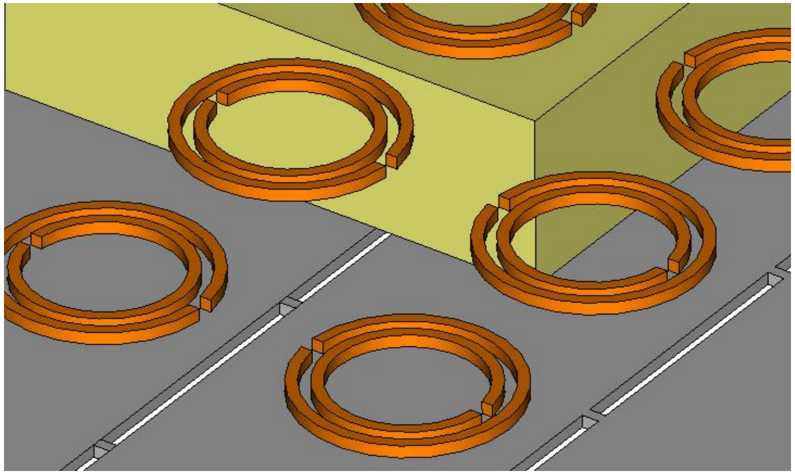
CST STUDIO SUITE™ 2006B
Application Note

Perodic Arrays : FSS / PBG / ...



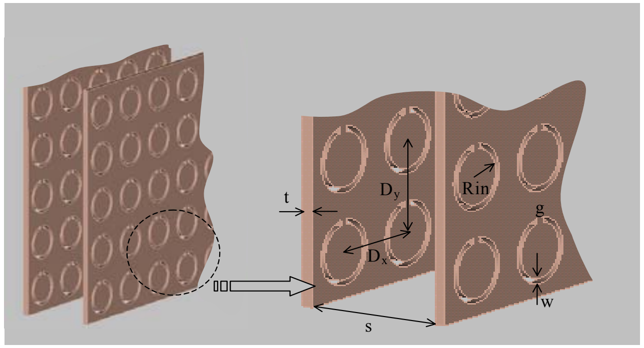
Frequency Selective Surfaces
Unit Cell
Complimentary Arrays
Tips + Tricks
Metamaterials
Dispersion Diagrams

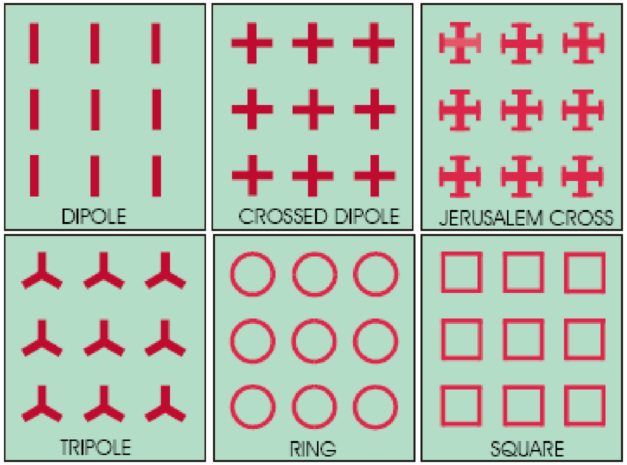
Periodic Arrays

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



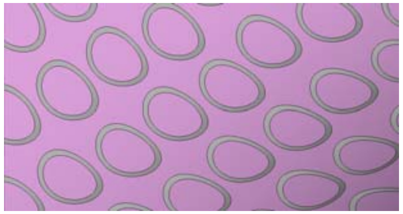


Applications

(Photo by Kockums AB).

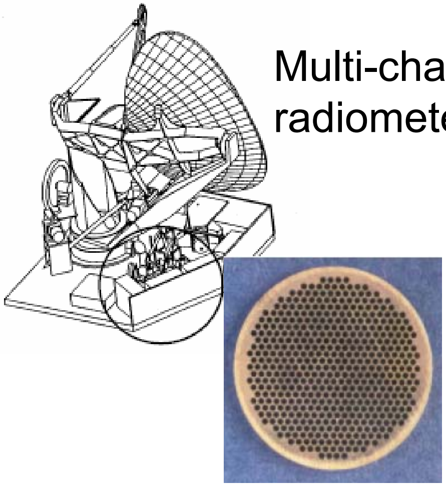
Ghost ships

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

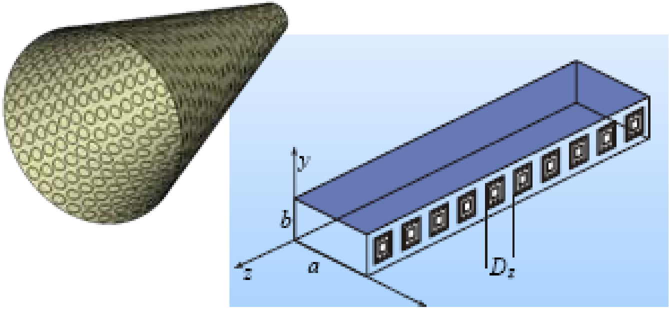


Stealthy wallpaper to block Wi-Fi signals

FSS Radomes



Multi-channel radiometer filters



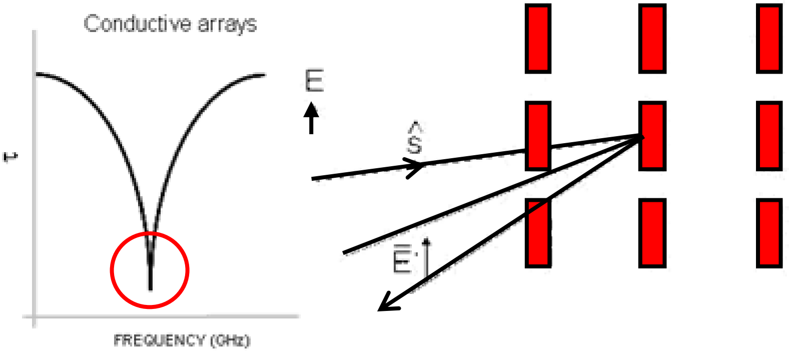
FSS horns and waveguides and reflector antennas

Optically tunable FSS arrays on Si

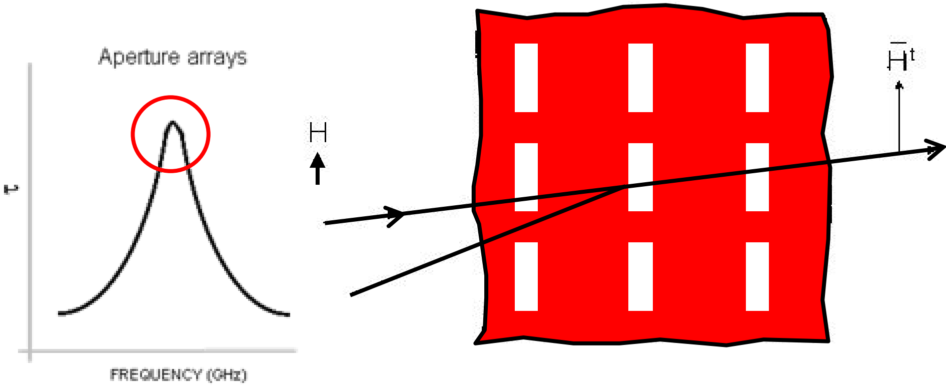
Conducting and Aperture Arrays

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



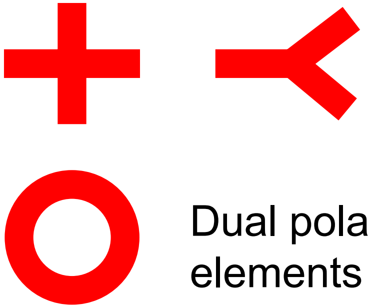
Band Stop



Band Pass

Typical FSS Elements

Single polar elements



Dual polar elements

Resonant wavelength λ_r for a conducting element without substrate

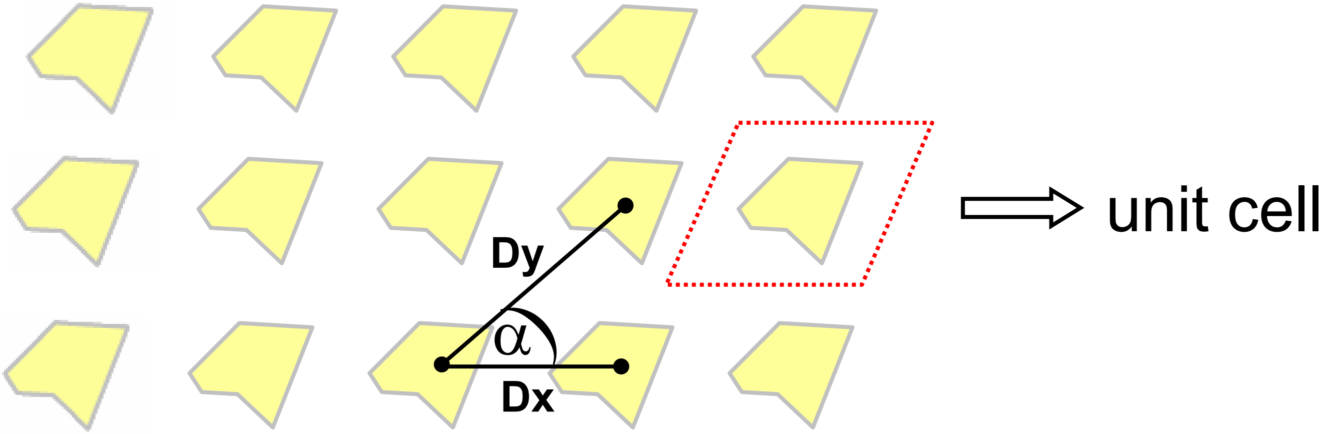
Dipoles = l/2

Rings=2π(Rin + 0.5w)

With a substrate the resonant wavelength

$$\lambda_\varepsilon = \frac{\lambda_r}{\sqrt{\varepsilon_r}}$$

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

Passive and Active Arrays

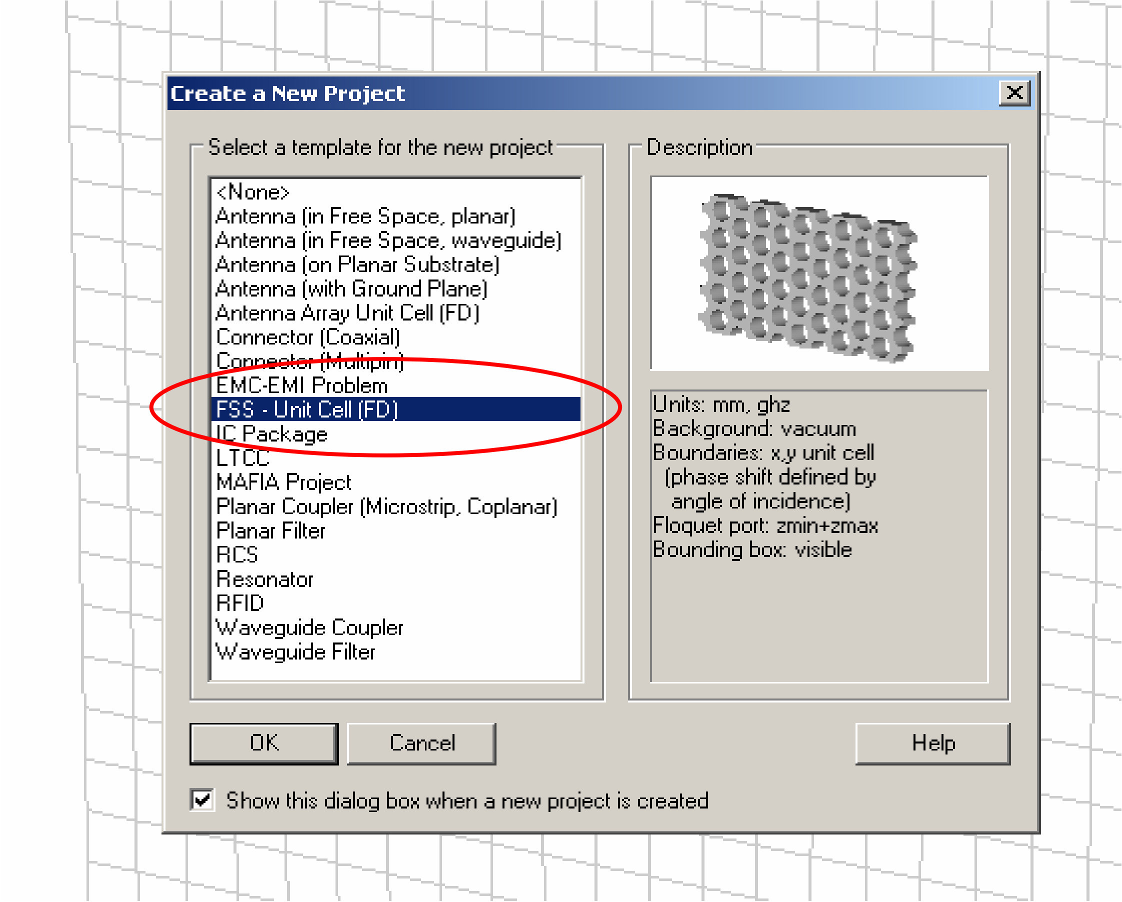
Methods of Excitation

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

CST MWS Example (F Solver)



Create a New Project

Select a template for the new project

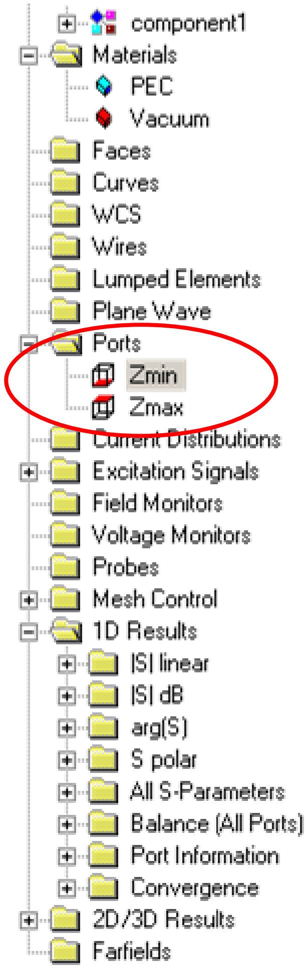
- <None>
- Antenna (in Free Space, planar)
- Antenna (in Free Space, waveguide)
- Antenna (on Planar Substrate)
- Antenna (with Ground Plane)
- Antenna Array Unit Cell (FD)
- Connector (Coaxial)
- Connector (Multipin)
- EMC-EMI Problem
- FSS - Unit Cell (FD)
- IC Package
- LTCC
- MAFIA Project
- Planar Coupler (Microstrip, Coplanar)
- Planar Filter
- RCS
- Resonator
- RFID
- Waveguide Coupler
- Waveguide Filter

Description

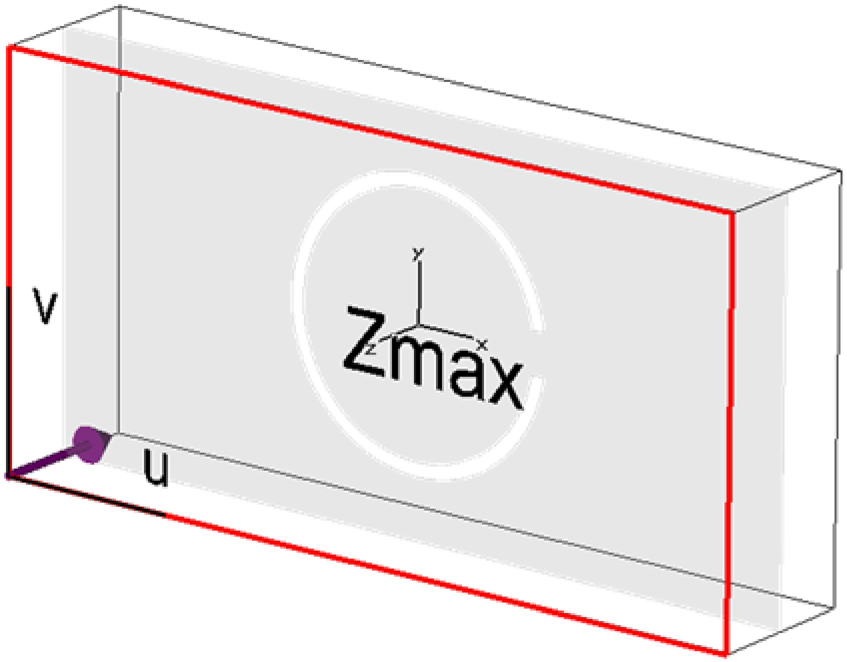
Units: mm, ghz
Background: vacuum
Boundaries: x,y unit cell
(phase shift defined by
angle of incidence)
Floquet port: zmin+zmax
Bounding box: visible

☑ Show this dialog box when a new project is created

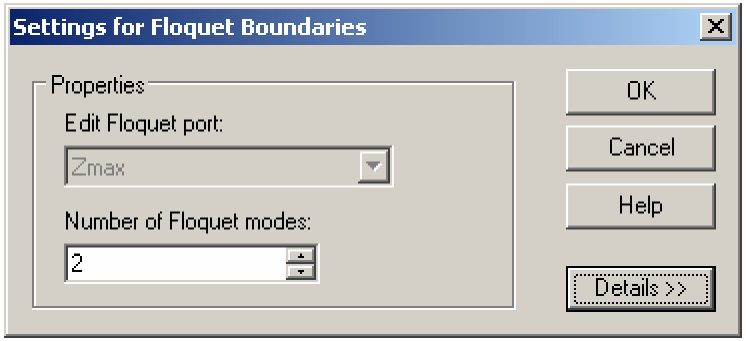
Floquet Ports



- component1
- Materials
  - PEC
  - Vacuum
- Faces
- Curves
- WCS
- Wires
- Lumped Elements
- Plane Wave
- Ports
  - Zmin
  - Zmax
- Current Distributions
- Excitation Signals
- Field Monitors
- Voltage Monitors
- Probes
- Mesh Control
- 1D Results
  - |S| linear
  - |S| dB
  - arg(S)
  - S polar
  - All S-Parameters
  - Balance (All Ports)
  - Port Information
  - Convergence
- 2D/3D Results
- Farfields



```
Number of modes      = 2
```



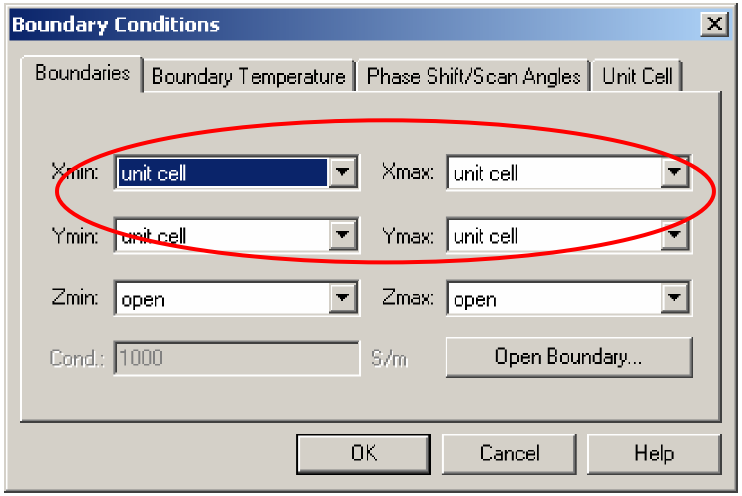
Settings for Floquet Boundaries

Properties

Edit Floquet port: Zmax

Number of Floquet modes: 2

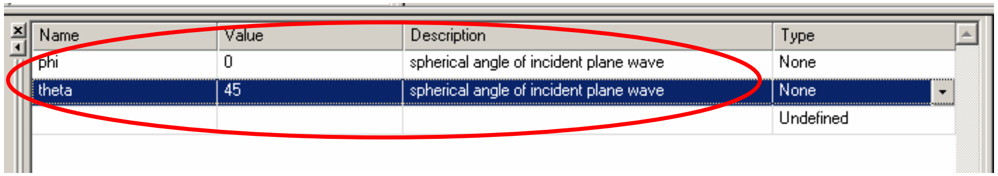
Unit Cell Boundaries



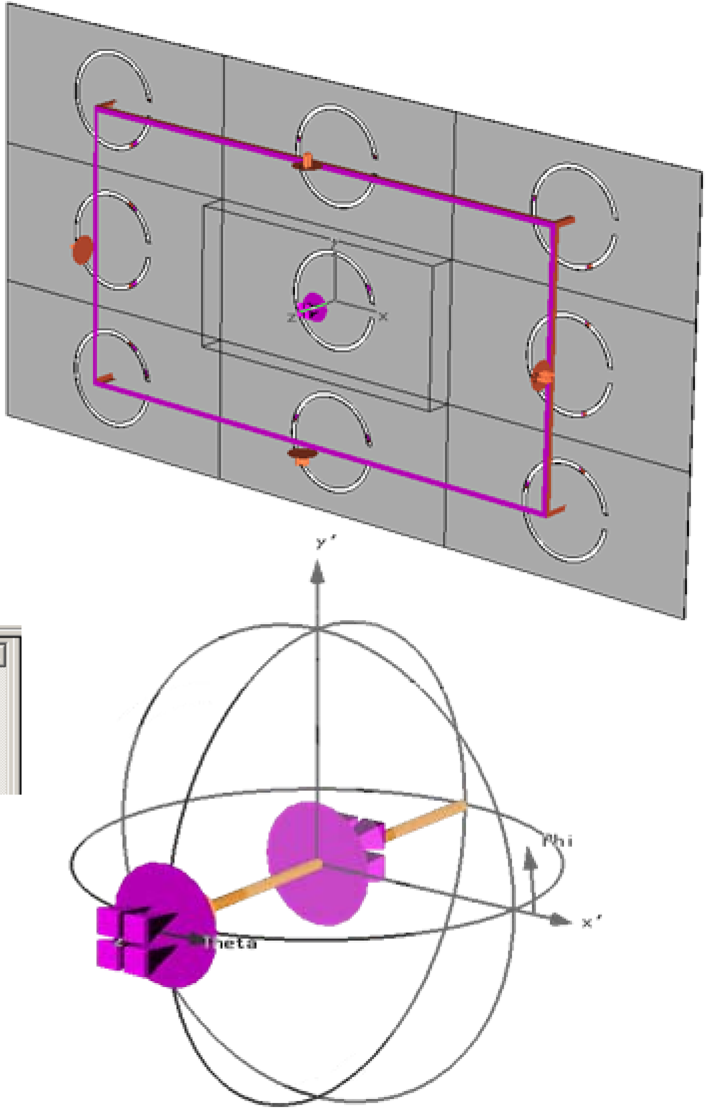
Boundary Conditions

Boundaries | Boundary Temperature | Phase Shift/Scan Angles | Unit Cell

Xmin: unit cell
Xmax: unit cell
Ymin: unit cell
Ymax: unit cell
Zmin: open
Zmax: open
Cond.: 1000 S/m

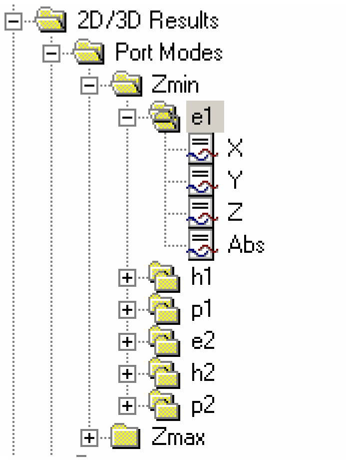


Name	Value	Description	Type
phi	0	spherical angle of incident plane wave	None
theta	45	spherical angle of incident plane wave	None
			Undefined



Unit cell boundaries allow plane waves at arbitrary angles

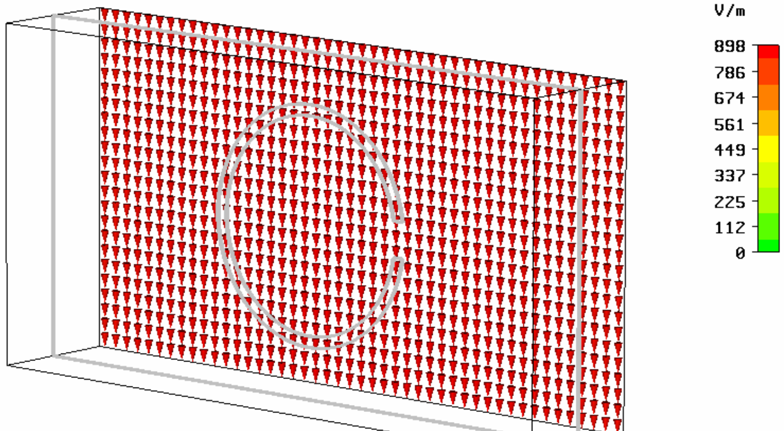
Plane Wave Incidence at arbitary Angles

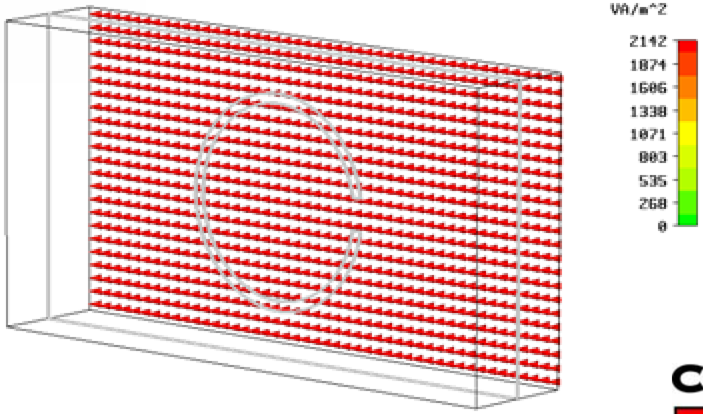


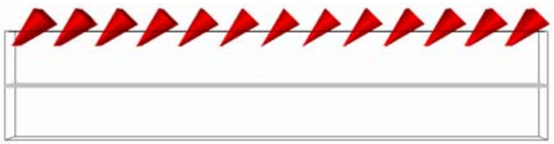
```
Type         = E-Field (peak)

Mode type    = Plane wave
Accuracy     = 1.52537e-007
Normal Beta  = 14.8201 1/m
Wave Imp.    = 376.732 Ohms

Plane at z   = -3
Frequency    = 1
Phi          = 0 degrees
Theta        = 45 degrees
Phase        = 0 degrees
Maximum-2d   = 898.22 V/m at 1.91748 / -7.68 / -3
```





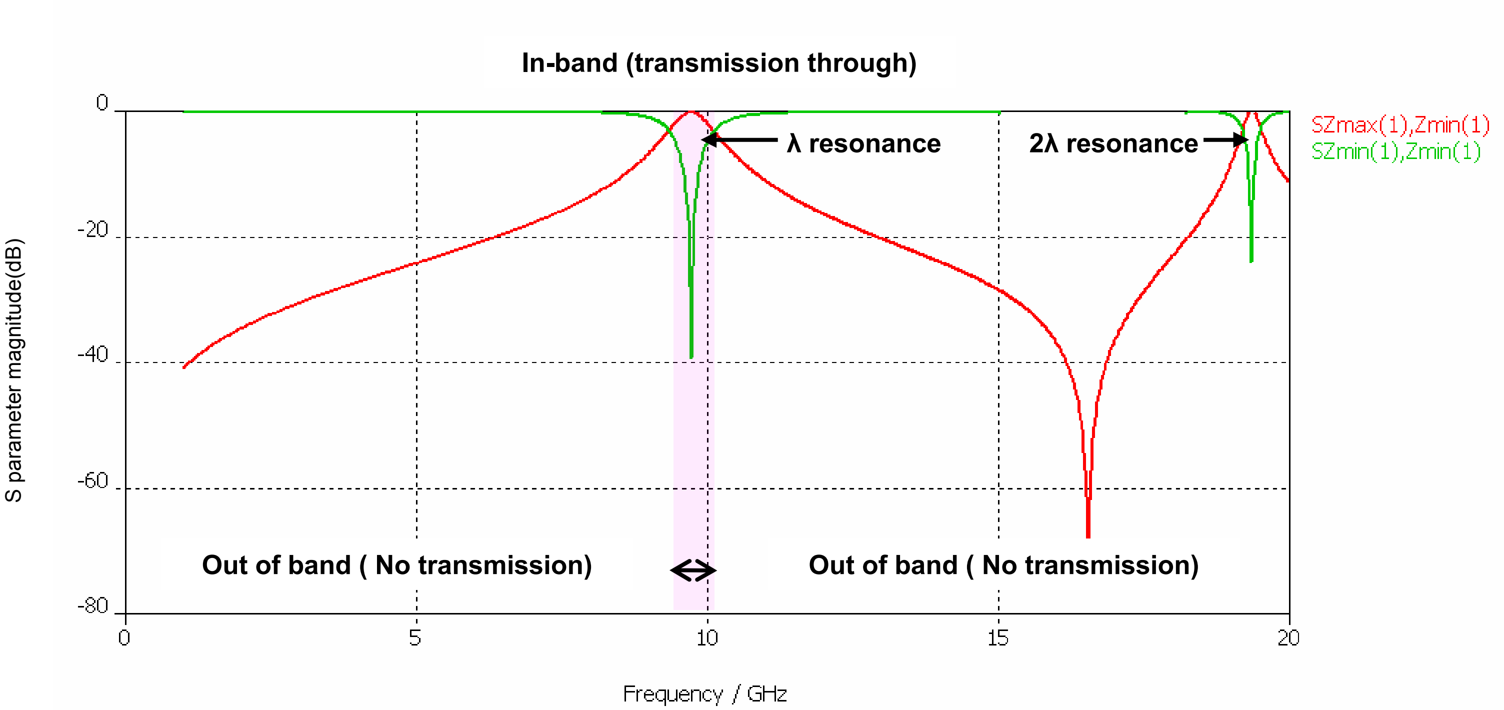


```
Type         = Powerflow (peak)

Mode type    = Plane wave
Accuracy     = 1.52537e-007
Normal Beta  = 14.8201 1/m
Wave Imp.    = 376.732 Ohms

Plane at z   = -3
Frequency    = 1
Phi          = 0 degrees
Theta        = 45 degrees
Maximum-2d   = 2141.57 VA/m^2 at -4.374 / -7.68 / -3
```

Transmission Coefficient



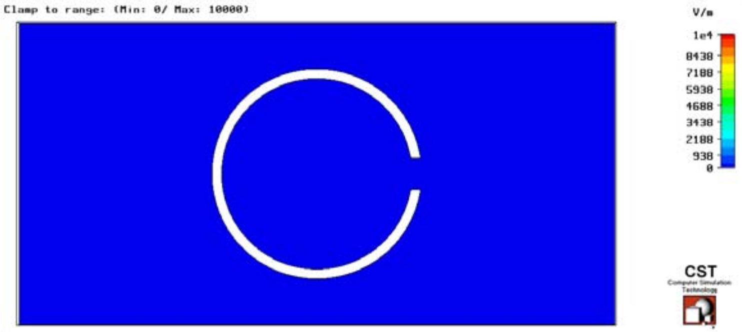
In-band (transmission through)

λ resonance

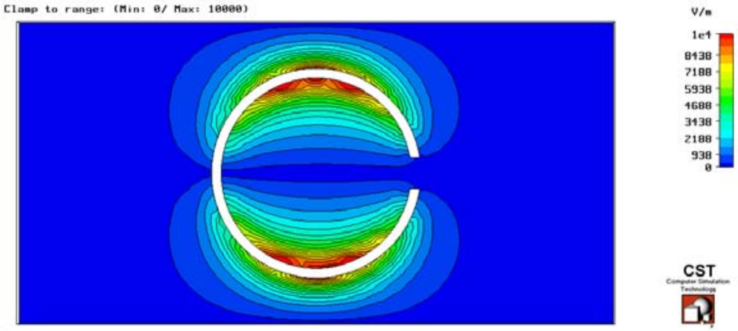
2λ resonance

Out of band (No transmission)

Out of band (No transmission)



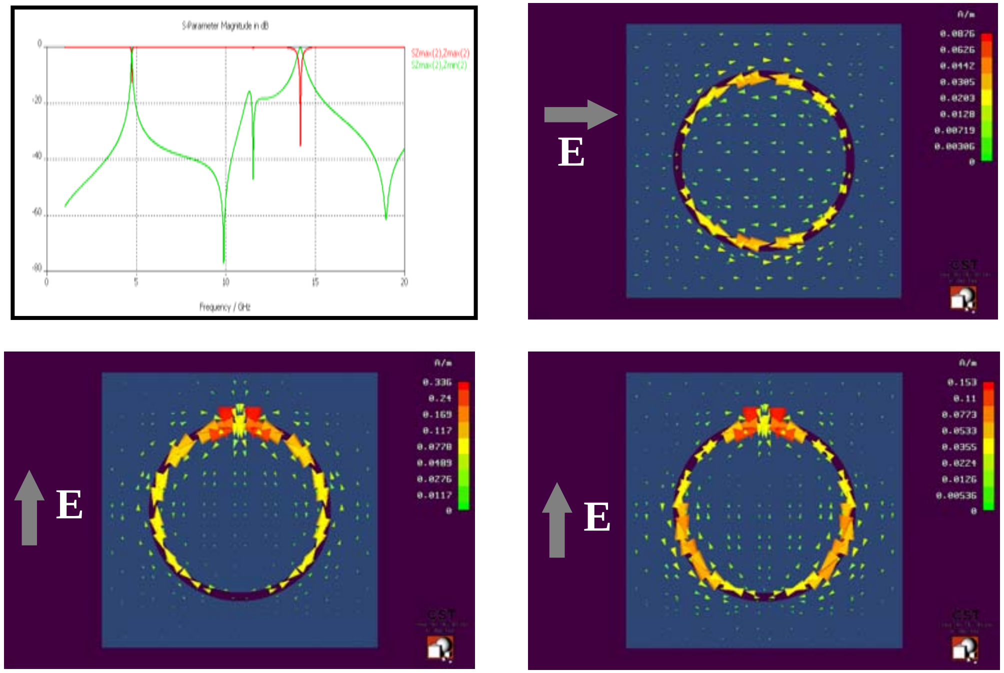
E field animation at 1GHz



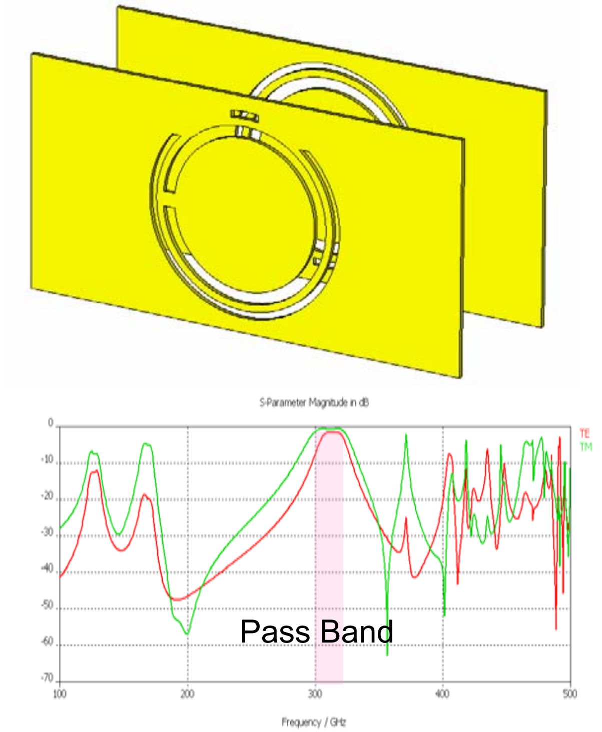
E field animation at 10GHz

RingResonator_FrequencyDomain.zip

Coupling Modes & Casacaded Arrays

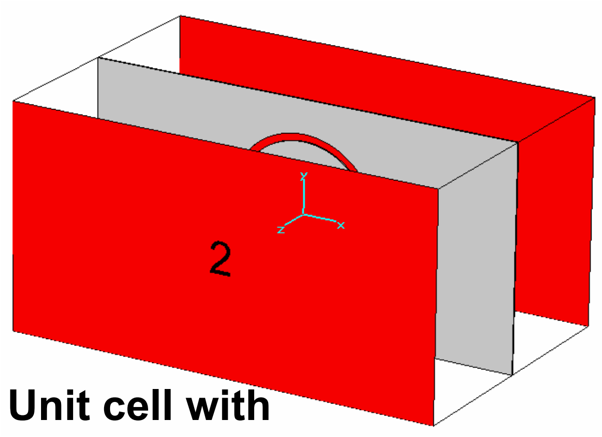


Coupling TE and TM modes by nesting rings allow for dual polar dual frequency filters to be designed

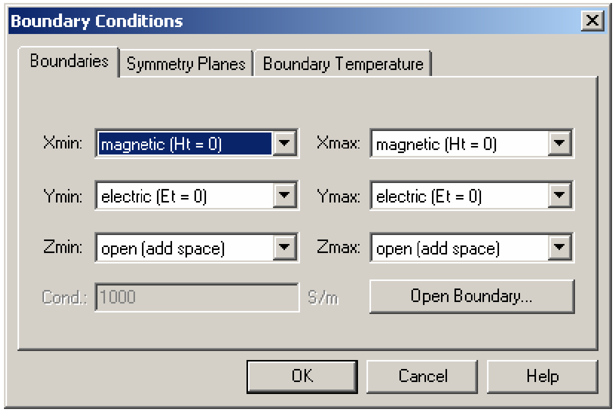


Cascaded arrays give higher BW and the separation allows to control the roll-off rate

Unit Cell (T Solver)

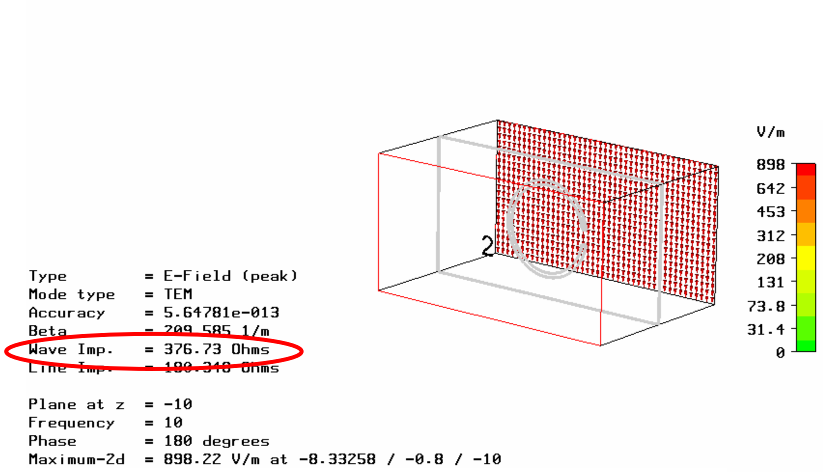


Unit cell with waveguide ports


Boundary Conditions

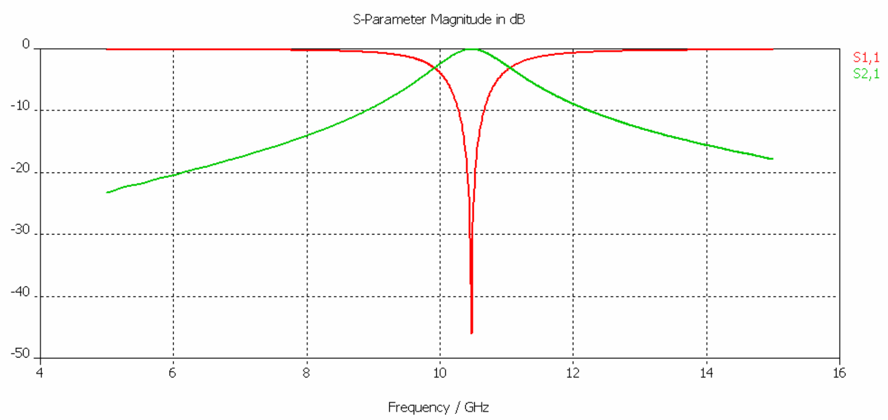
Xmin: magnetic (Ht = 0)
Xmax: magnetic (Ht = 0)
Ymin: electric (Et = 0)
Ymax: electric (Et = 0)
Zmin: open (add space)
Zmax: open (add space)
Cond.: 1000 S/m

Only valid for normal incidence (theta and phi =0)



```
Type          = E-Field (peak)
Mode type     = TEM
Accuracy      = 5.64781e-013
Beta          = 209.585 1/m
Wave Imp.     = 376.73 Ohms
Line Imp.     = 180.348 Ohms

Plane at z    = -10
Frequency     = 10
Phase         = 180 degrees
Maximum-2d    = 898.22 V/m at -8.33258 / -0.8 / -10
```



RingResonator_TimeDomain.zip

Metamaterials

AMC

(Artificial Magnetic Conductor)

DNG

(Double Negative)

EBG

Electromagnetic Bandgap

LHM

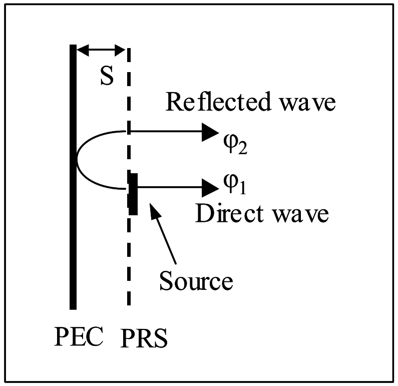
(Left Handed Materials)

PBG

(Photonic Bandgap)

AMC

- PEC: reflect incident waves with 180° phase shift
- PMC : Would reflect waves with 0° (dual)



- Direct wave φ_1
- Reflected wave $\varphi_2 = 2\varphi_T - \frac{2\pi}{\lambda}2S - \pi + \varphi_1$

Transmission phase of the FSS

Phase delay along S

Reflection phase at PEC

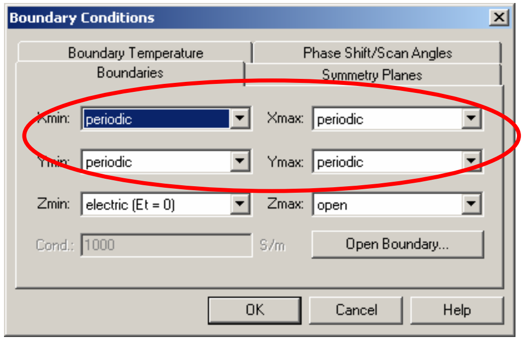
Direct wave phase

Resonance Condition:

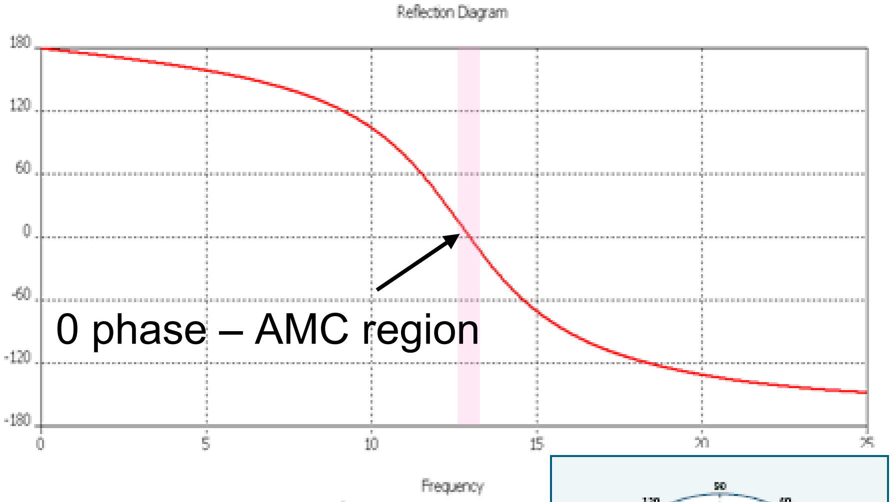
$$\varphi_2 - \varphi_1 = 2\varphi_T - \frac{2\pi}{\lambda}2S - \pi = 2N\pi$$

An AMC can be generated by having a ground plane at close proximity to the FSS. The combination provides a 0° phase shift from the reflected wave

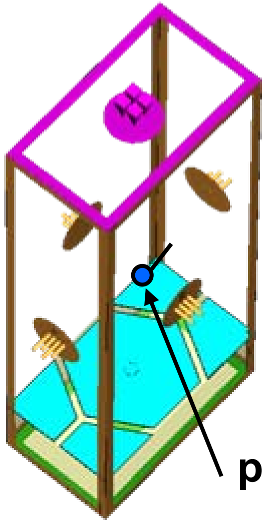
Plane Wave Incidence (T Solver)



Xmin: periodic
Xmax: periodic
Ymin: periodic
Ymax: periodic
Zmin: electric (Et = 0)
Zmax: open
Cond.: 1000 S/m

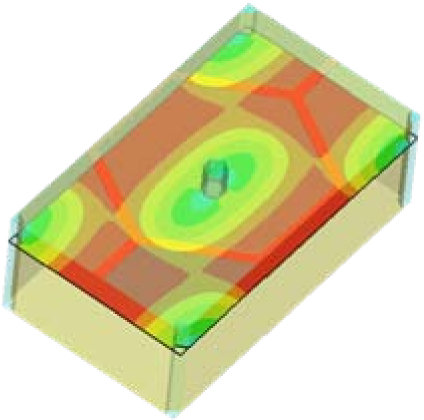


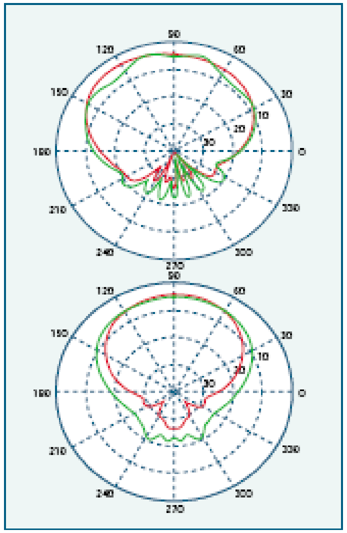
0 phase – AMC region



Incident plane wave onto a unit cell (difference between phase diagram with and without AMC structure)

probe





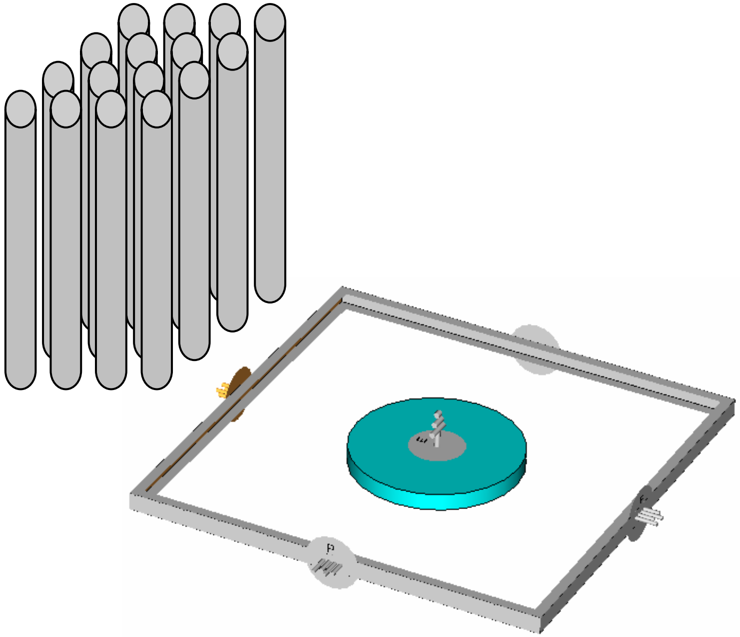
EBG and PBG

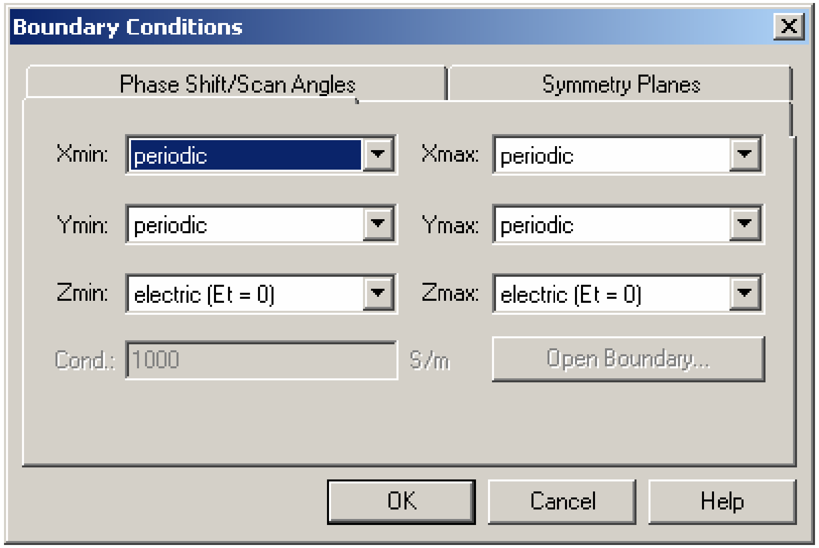
EBG are the Electromagnetic equivalent of Photonic Band Gaps (PBG). PBG are dielectric structures with a forbidden gap for electromagnetic waves.

Surface waves on a periodic array are suppressed from propagating at the band gap frequency

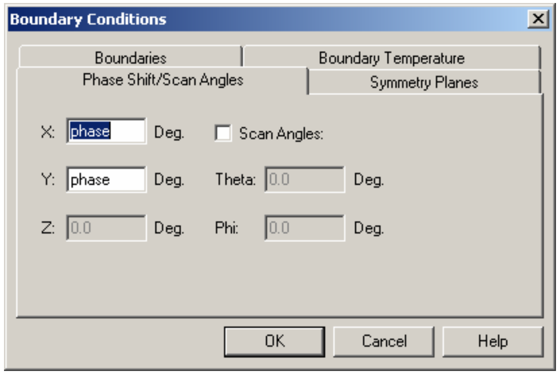
Dispersion diagrams can be used to identify EBG/PBG regions

Unit Cell Modelling (E Solver)





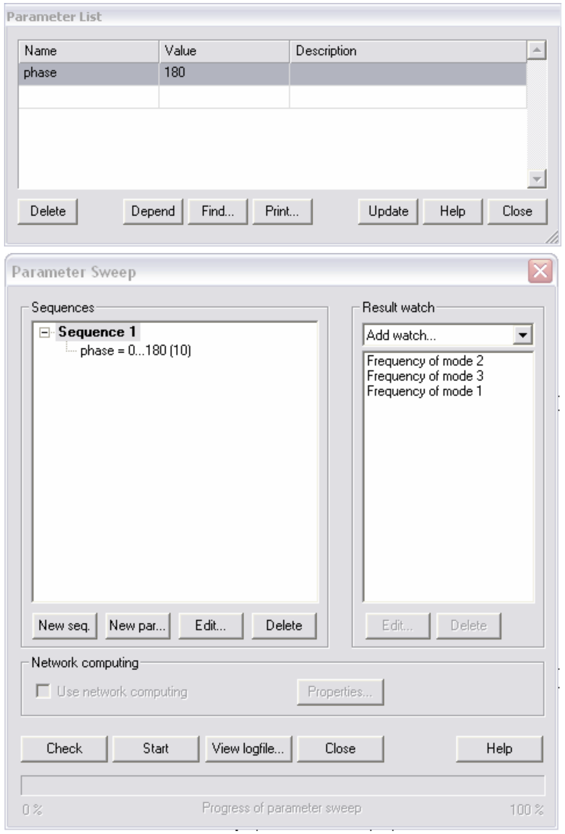
Xmin: periodic
Xmax: periodic
Ymin: periodic
Ymax: periodic
Zmin: electric (Et = 0)
Zmax: electric (Et = 0)
Cond.: 1000 S/m



X: phase Deg.
☐ Scan Angles:
Y: phase Deg.
Theta: 0.0 Deg.
Z: 0.0 Deg.
Phi: 0.0 Deg.

- Periodic boundary conditions are used to model the whole crystal structure
- Z axis boundaries are either E or H walls, in order to obtain TE and TM modes

Dispersion Diagram



Name	Value	Description
phase	180	

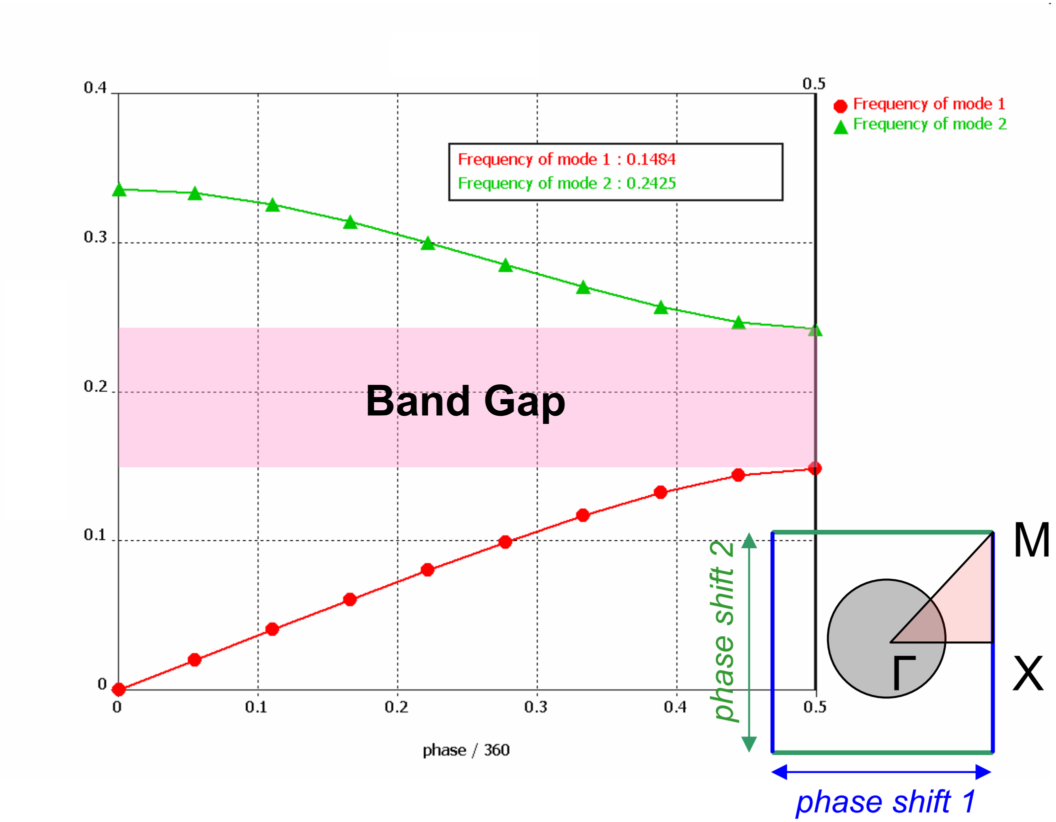
Sequence 1
phase = 0...180 (10)

Frequency of mode 2
Frequency of mode 3
Frequency of mode 1

☐ Use network computing

0 % … 100 %

Eigen mode solver parameter sweep is used to step through the phase assigned to the periodic boundaries



Each third of the overall dispersion curve can be reproduced by plotting found Eigen solutions against boundary condition phases

LHM

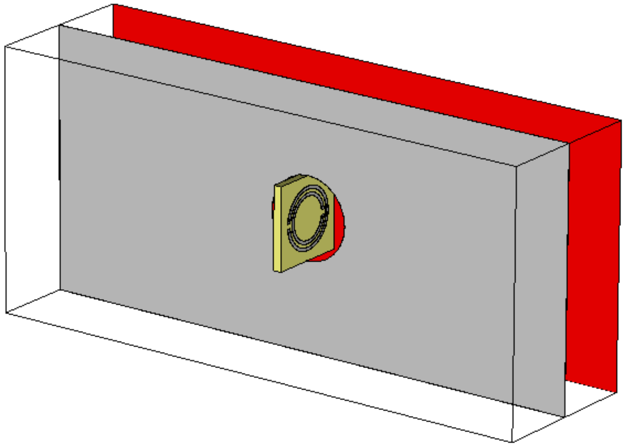
All transparent or translucent materials that we know of possess positive refractive index

Materials with simultaneously negative ε and μ are frequently referred to as left handed, negative refractive index and double negative materials

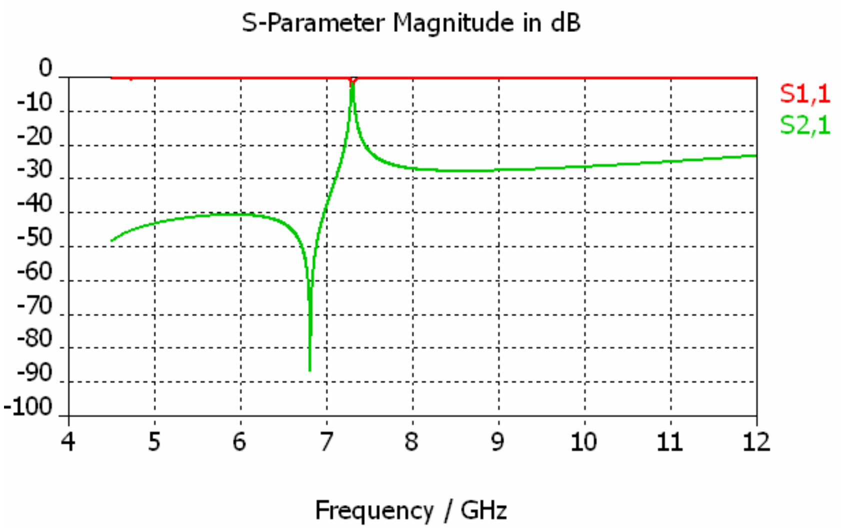
In these materials, the group velocity and phase velocity are anti-parallel

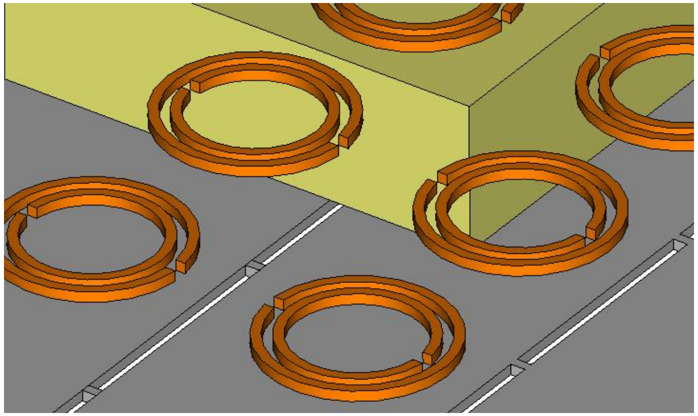
Artificially structured materials mimic the negative μ with SRR and the negative ε by an array of conducting wires where the unit cell dimensions are <<< λ

LHM Split Ring Resonator

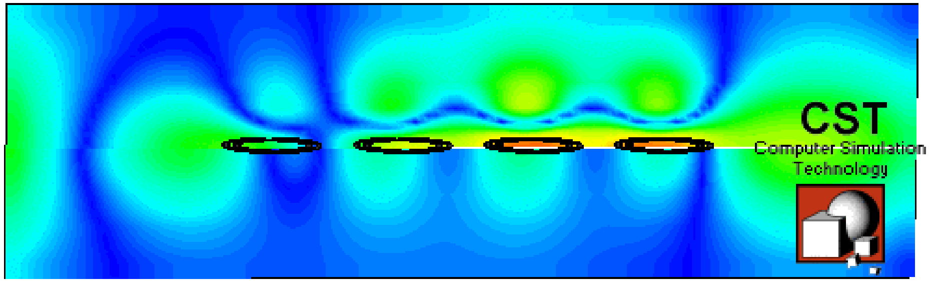


An edge-coupled SRR design with waveguide ports





Port excitation from left to right but reversed phase propagation in the SRR region



Application note on the web (http://www.cst.com/Content/Articles/article246.aspx)

Summary

Passive and Active FSS arrays exhibit band stop or band pass filter responses

Unit cell with appropriate boundary conditions allow to accurately model an infinite periodic array

T solver with E and H boundaries (and waveguide ports) can be used to model 0 degree incidence

F solver with unit cell boundaries allow arbitrary angles of incidence with Plane wave incidence

E solver with periodic boundaries is used to step through the phase assigned to the periodic boundaries to solve for the Eigen modes against phase