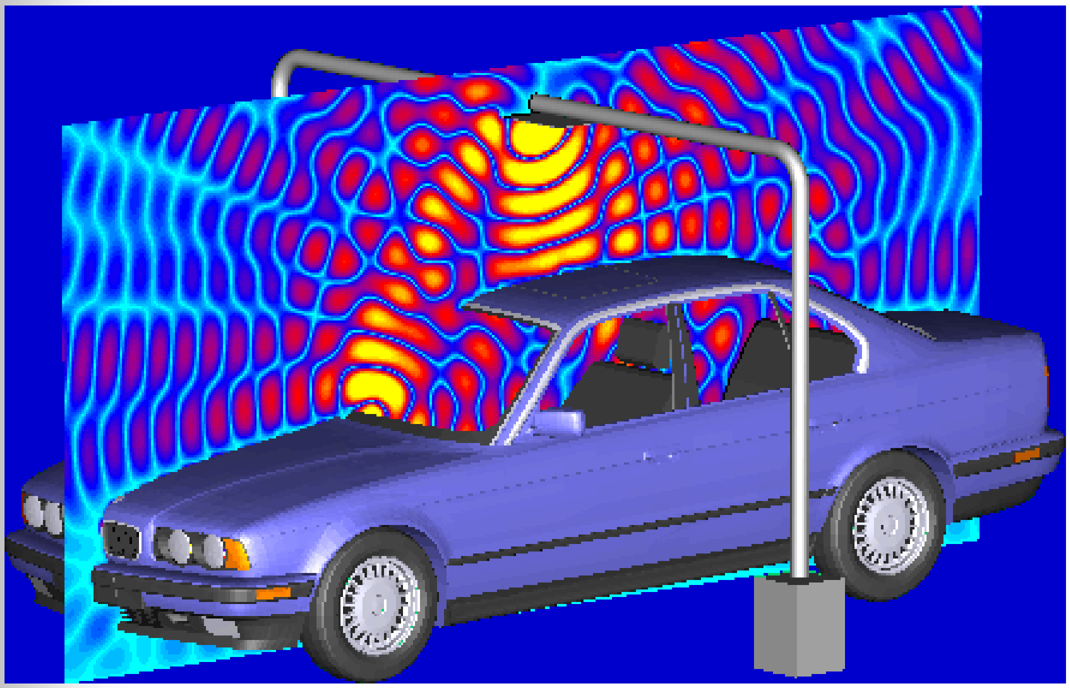
2nd Resonator mistuned



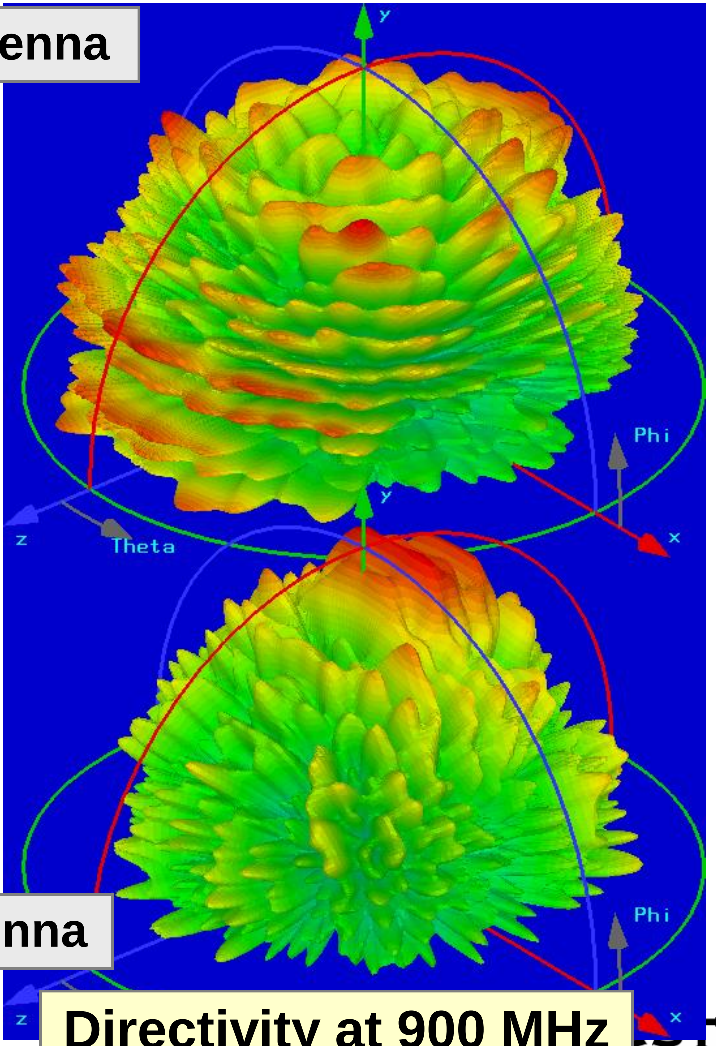
Physically Large Structures (>>λ)

Time Domain Solver or MLFMM Solver

Electric field of ETC & car antenna at 900 MHz



ETC antenna



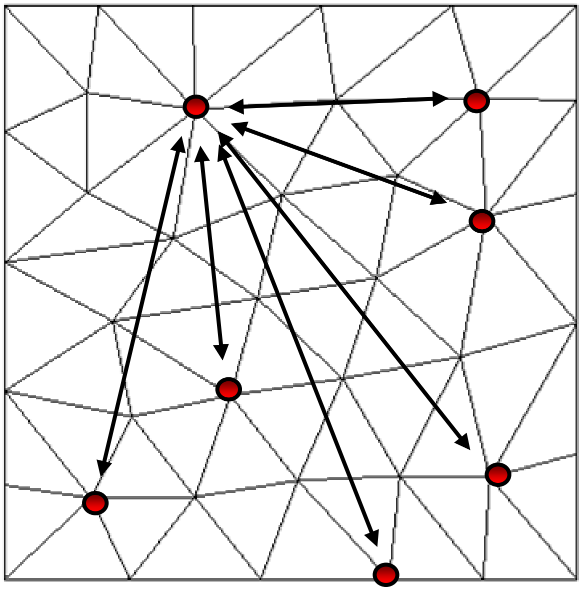
car antenna

Directivity at 900 MHz

New MLFMM Solver

- Discretization by Method of Moments
- „Open“ formulation
- Surface mesh only (triangles)
- Much less elements than volume methods
- Dense matrices

Every element couples to all other elements



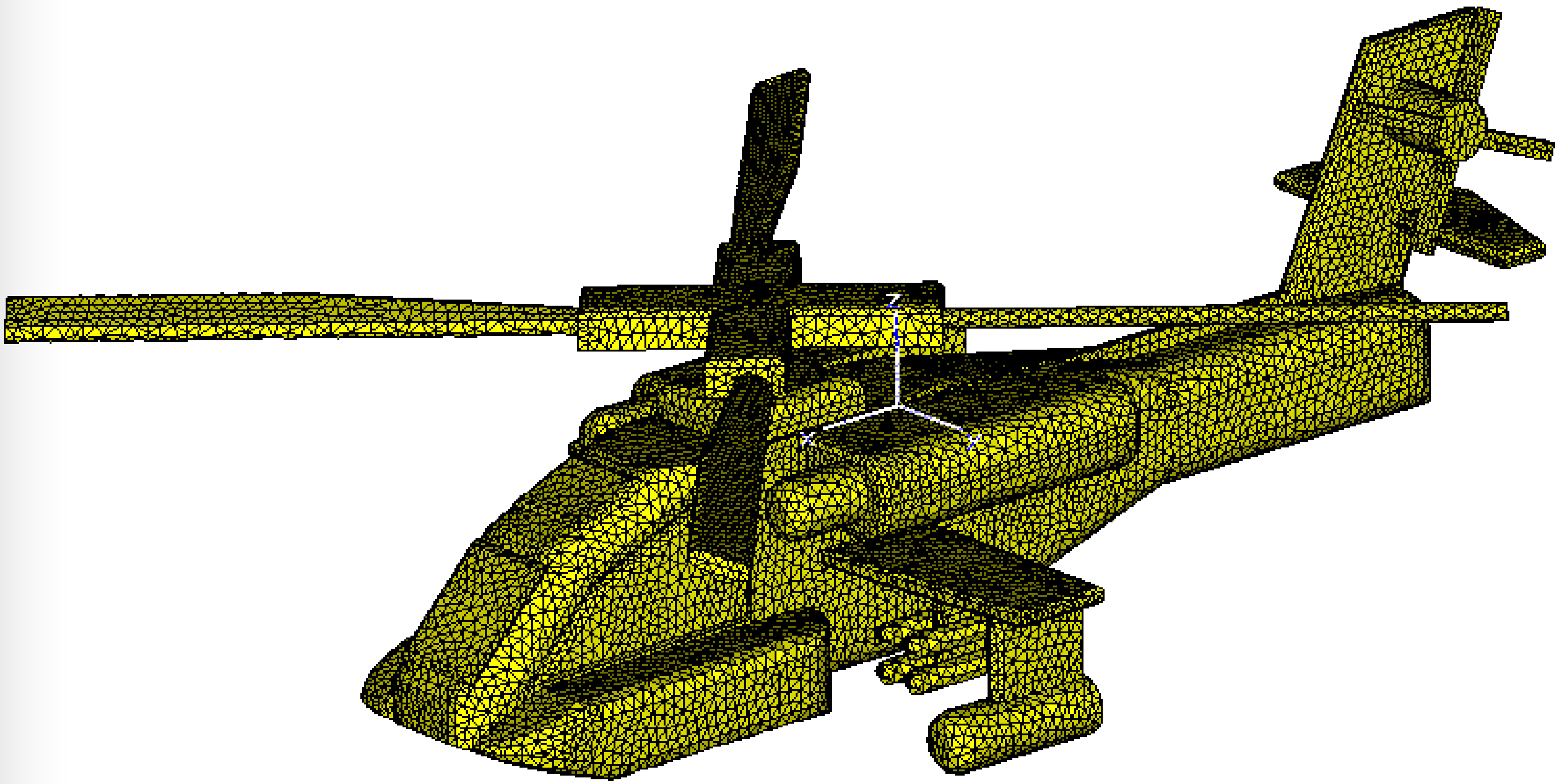
New MLFMM Solver

- MLFMM scales very good for large problems (>> λ)
- O(N log(N))
- Iterative solution only (matrix does not exist)

- Features of first version
  - Surface triangles
  - 1st, 2nd and 3rd order elements
  - PEC and dielectrics (loss free & lossy)
  - Delta gap source, plane wave
  - Direct and iterative solvers (MLFMM)
  - S-parameters, farfields, surface current

RCS Examples

Surface Mesh on Apache Helicopter



Summary

- Solver Suite in CST MICROWAVE STUDIO
  - Time Domain
  - Frequency Domain
  - Fast resonant
  - Eigenmode
  - MLFMM
  - Coupled with CST DESIGN STUDIO
- .... applied to
  - Filter applications
  - Periodic structures
  - Large structures (>> λ)