Investigation of the Photonic Band Gap accelerator cells using Ansoft HFSS

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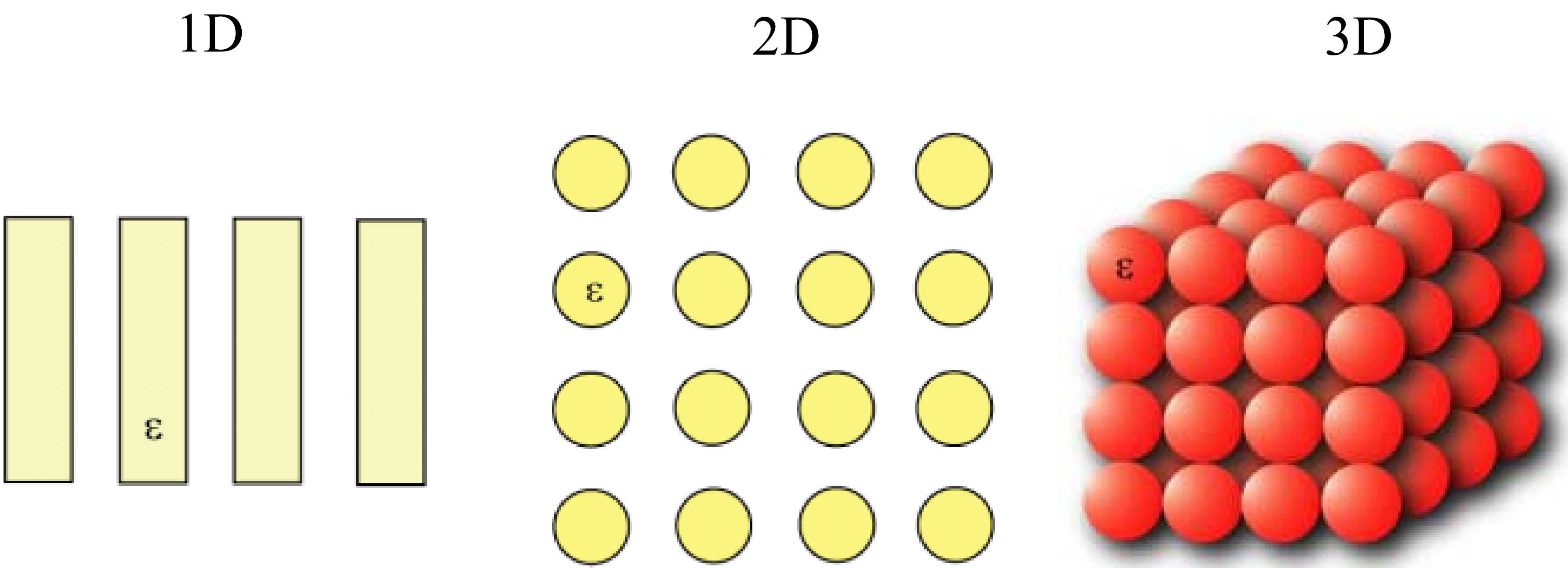
Outline

- PBG structures: definition and applications
- 2D PBG resonators: eigenmodes and coupling
- 3D PBG cells: eigenmodes, acceleration properties and field enhancement on the rods
- Coupling into a PBG accelerating structure

Photonic band gap structures

A photonic bandgap (PBG) structure is a one-, two- or three-dimensional periodic metallic and/or dielectric system (for example, of plates, rods or balls).



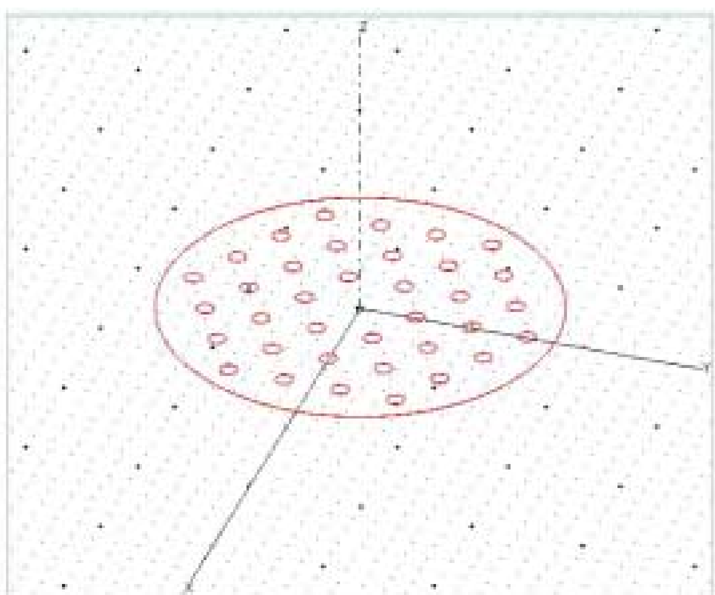
2D PBG resonators

2D PBG resonators were manufactured out of brass

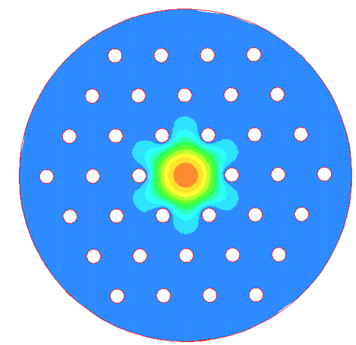
	Cavity 1	Cavity 2
Lattice spacing *b*	1.06 cm	1.35 cm
Rod radius *a*	0.16 cm	0.40 cm
a/b	0.15	0.30
Cavity radius	3.81 cm	4.83 cm
Freq. (TM_{01})	11.00 GHz	11.00 GHz
Freq. (TM_{11})	15.28 GHz	17.34 GHz
Axial length	0.787 cm	0.787 cm

Eigenmodes of 2D resonators

The HFSS mode of a 2D PBG resonator is very thin. We want to obtain high quality field patterns with smaller meshes.

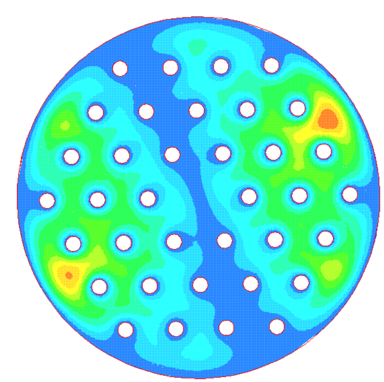


Confined mode: TM_{01}-like

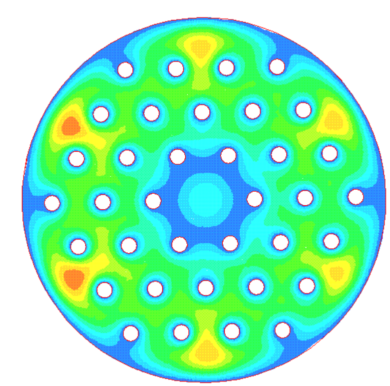


Non-confined modes:

TM_{11}-like

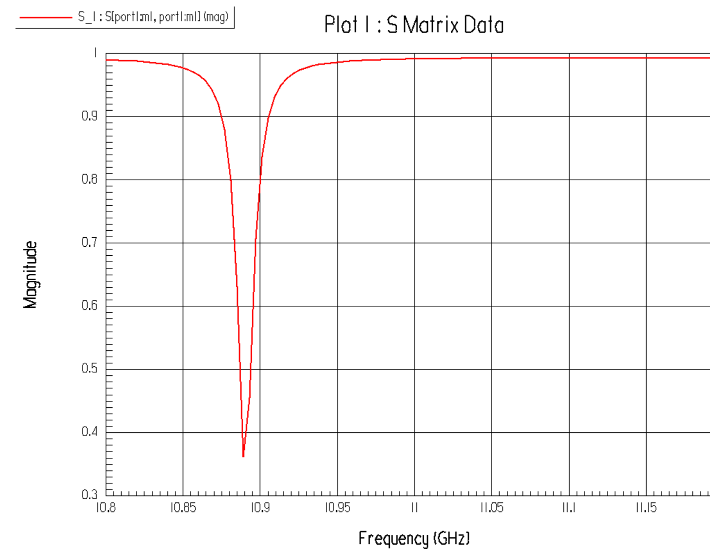


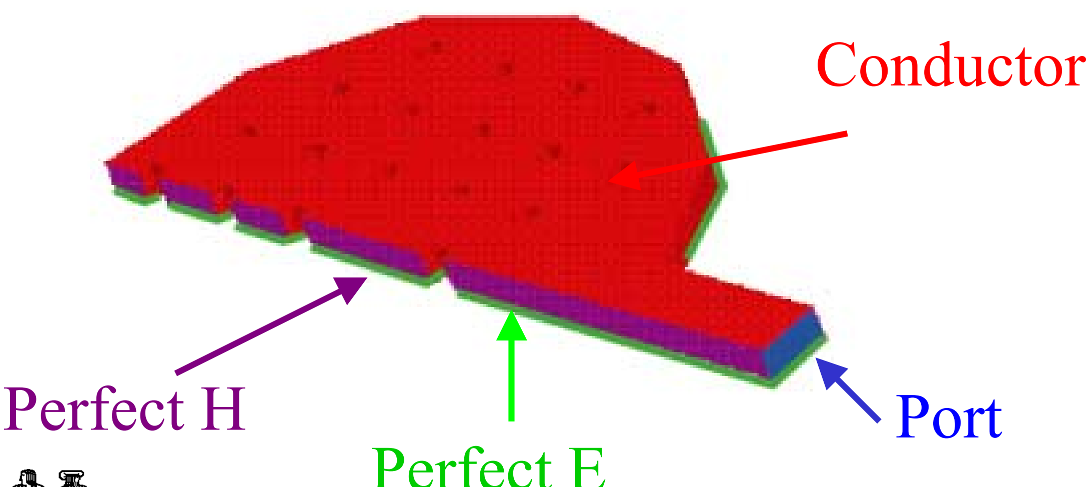
TM_{02}-like

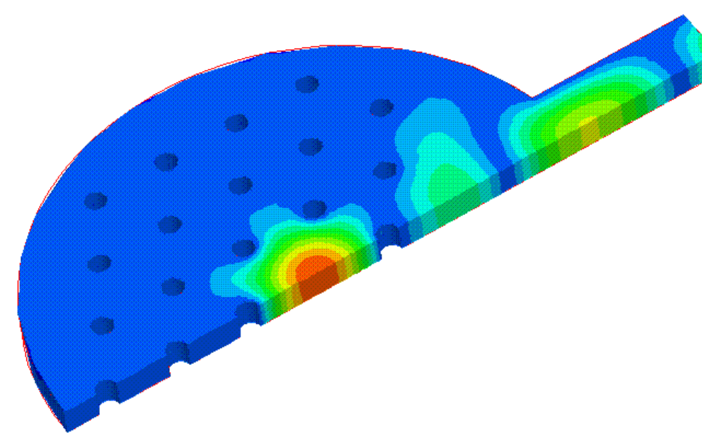


Coupling into a PBG resonator

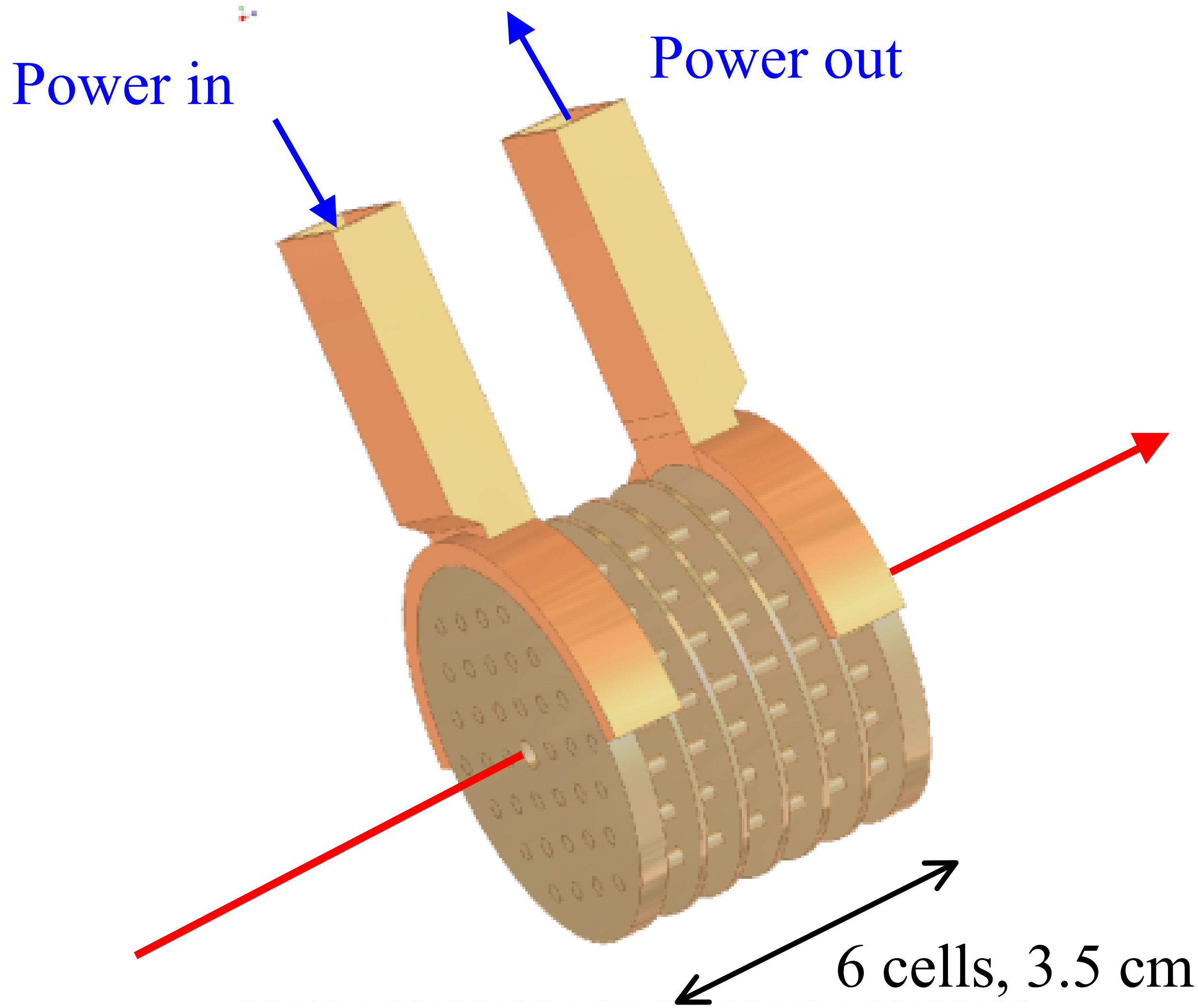
When studying the coupling, the PBG resonator cannot be thin: the volume and the wall conductance determine the Ohmic Q. Two symmetry planes are used to simplify the simulation.







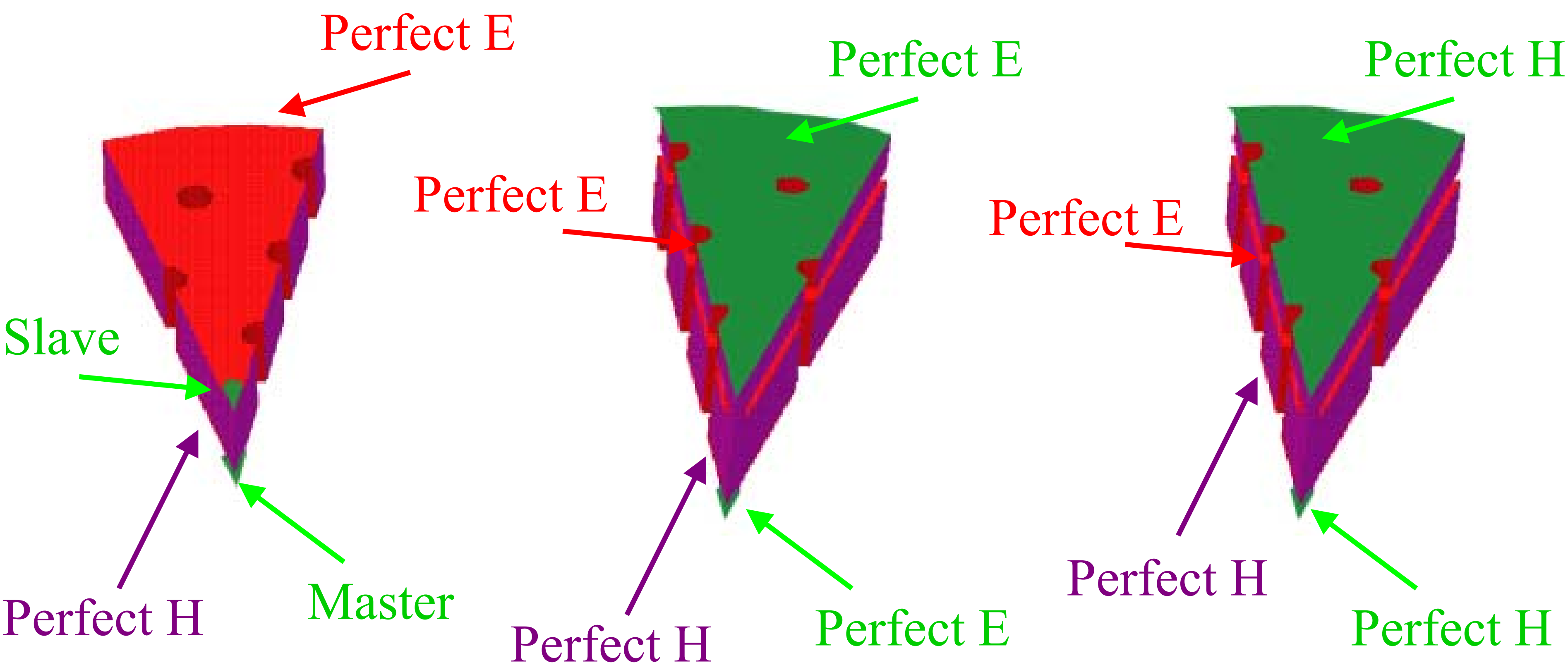
3D PBG accelerator structures



3D resonators: HFSS models

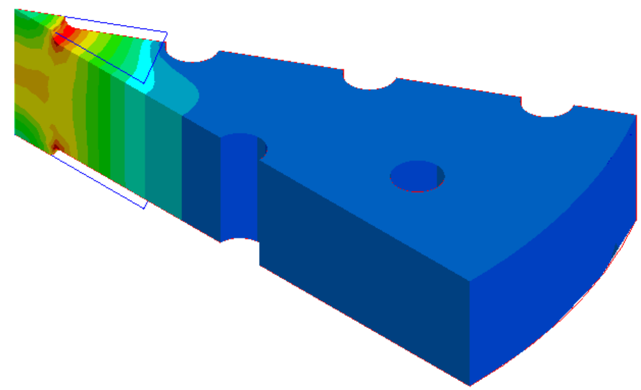
Three geometries must give the same results when modeling:

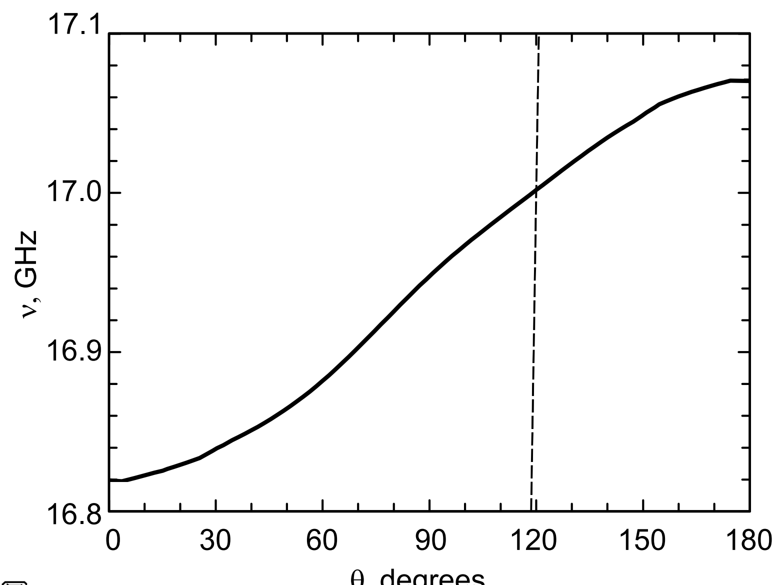
1 cell | 1 1/2 cell, perf. E | 1 1/2 cell, perf. H

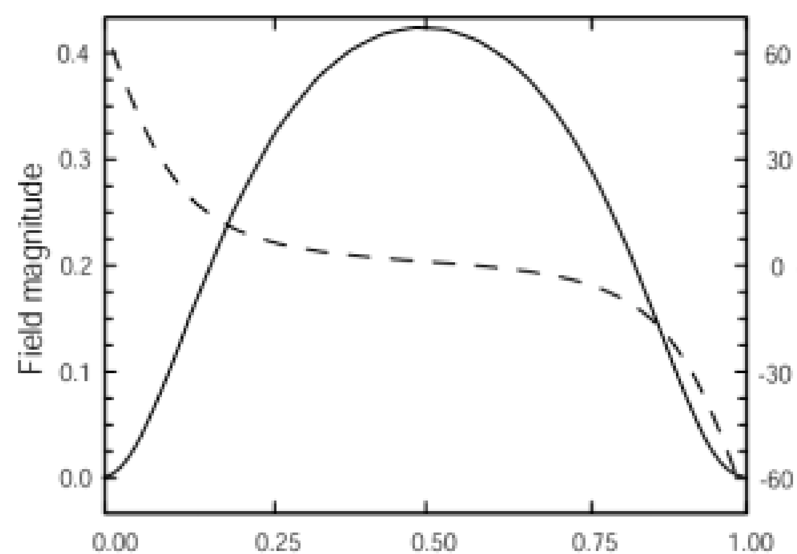


Eigenmodes of 3D resonators

Accelerating mode of the PBG cell is TM_{01} -like. We study the structure of the mode and its dispersion properties.







Calculation of acceleration properties

Acceleration properties of PBG cells are calculated by the HFSS:

- The Q-factor
- Dispersion characteristics $\omega(\Delta\phi_{cell})$ and group velocity $d\omega / dk_z$
- Shunt impedance $\dfrac{R_s}{Q} = \dfrac{(V_0 T)^2}{\omega W}, \; W = \iiint\limits_V \dfrac{\varepsilon_0 \, |E|^2}{2} dV,$

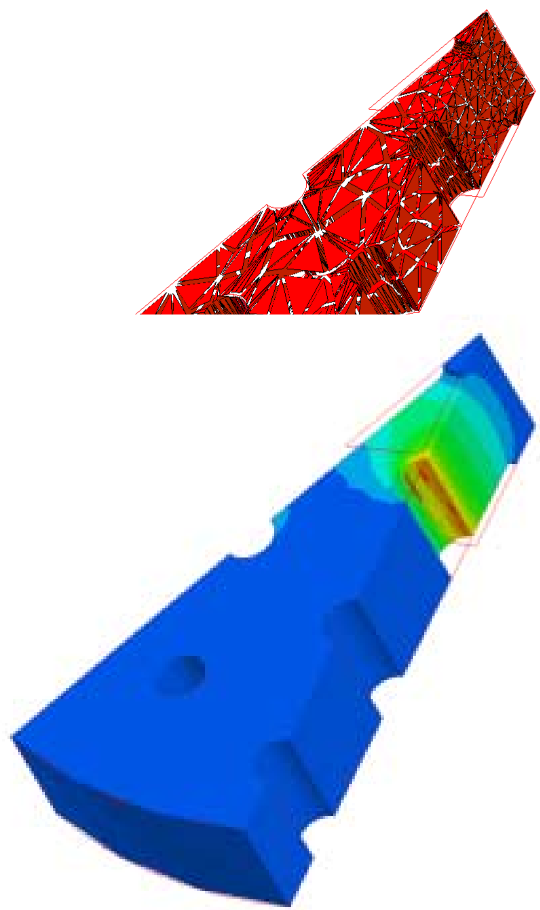
$$V_0 T = \int_0^{3L} \operatorname{Re} E(s) \sin \frac{\omega s}{c} ds = \frac{3}{2} \int_0^{L} \left[\operatorname{Re} E(s) \sin \frac{\omega s}{c} - \operatorname{Im} E(s) \cos \frac{\omega s}{c} \right] ds$$

Field enhancement on the rods

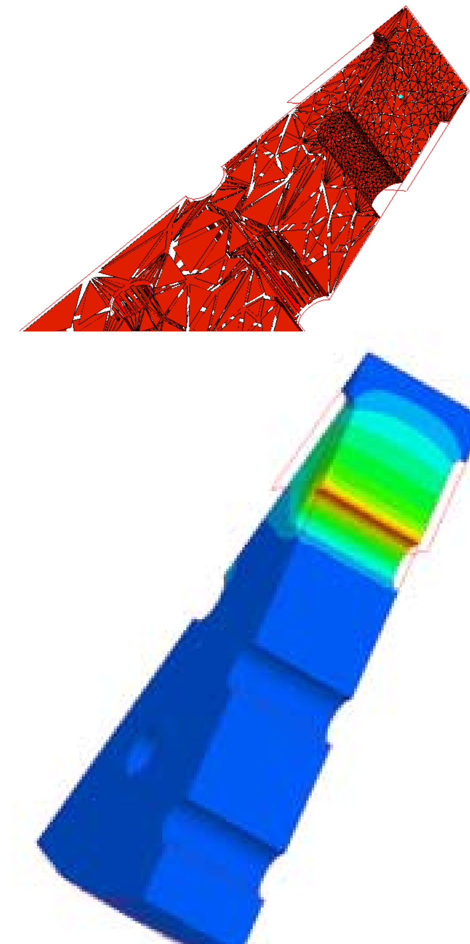
Calculation of the magnetic field enhancement on the inner rod is an important problem.

Mesh on the rod is refined manually for the accurate field calculation.

Adaptive mesh:



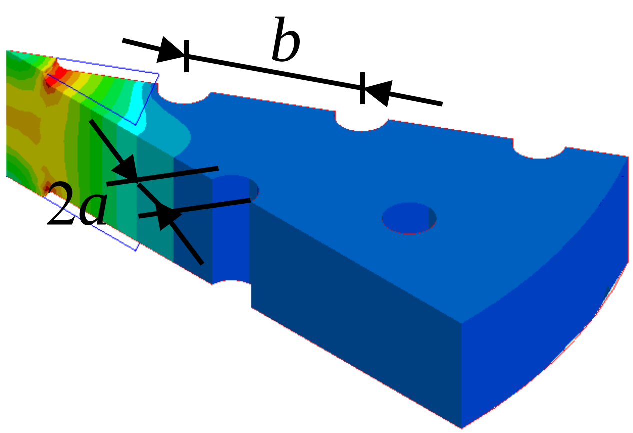
Manual mesh:

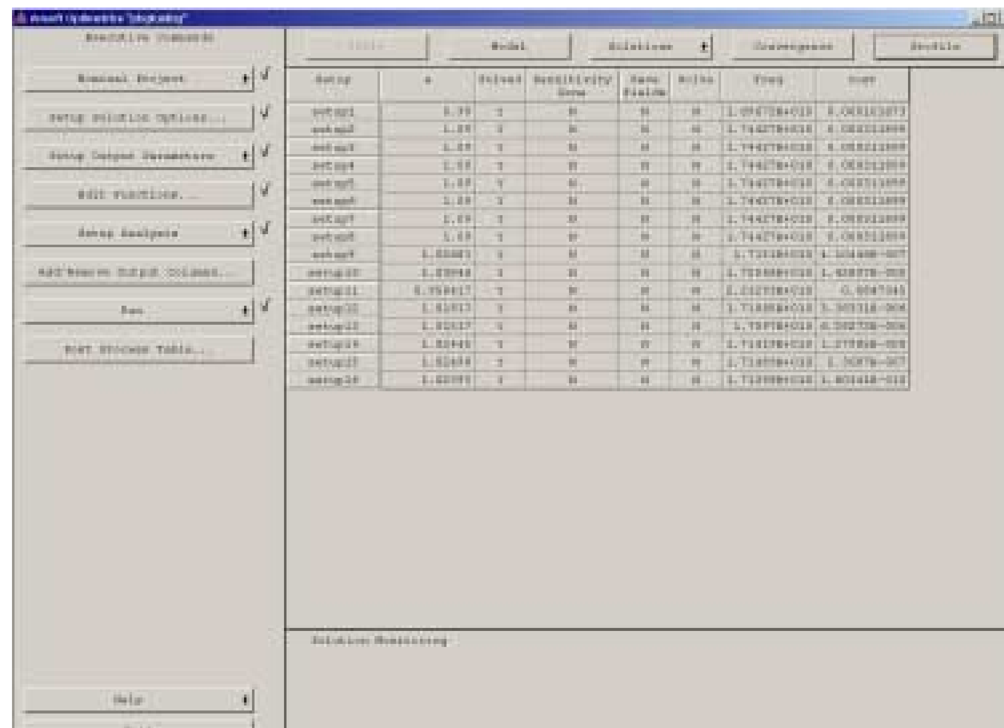


Tuning of PBG structures

The HFSS Optimetrics is used to tune the PBG cell for the frequency of 17.140 GHz.

Fastest calculations for the 1 1/2 cell, perf. E geometry

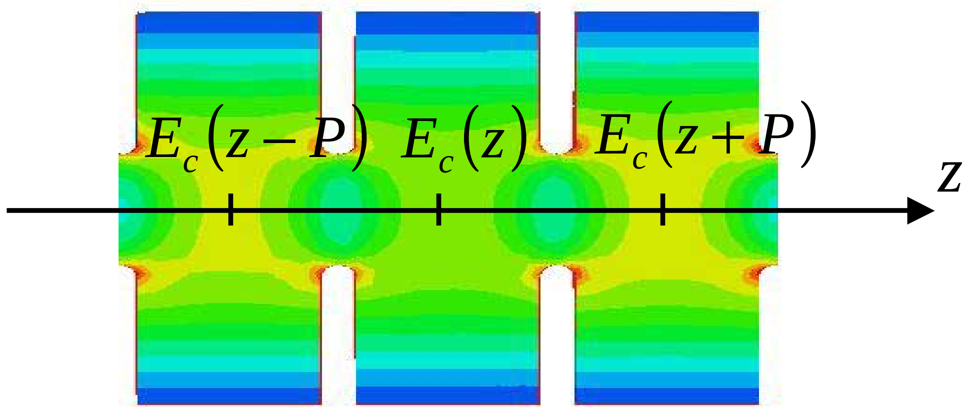




- *a* is given, find *b*
- *b* is given, find *a*
- *a/b* is given, find *a* and *b*

Tuning of the couplers

Calculation of the reflection from the couplers in periodical structures:



$$|R| = \left| [2\sin\psi - j\Delta(z)] / [2\sin\psi + j\Delta(z)] \right|,$$

where $\Delta(z) = F^{+}(z) - F^{-}(z),\ 2\cos\psi = \Sigma(z),$

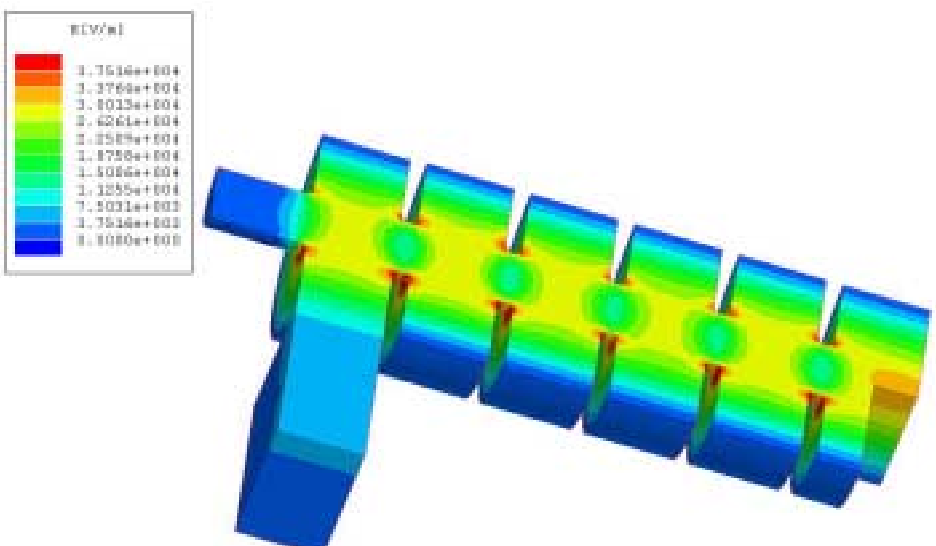
$$\Sigma(z) = F^{+}(z) + F^{-}(z),\ F^{\pm}(z) = E_c(z \pm L) / E_c(z)$$

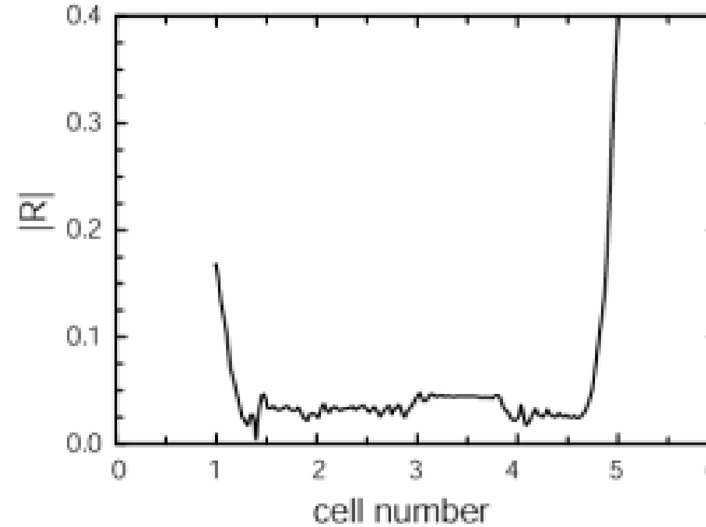
N.M. Kroll at al., LINAC2000, Monterey, CA

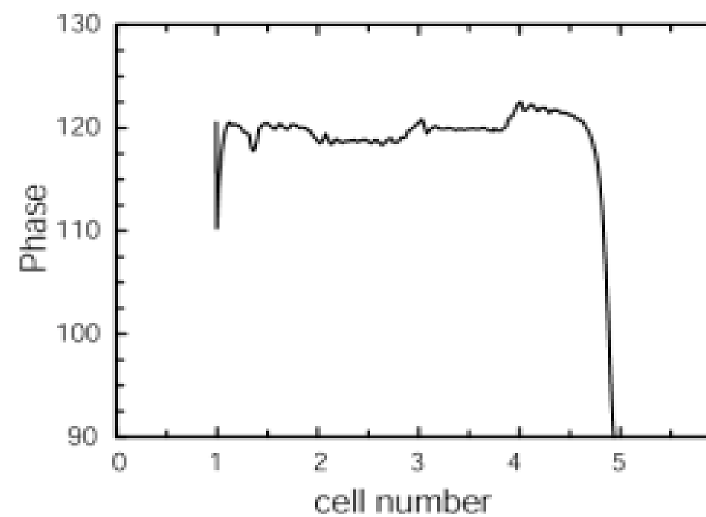
V.A. Dolgashev, HFSS User's Workshop, 2001, Los Angeles, CA

Pillbox coupler

The pillbox coupler is tuned to R=3.8 %. The HFSS solution is postprocessed by a C++ program to calculate the reflection and the phase shift per cell.

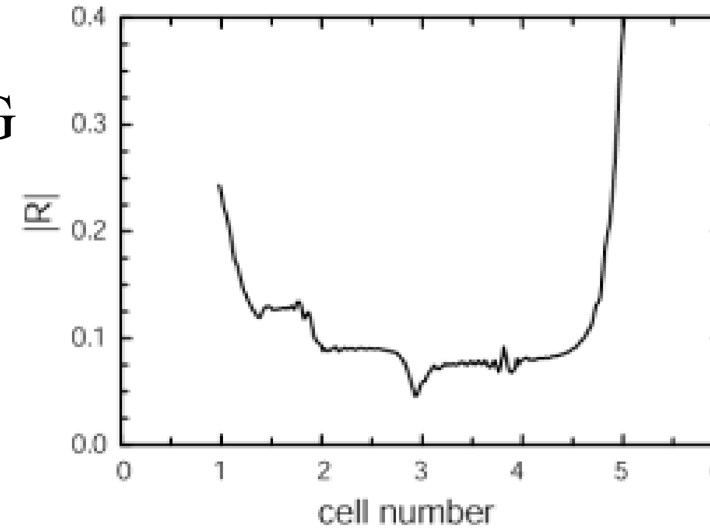


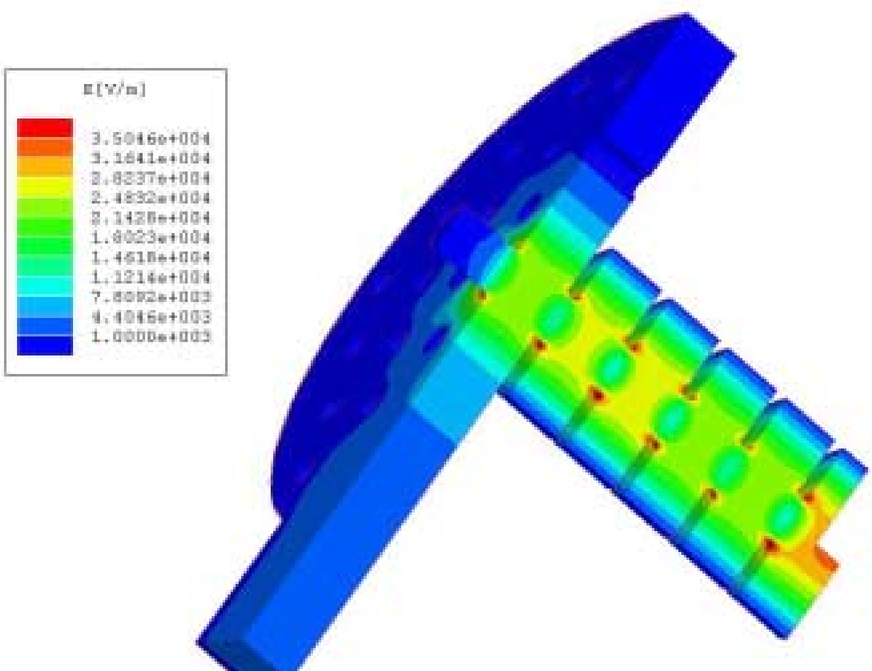


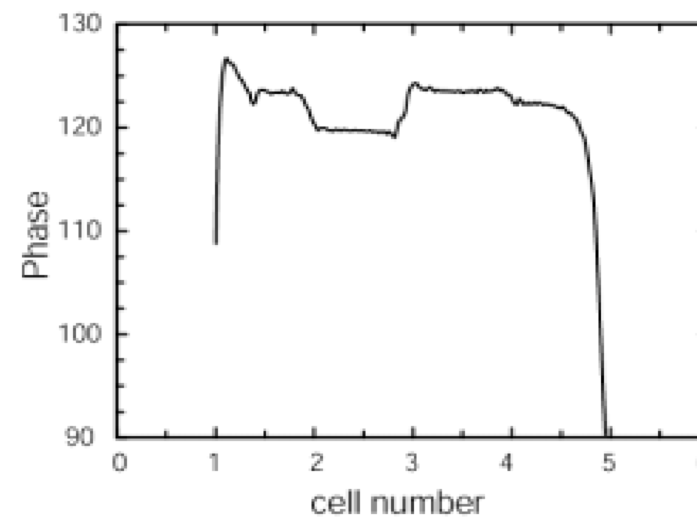


PBG coupler

The PBG coupler is tuned to R=7.8 %. To reduce the amount of computation the PBG cells are replaced by the pillbox cells with the same dispersion relation.







Conclusions

- The HFSS is used at MIT to model PBG structures
- The eigenmode solver is used to calculate the eigenmodes of 2D resonators and 3D PBG cells
- Driven solution is used to study the coupling into 2D resonators
- Manual meshing is applied to calculate the magnetic field enhancement on the rod
- HFSS Optimetrics is used to tune the 3D cell for the frequency of 17.140 GHz
- PBG coupler is tuned using the HFSS and C++ and Fortran optimization routines