DEPARTMENT OF RADIO ELECTRONICS

Antennas for the THz Region

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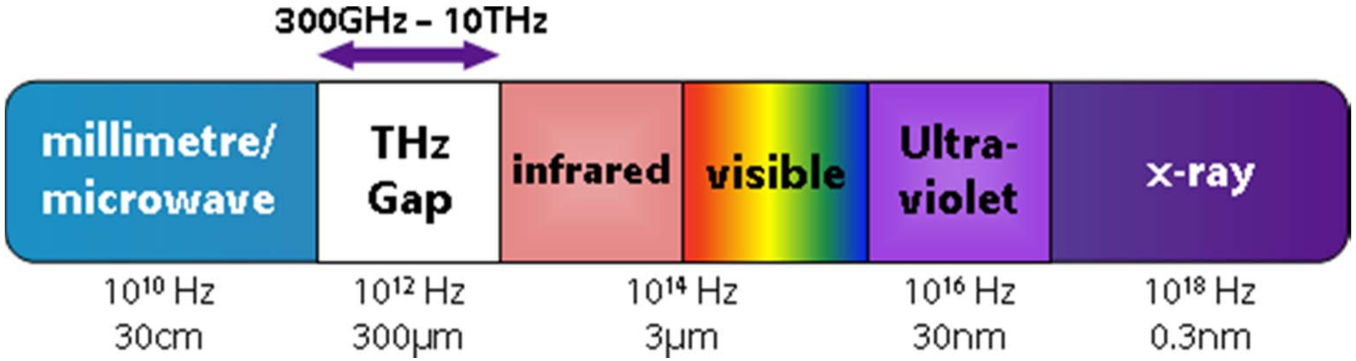
- Brno University of Technology

Presentation schedule

- ☐ Introduction
- ☐ CP THz antenna with Si lens
- ☐ CP THz antenna with metamaterials
- ☐ CP THz antenna with high resistivity and metamaterials

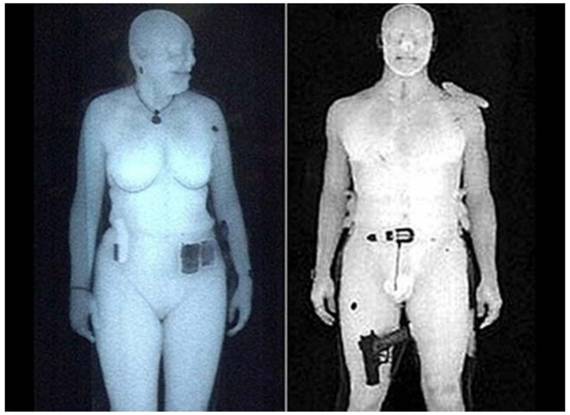
- ☐ Conclusions

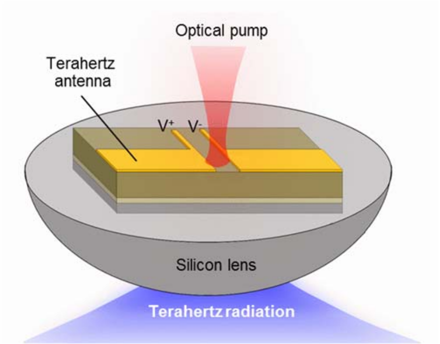
Introduction

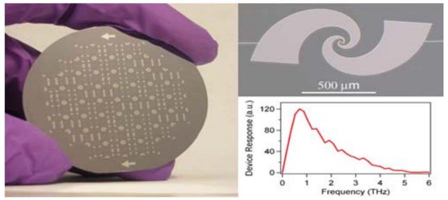


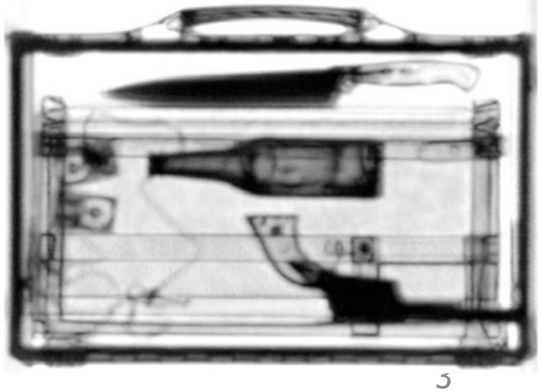
THz applications:

- Biology
- Medicine
- Imaging
- Material spectroscopy
- Security









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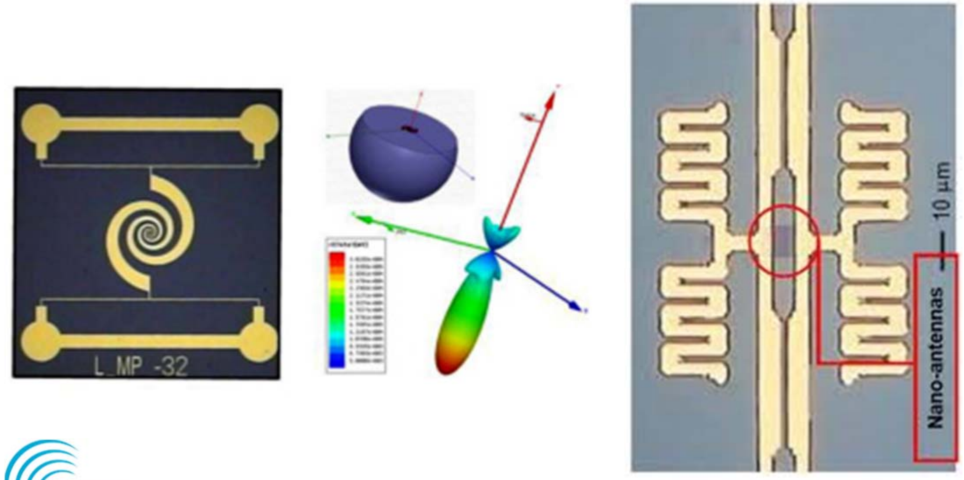
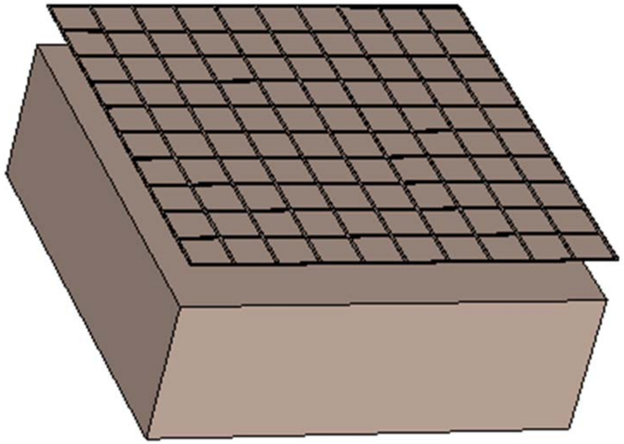
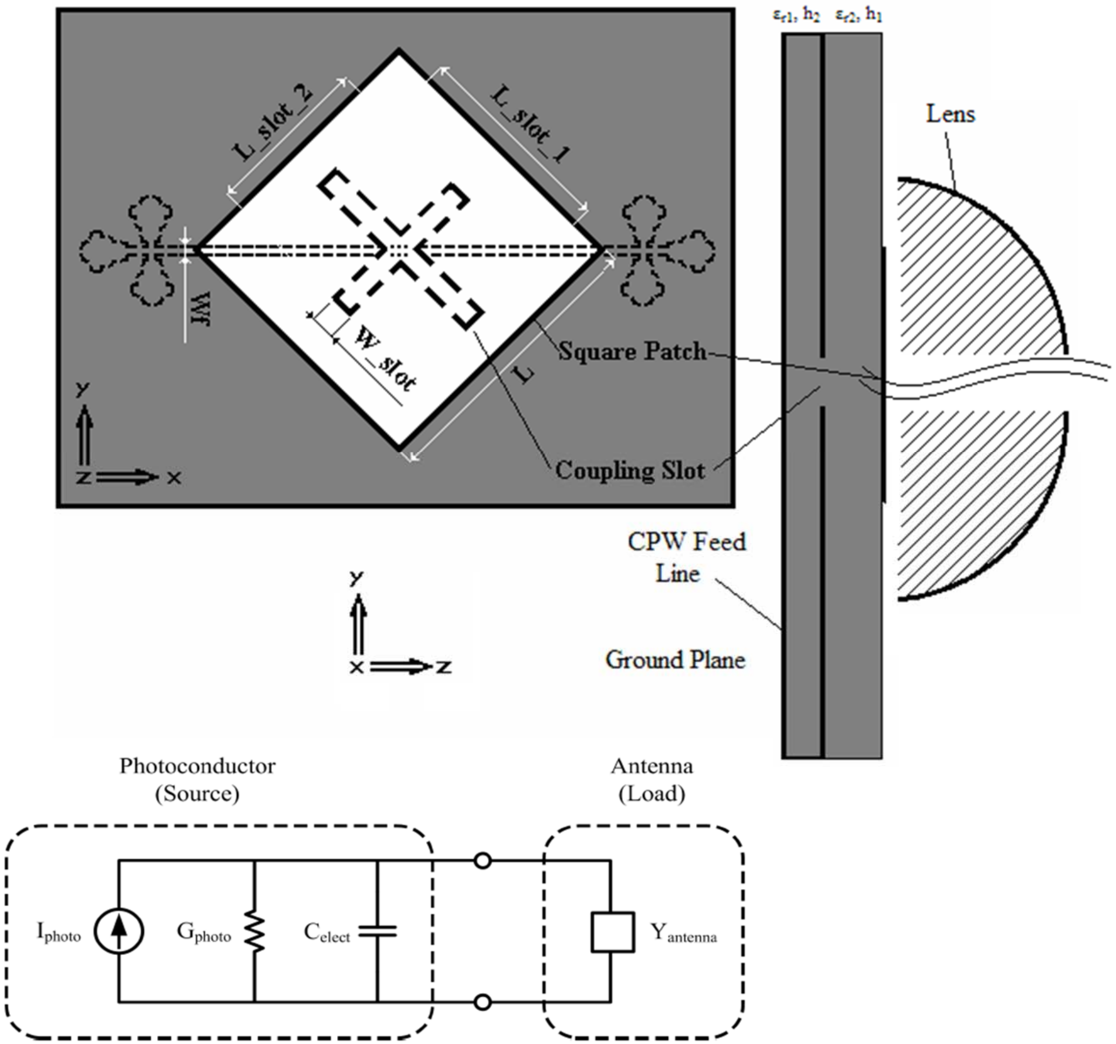
Introduction

- Classical approach
  - Silicon Lens
  - Linear polarization
  - Narrowband and wideband applications
- My approach
  - Metamaterial Lens
  - Circular polarization
  - Complete planar structure





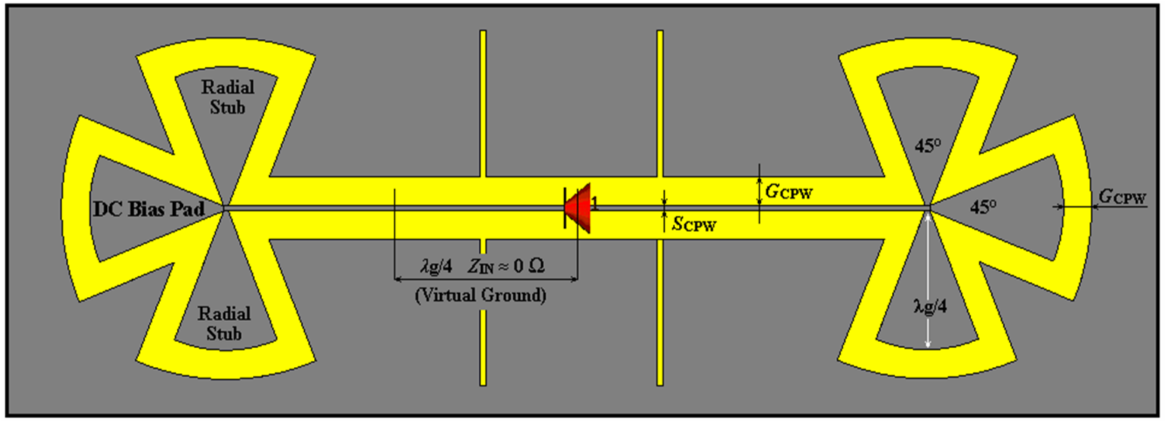
CP THz Antenna with Si Lens

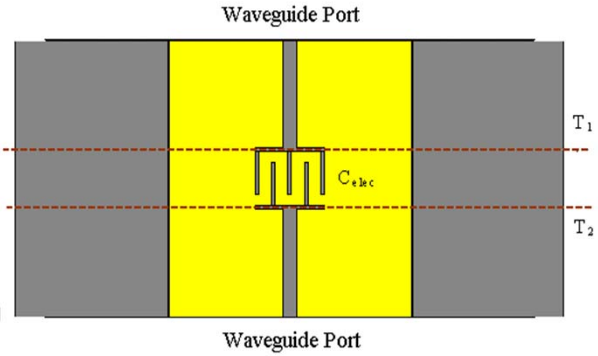


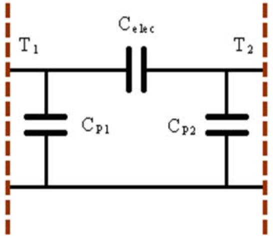
Parameters	**Value [μm]**
L	55.00
L_slot_1	20.83
L_slot_2	17.8
W_slot	1.00
S_{CPW}	1.00
G_{CPW}	6.00
t	0.10

CP THz Antenna with Si Lens

- Photomixer and dual slot antennas create a THz source
- RF choke for blocking DC biasing.
- The patterns of E-plane and H-plane are symmetric because the RF filter is symmetric.



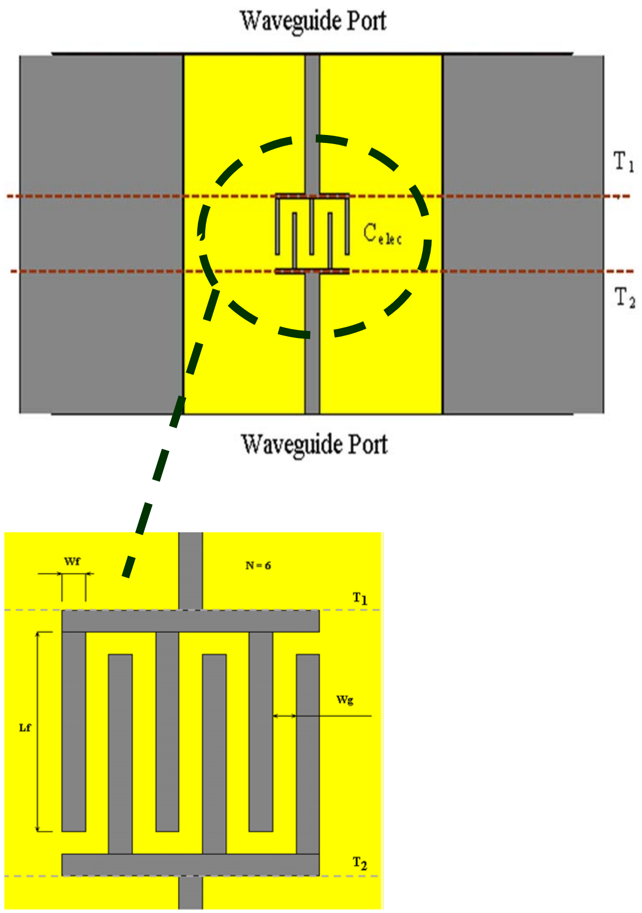


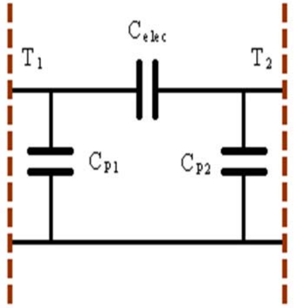


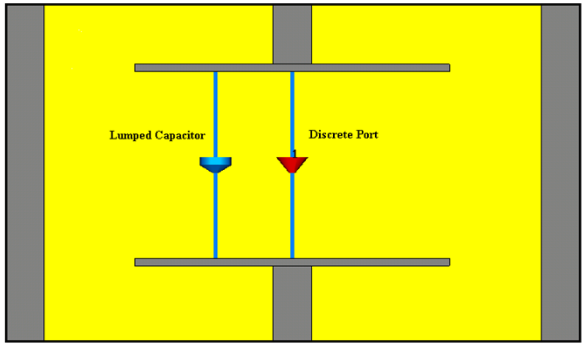
Test capacitor:
*W*f = 1μm,
*L*f = 9 μm,
*W*g = 1 μm,
N = 6.

CP THz Antenna with Si Lens

Test capacitor: *Wf* = 1µm, *Lf* = 9 µm, *Wg* = 1 µm, *N* = 6.





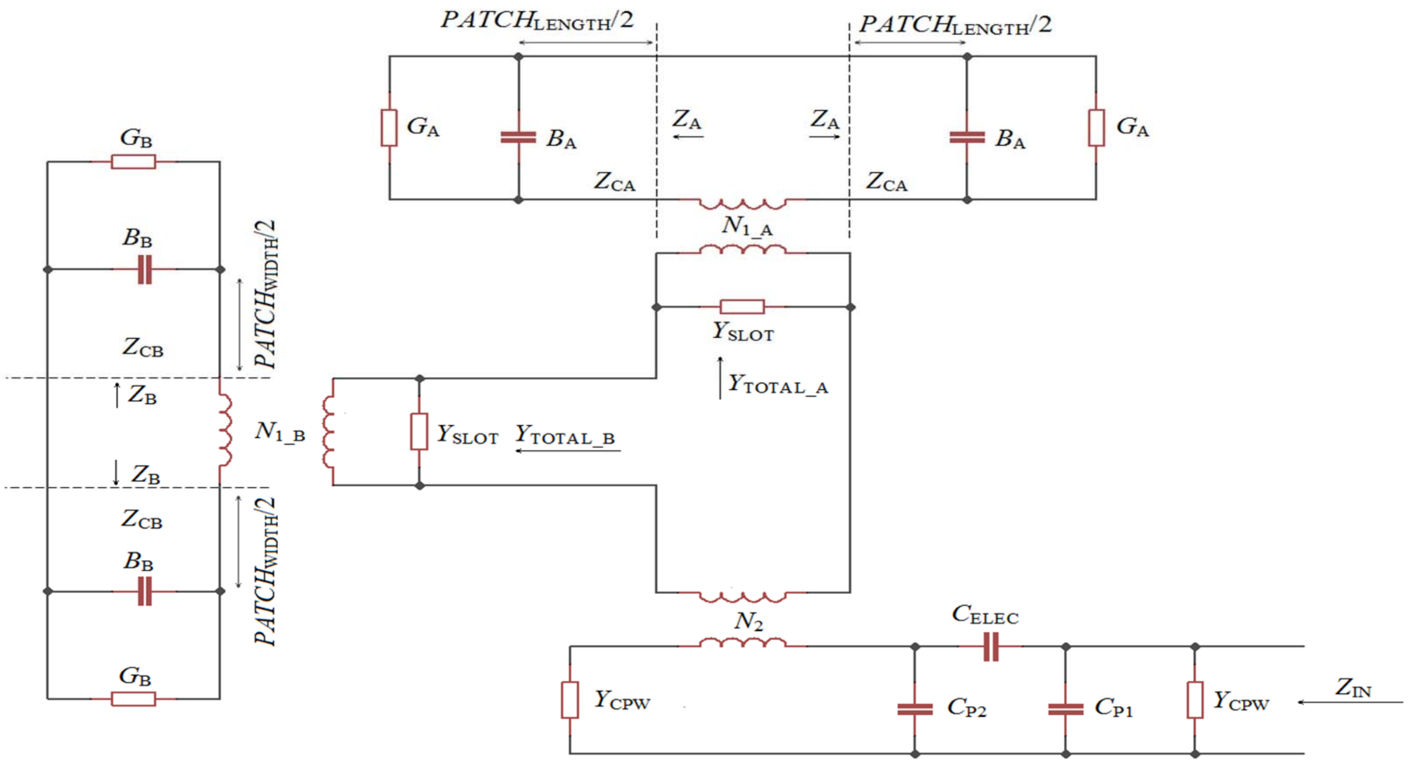


Comparison of the obtained results

Approach (*f* = 1 THz)	**Value of the capacity [fF]**
Conformal Mapping [4]	3.024
Simple Approximation	7.912
CST MWS (frequency solver)	3.046
Published results [3]	3.061

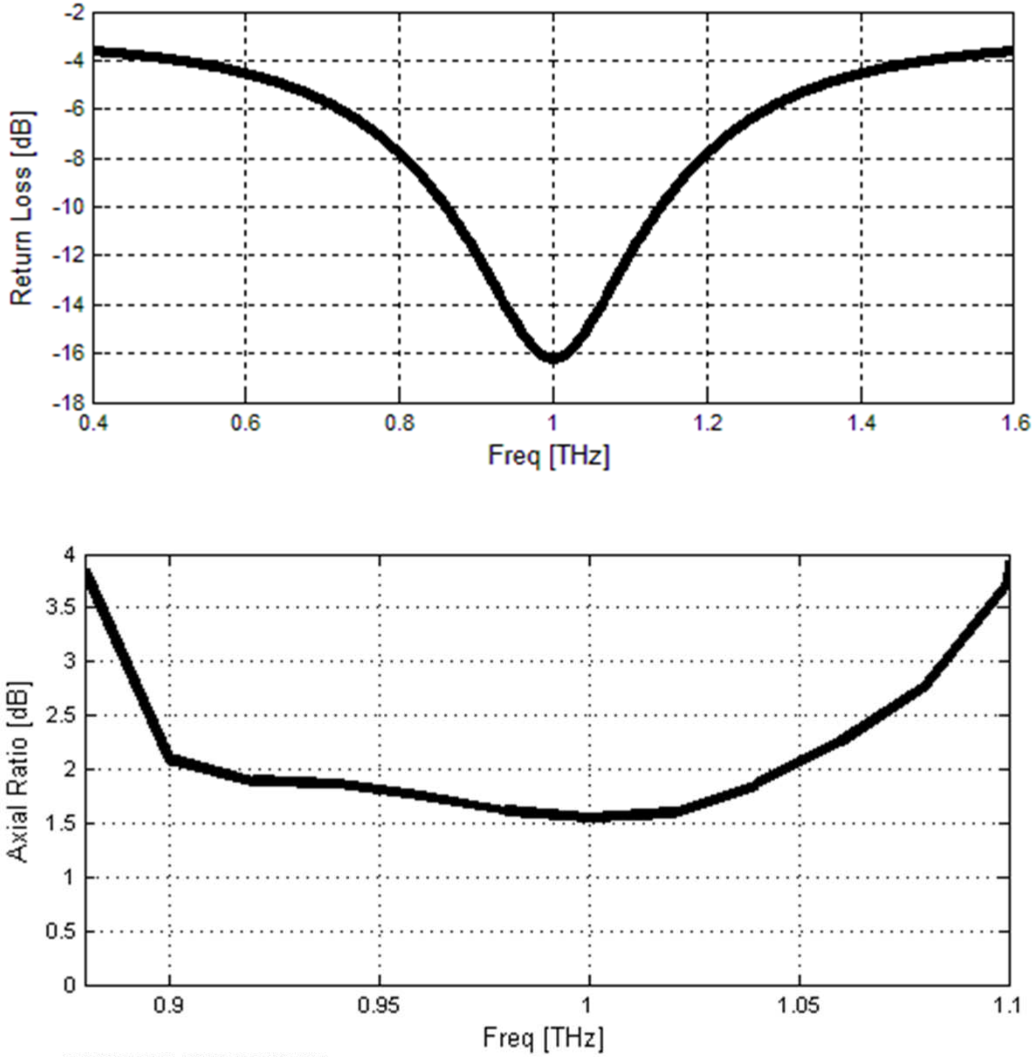
CP THz antenna with Si lens

- The resonant frequency of the square patch can be split into two degenerated resonant modes *TM* 10 and *TM* 01 with 90° phase difference.



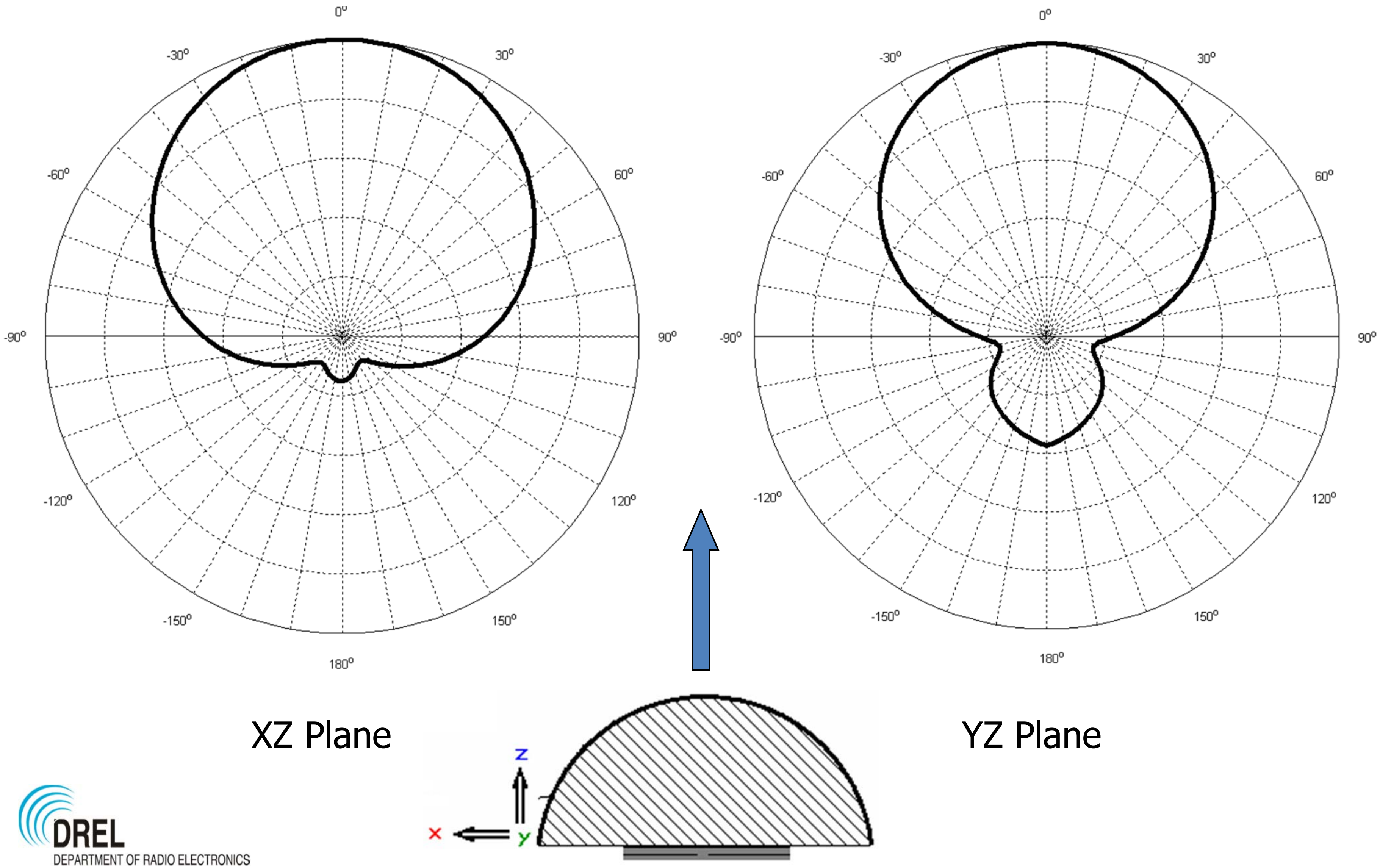
Results #1

Frequency responses of return loss and axial ratio of the simulated antenna



Parameters *f* = 1 THz	**Value**
Main Lobe Magnitude	5.27 dBi
Side Lobe Level in the YZ Plane	-6.3 dB
Side Lobe Level in the XZ Plane	-8.3 dB
Angular Width (3 dB) in the XZ Plane	97.3 deg
Angular Width (3 dB) in the YZ Plane	123.6 deg
Radiation Efficiency	61 %

Results #2

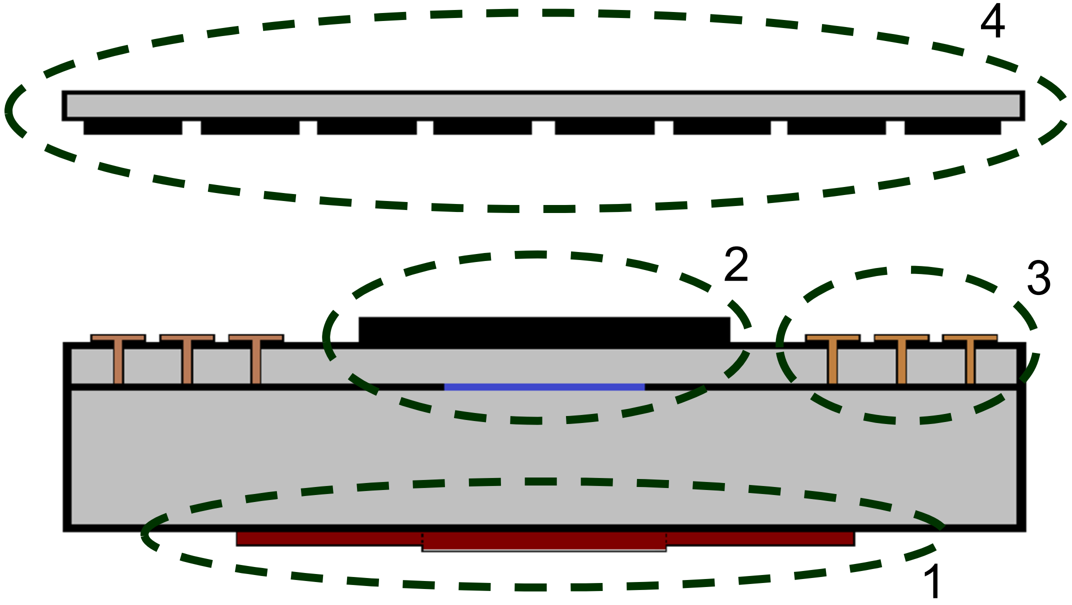


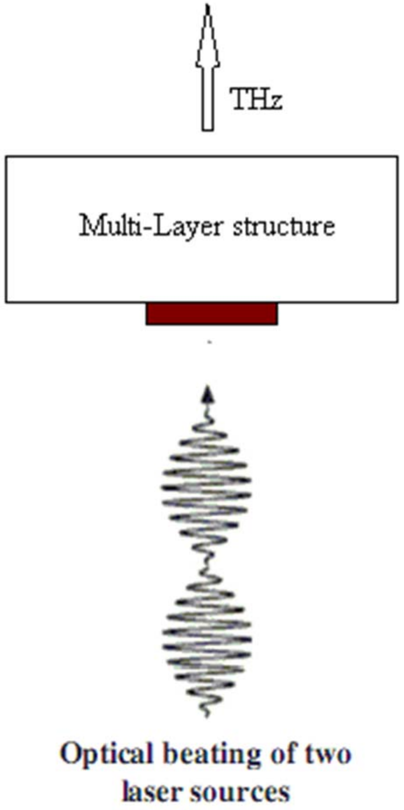
XZ Plane

YZ Plane

CP THz Antenna with Metamaterials
(Full concept)

CP THz Antenna with Metamaterials





Region 1: Feeding line and GaAs photomixer

Region 2: CP antenna fed by cross slot

Region 3: EBG like mushroom structure

Region 4: EBG Superstrate

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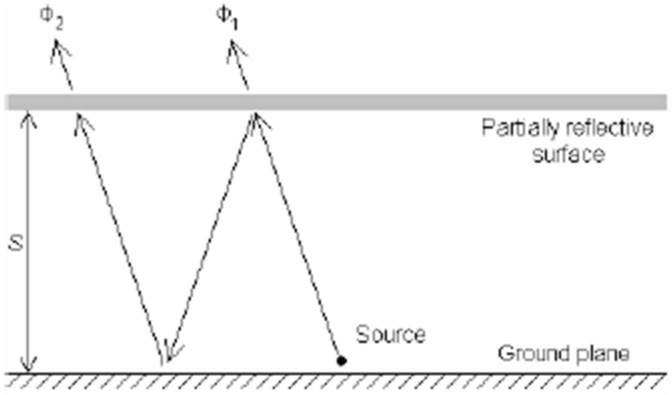
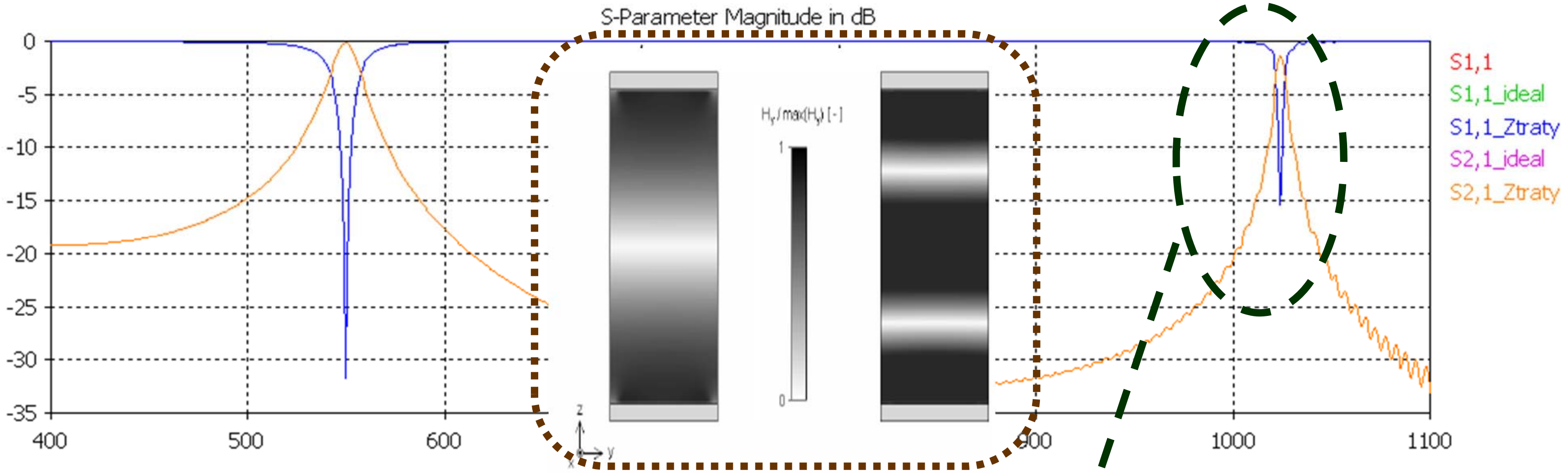
Metamaterials: Superstrate at 1 THz

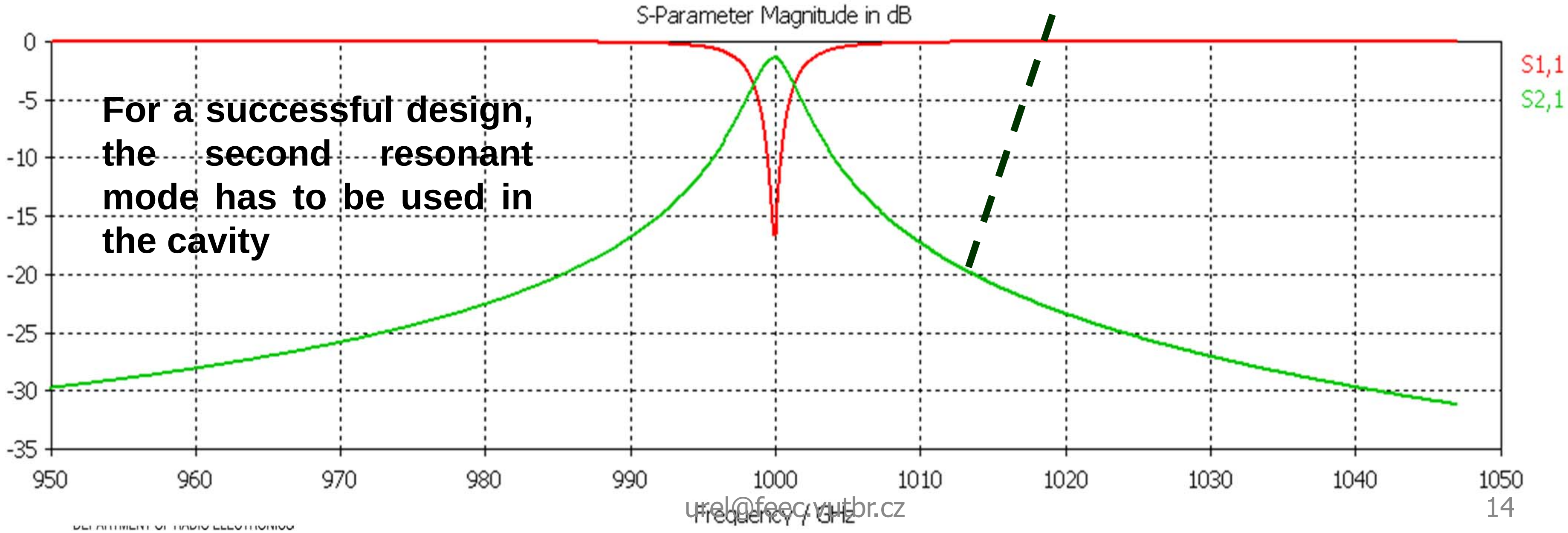
- Superstrates are able to focus the electromagnetic energy, thus they can be used for gain improvement of the antennas.
- The basic principle of superstrate corresponds to the principle of Fabry-Perot resonators.
- Radiation source is placed between the ground plane and superstrate layer and forming together a resonant cavity.
- Superstrate can be used like replacement of the conventional lens.



Principle of the Febry-Perot resonator

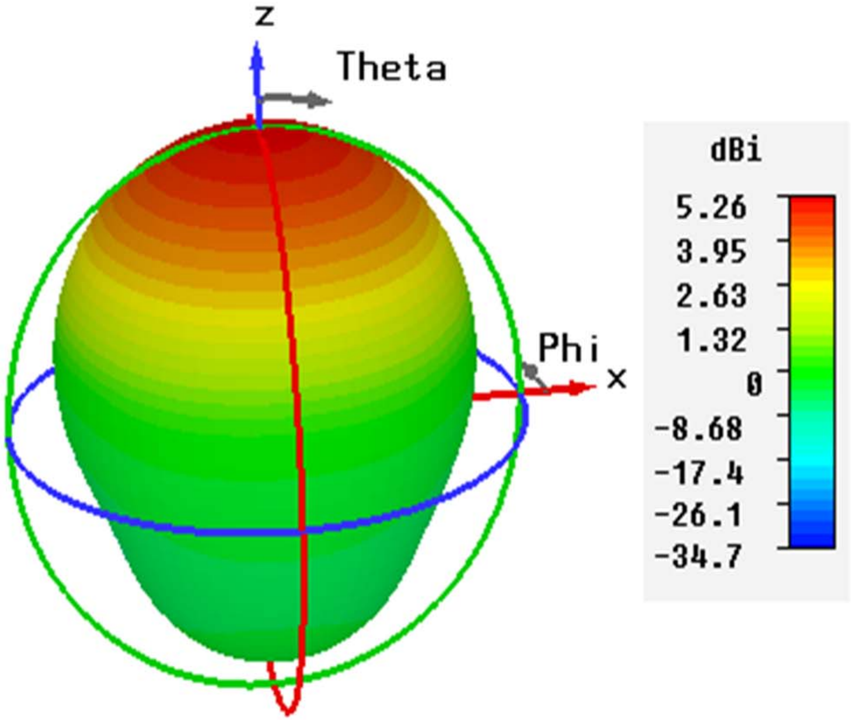
Results #1 at 1 THz

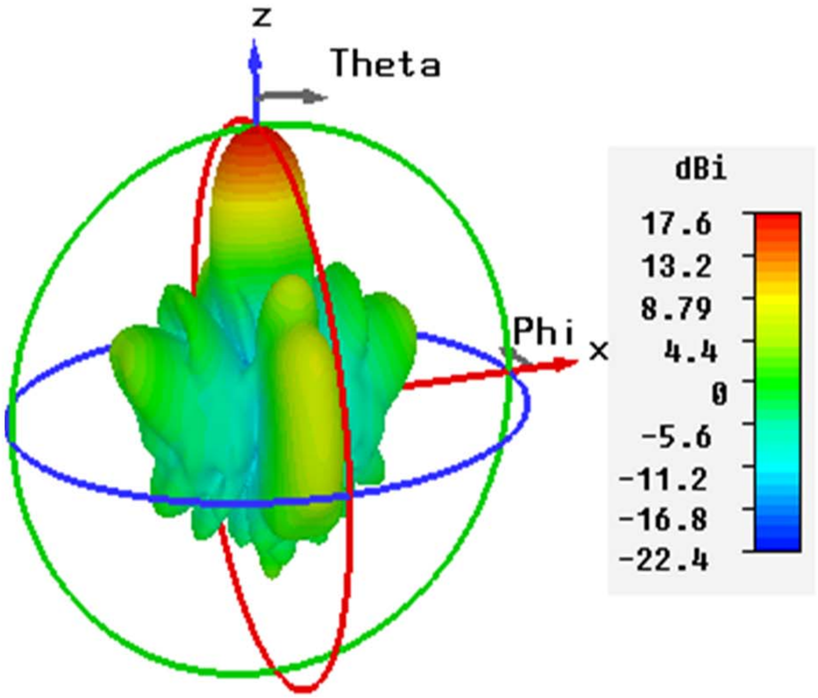




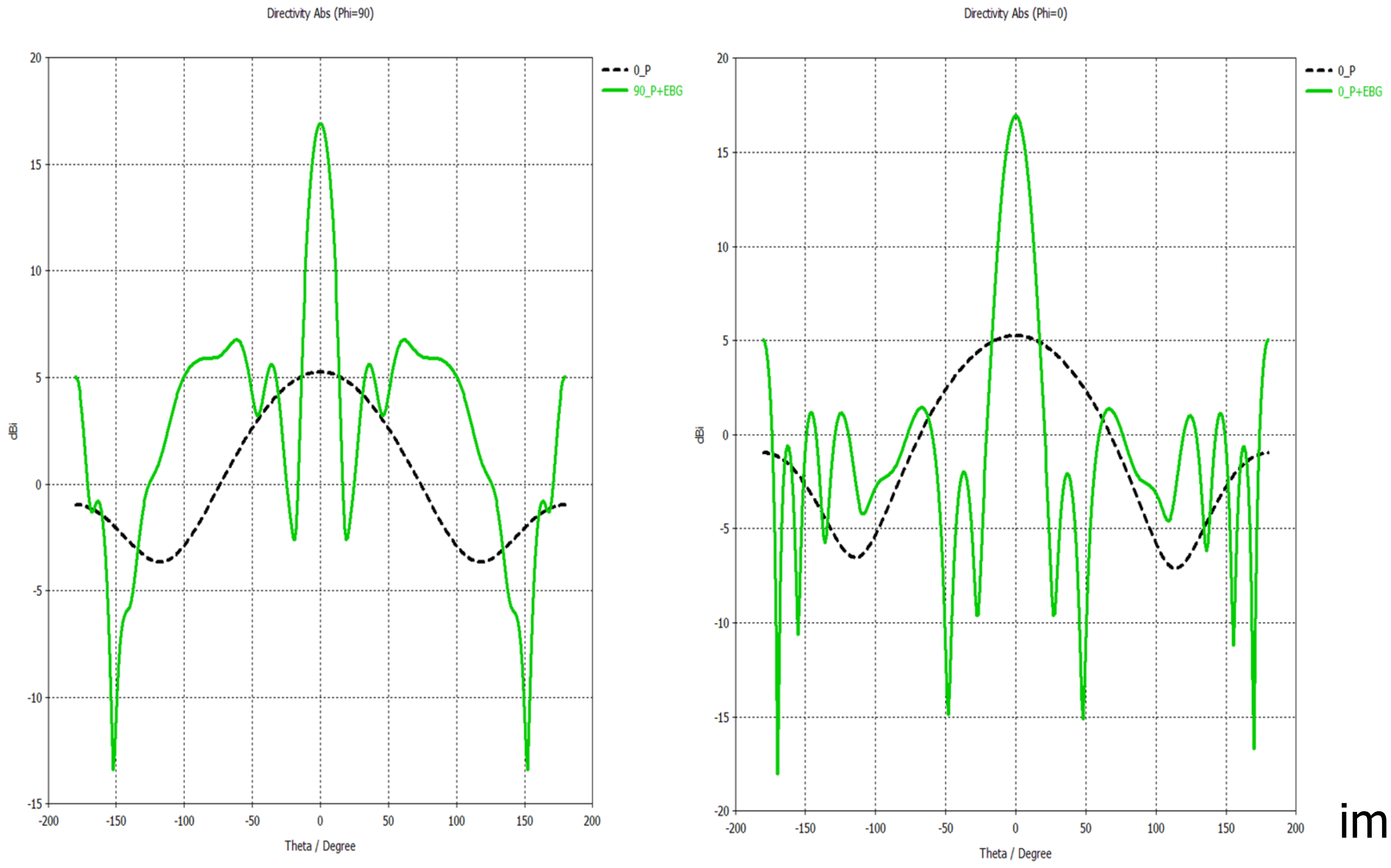
For a successful design, the second resonant mode has to be used in the cavity

Results #2 at 1 THz





Results #3 at 1 THz



Radiation patterns phi = 0º, 90º

Single antenna

G = 5.26 dBi

Superstrate cover

G = 17.6 dBi

Teoretical value

G = 20.9 dBi

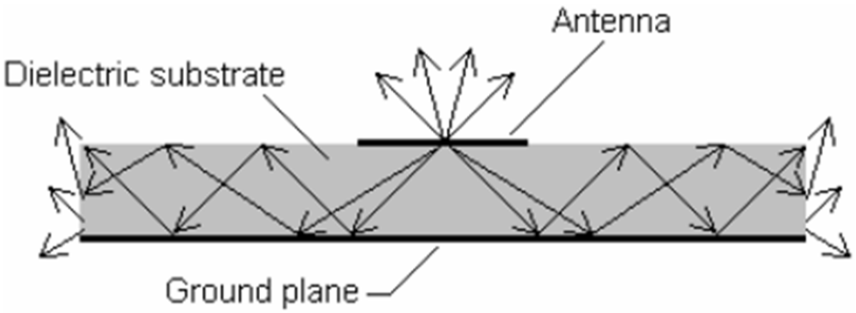
improvement of Gain

G = 13.07 dB

Circular polarization is not affected by superstate

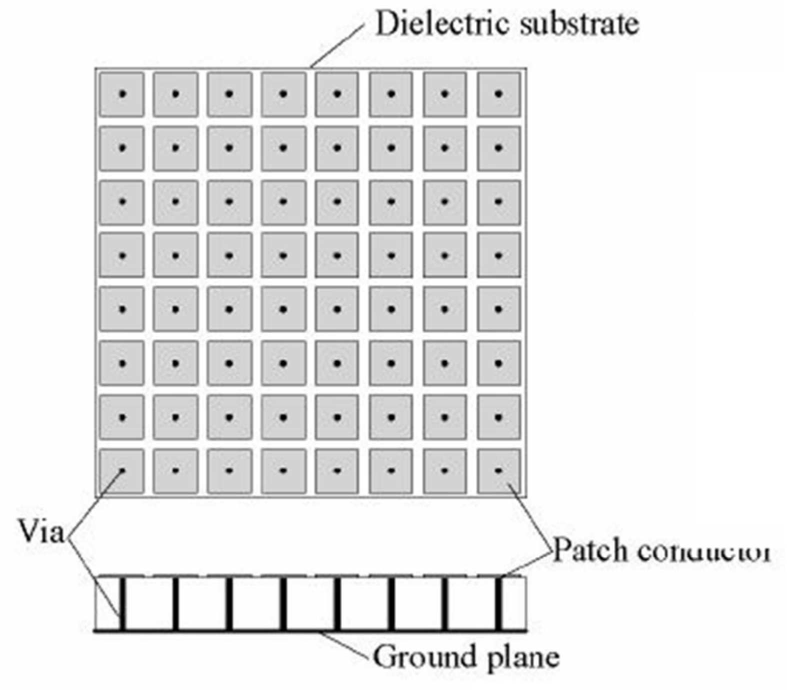
Metamaterials: Mushroom structure

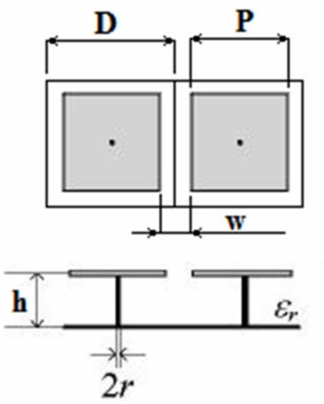
- Mushroom structures are able to reduce surface wave propagation.
- Mushroom structures can be used for mutual isolation improvement of the antennas in the matrix.
- Mushroom structures are able to improve axial ratio of the antenna.

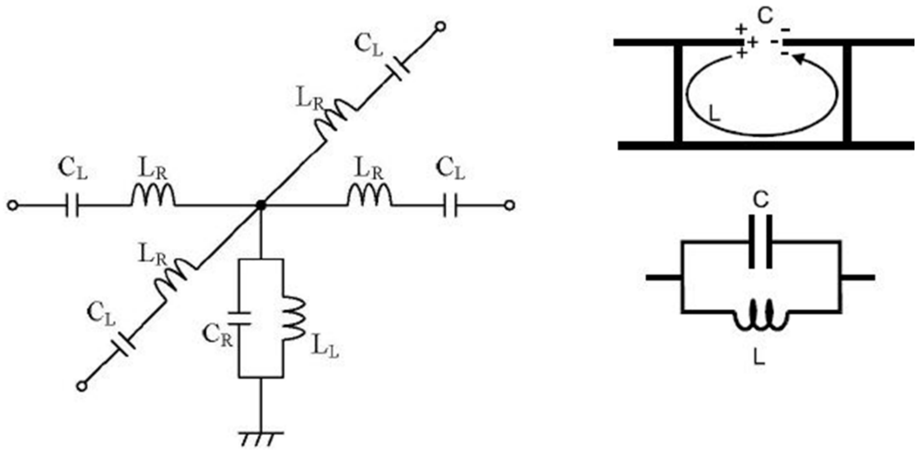


Surface wave propagation inside the gounded dielectric plate

Metamaterials: Mushroom structure

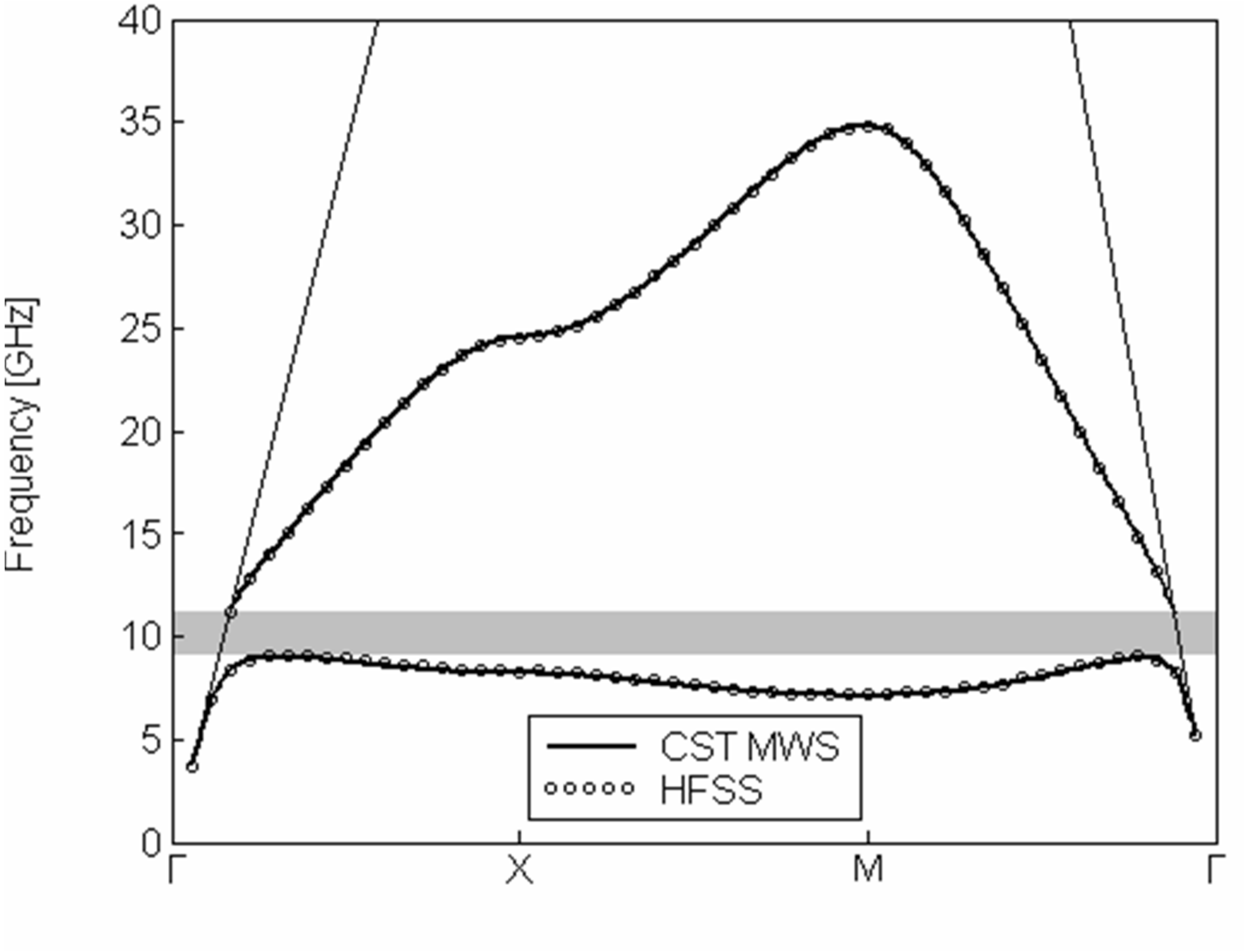






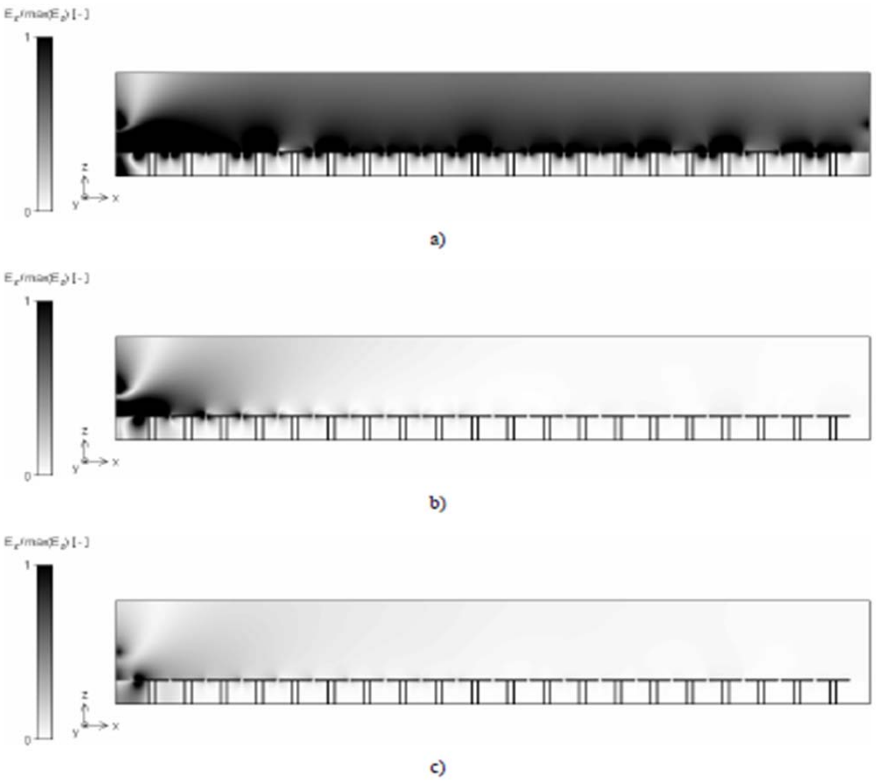
Equivalent circuit model of the unit cell.

Results #1 at 10 GHz

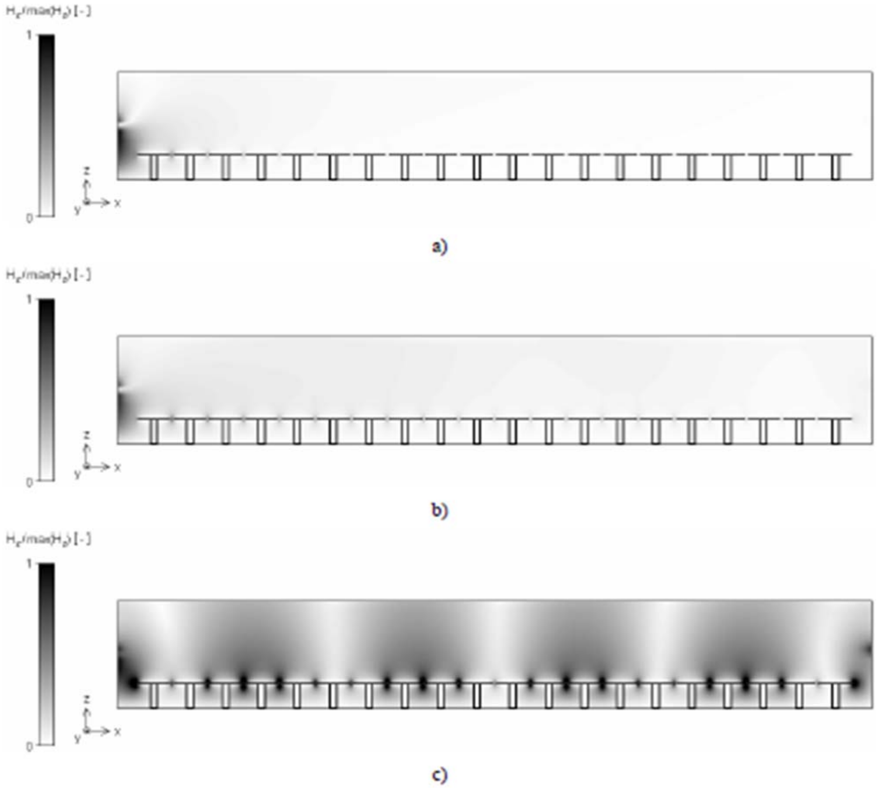


Results #2

TM (normalized electric field intensity)



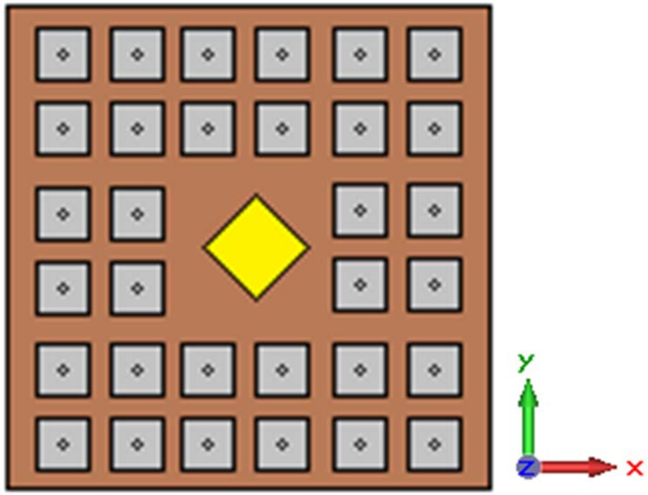
TE (normalized magnetic field intensity)



8 GHz :TM waves in propagation, TE waves in cutoff
10 GHz: both the TM and TE waves in cut off (waves do not propagate)
12 GHz: (TM waves in cutoff, TE waves in propagation
Confirm the results of the dispersion analysis.

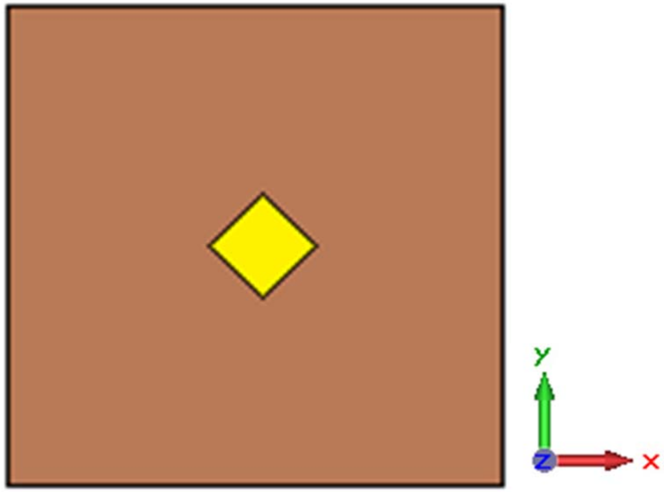
Results #3: Comparison at 10 GHz

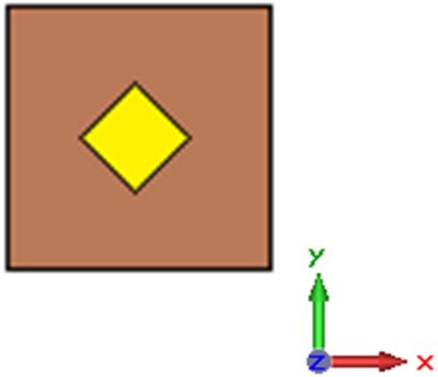
- CPA with EBG structure around radiator (design for $\varepsilon_R = 2.94$, $h = 0.7874$ mm)
- CPA with different dimensions of the ground plane
- Results with mushroom structure



EBG: ground plane 53x53mm

No EBG: ground plane 53x53mm

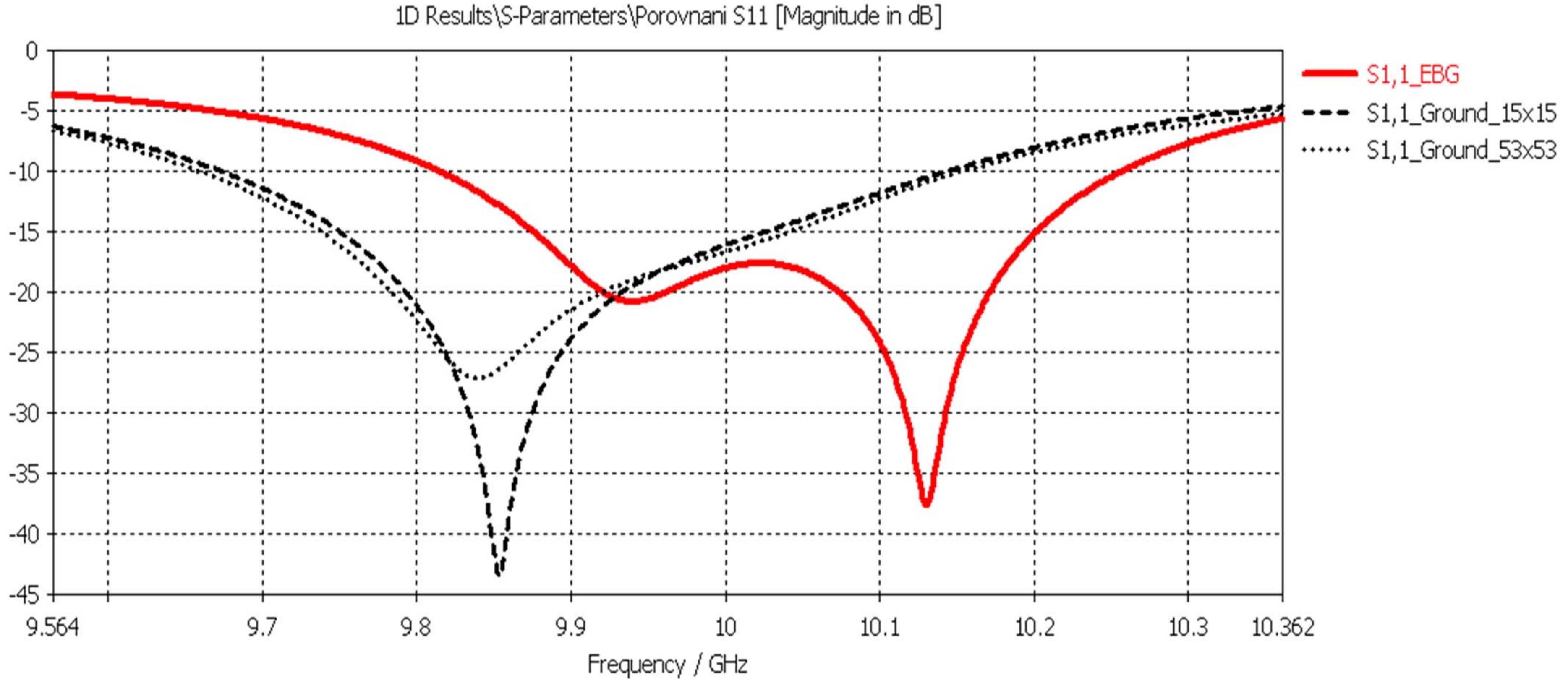




Ground plane 15x15mm

Results #4: Comparison at 10 GHz

- Frequency responses of return loss



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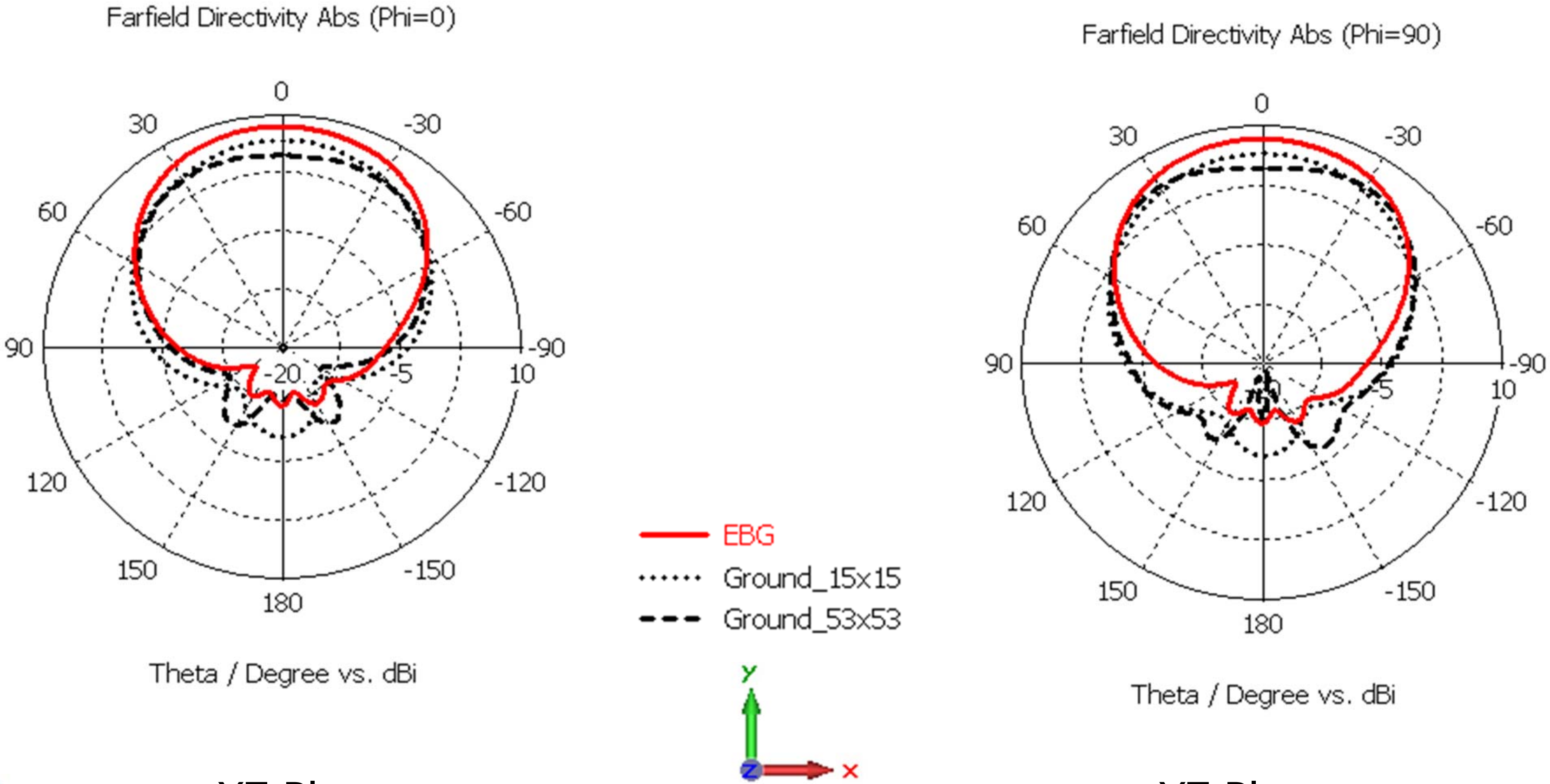
Results #5: Comparison at 10 GHz

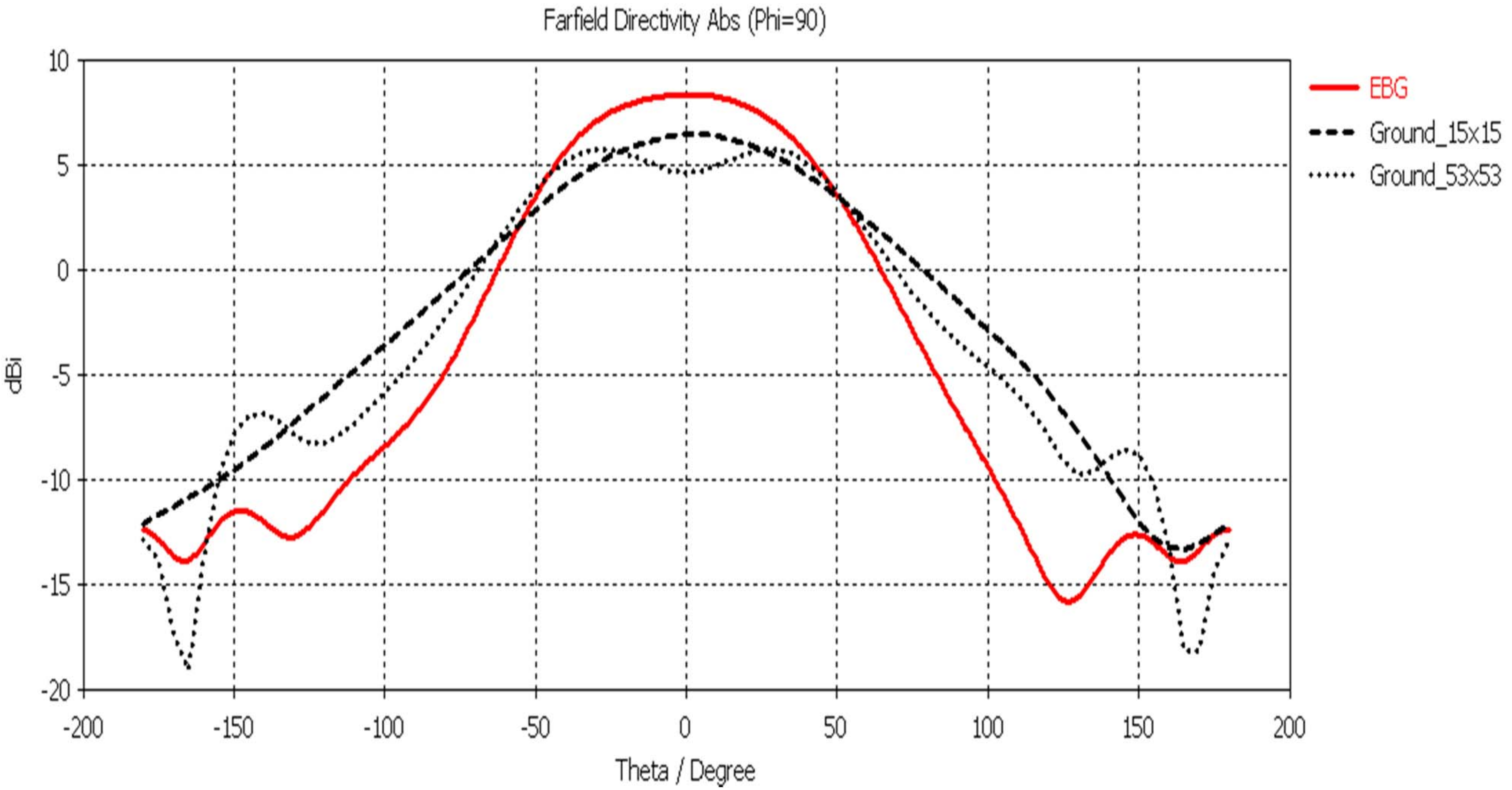
- Radiation patterns at 10 GHz



XZ Plane

YZ Plane

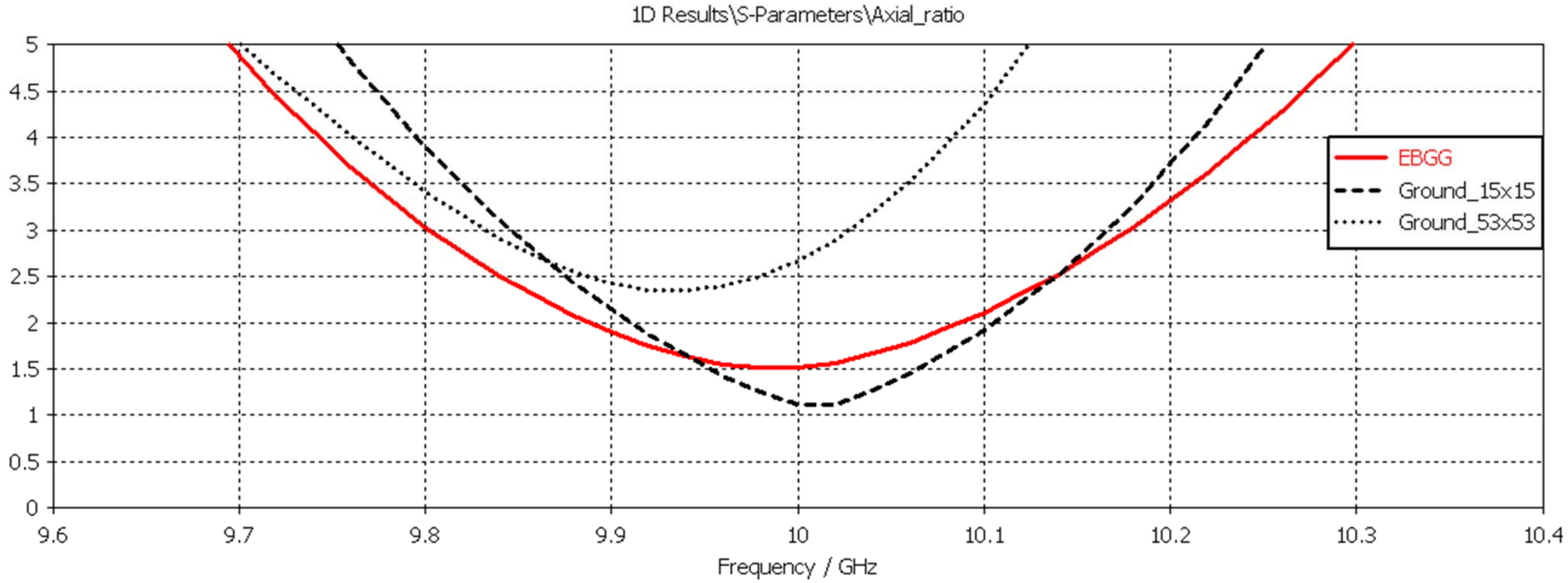
Results #6: Comparison at 10 GHz



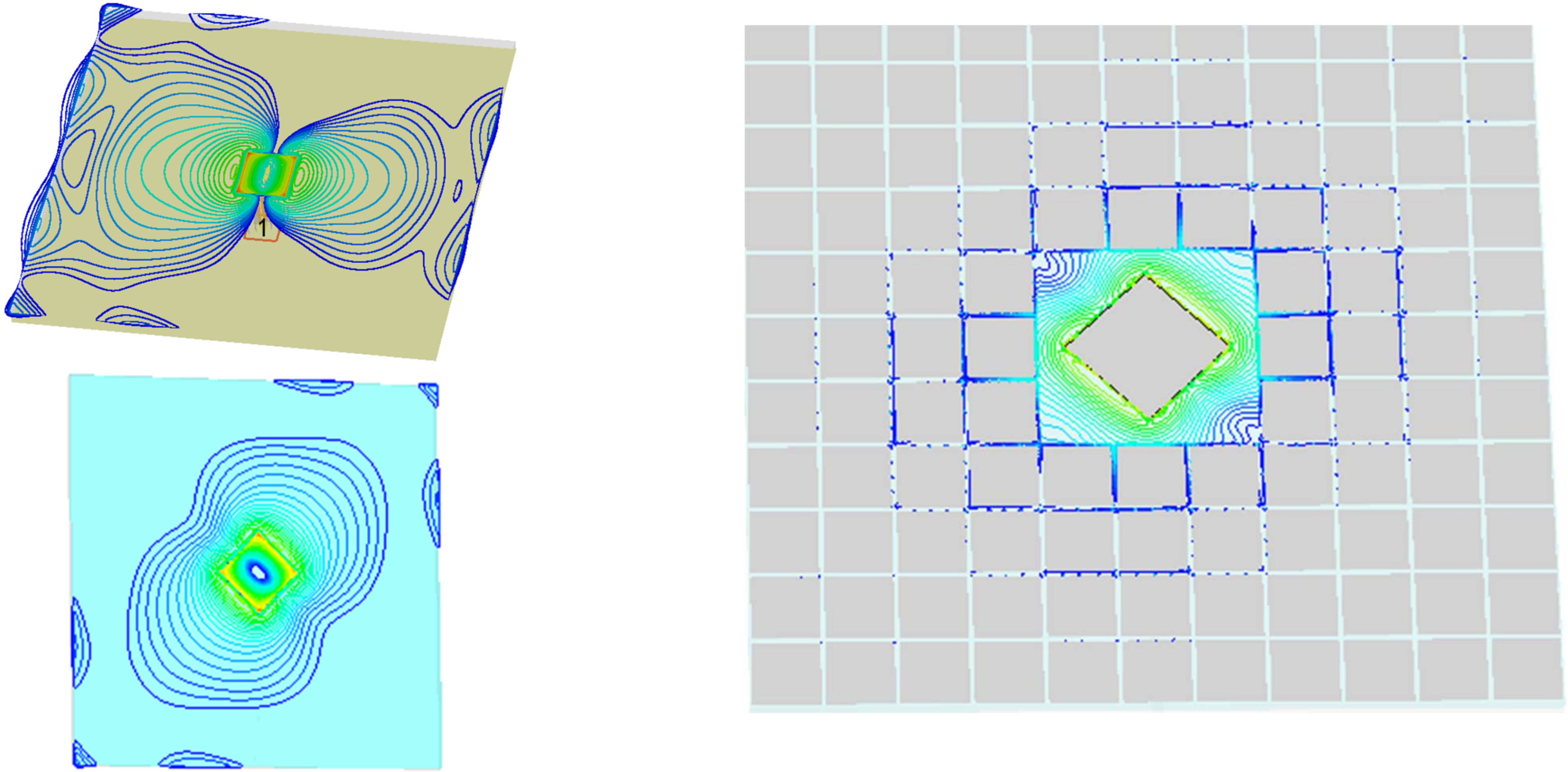
Results #7: Comparison at 10 GHz

- Obtained results

Antenna	SLL in XZ Plane	SLL inYZ Plane	Gain
With EBG	**-19.9 dB**	**-19.9 dB**	**6.93 dB**
Ground 53x53 mm	-13.3 dB	-13.3 dB	3.18 dB
Ground 15x15 mm	**-13.5 dB**	**-13.5 dB**	**4.53 dB**



Results #8: Comparison at 10 GHz

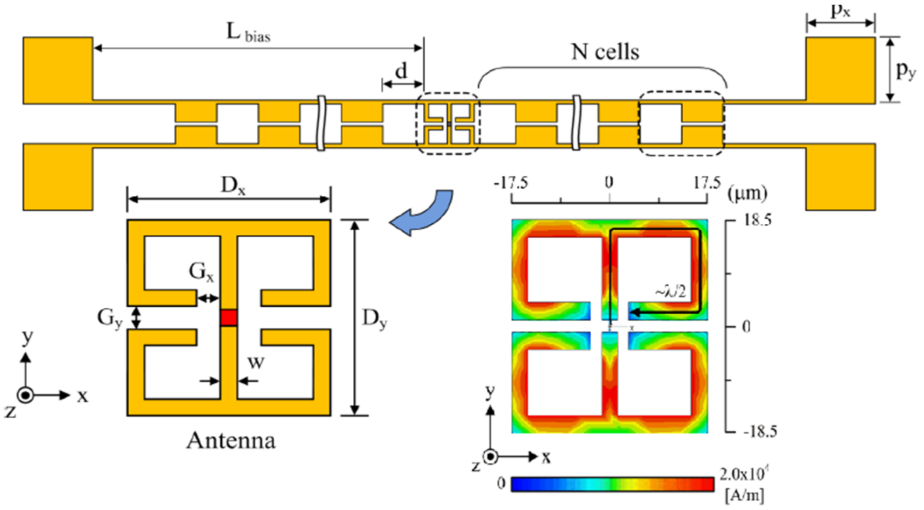


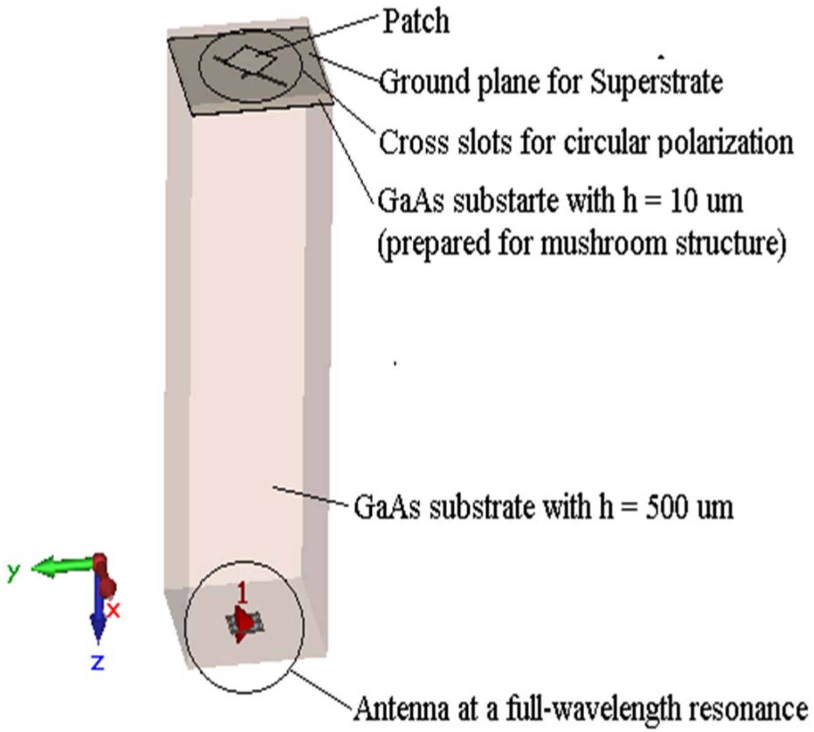
Normalized electric field distribution over the antenna

CP THz antenna with high resistivity and metamaterials

THz Antenna with High Resistance

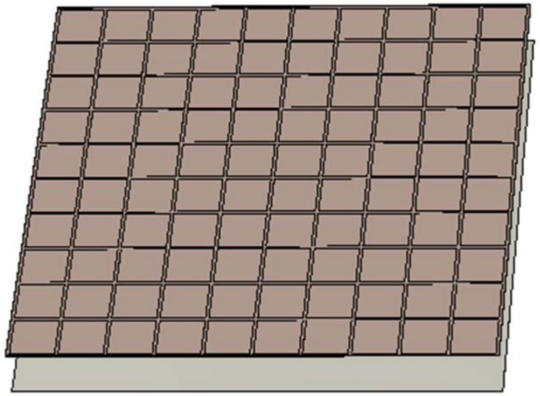
- High output power
- High input resistance

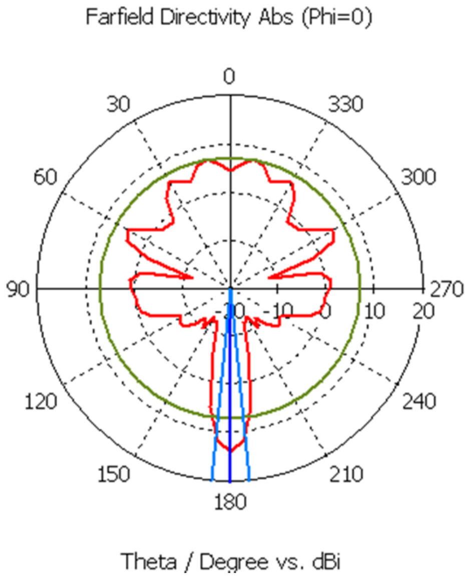


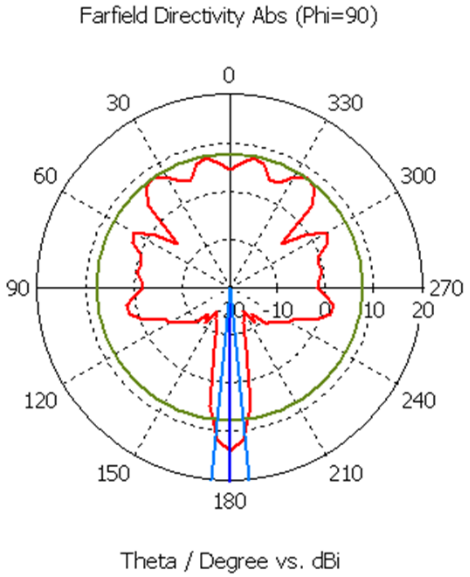


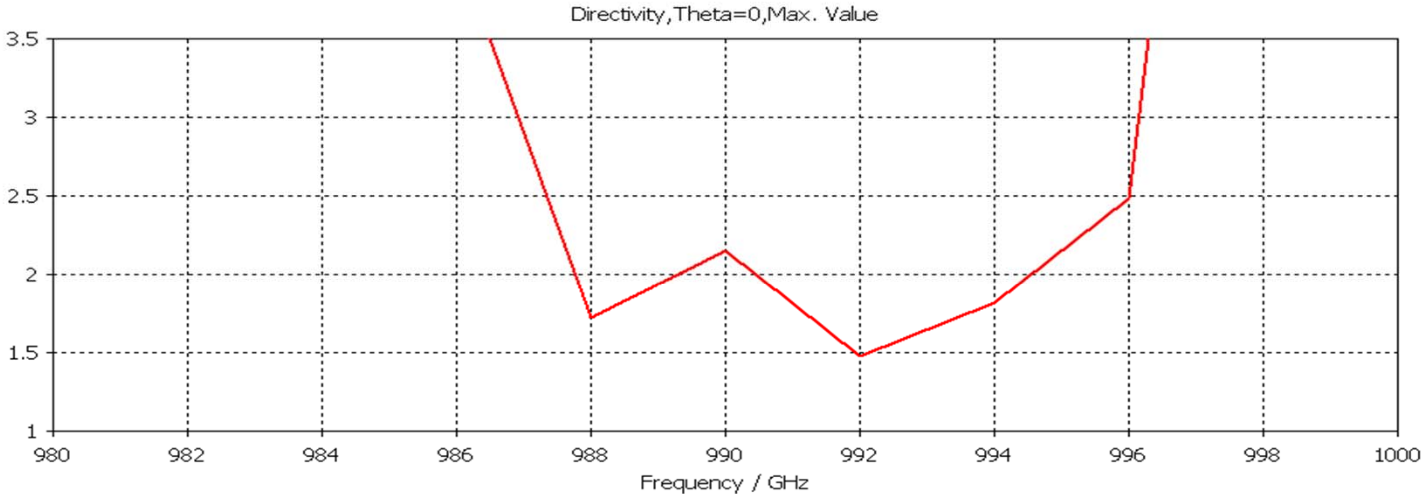
Insang W., Haewook H., Ikmo P., Hanjo L. “Four-leaf clover-shaped antenna on an extended hemispherical lens for a high-output-power THz photomixer” 35th International Conference on Infrared Millimeter and Terahertz Waves (IRMMW-THz), 2010

Results #1




Farfield Directivity Abs (Phi=0)
0
30
330
60
300
90
270
120
240
150
210
180
-10
-10
0
10
20
Theta / Degree vs. dBi

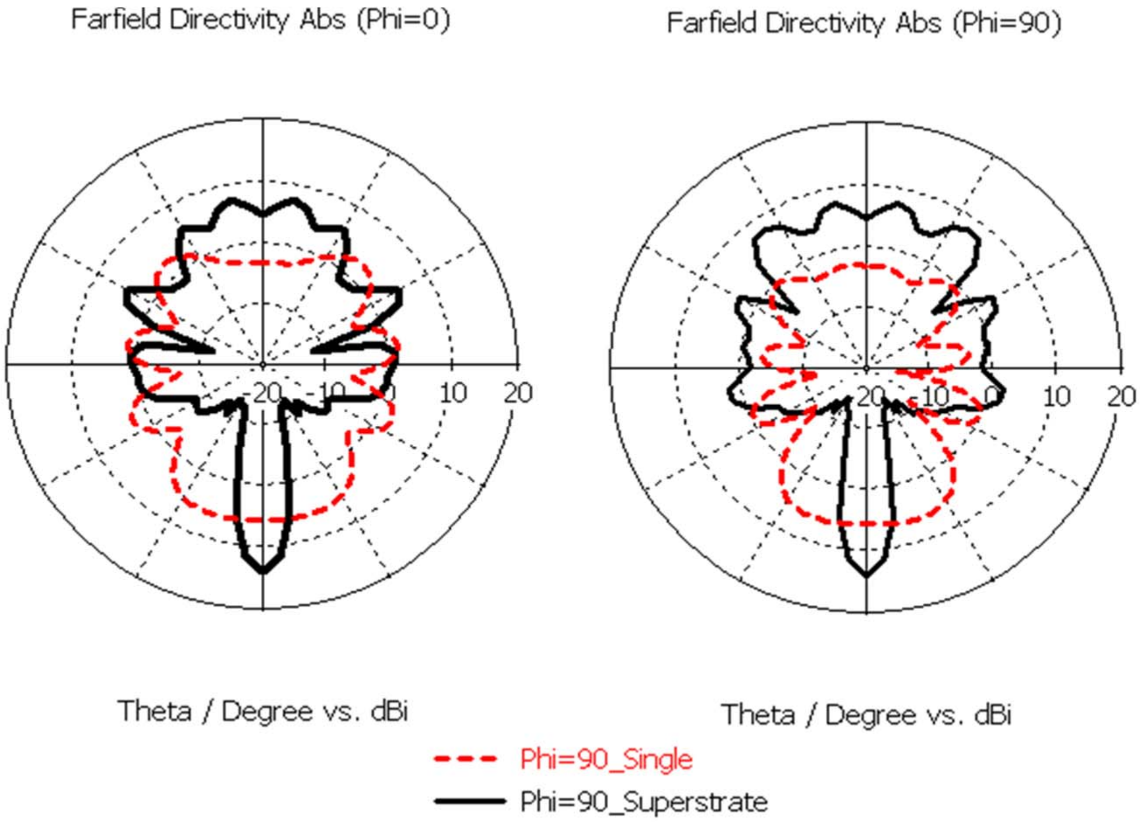

Farfield Directivity Abs (Phi=90)
0
30
330
60
300
90
270
120
240
150
210
180
-10
-10
0
10
20
Theta / Degree vs. dBi


Directivity,Theta=0,Max. Value
3.5
3
2.5
2
1.5
1
980
982
984
986
988
990
992
994
996
998
1000
Frequency / GHz

Results #2

Antenna	SLL in XZ Plane	SLL in YZ Plane	Gain
Single antenna	-6.5 dB	-6.4 dB	15.5 dB
Antenna with superstrate	-4 dB	-6.4 dB	5.8 dB

Gain improvement = 9.8 dB

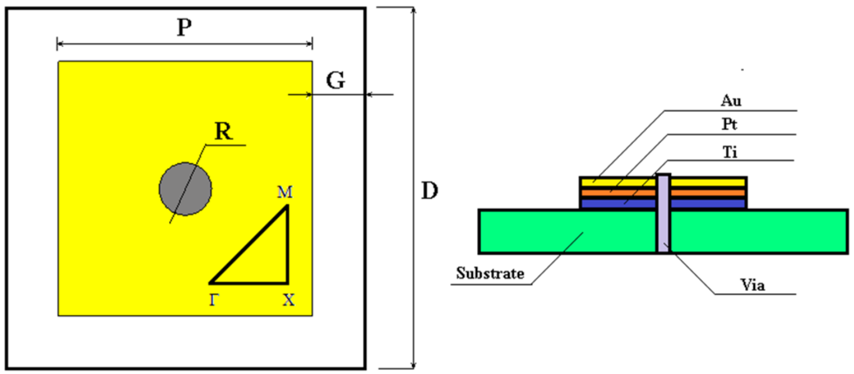


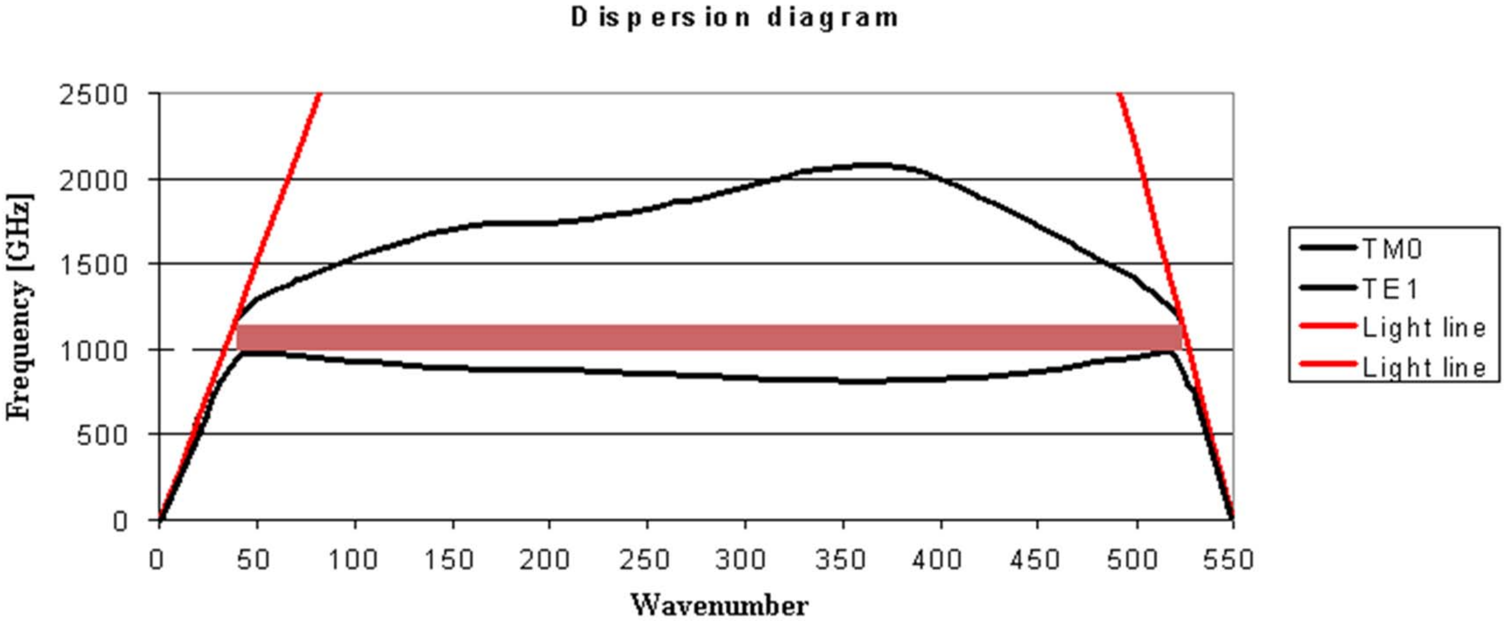
Farfield Directivity Abs (Phi=0)

Farfield Directivity Abs (Phi=90)

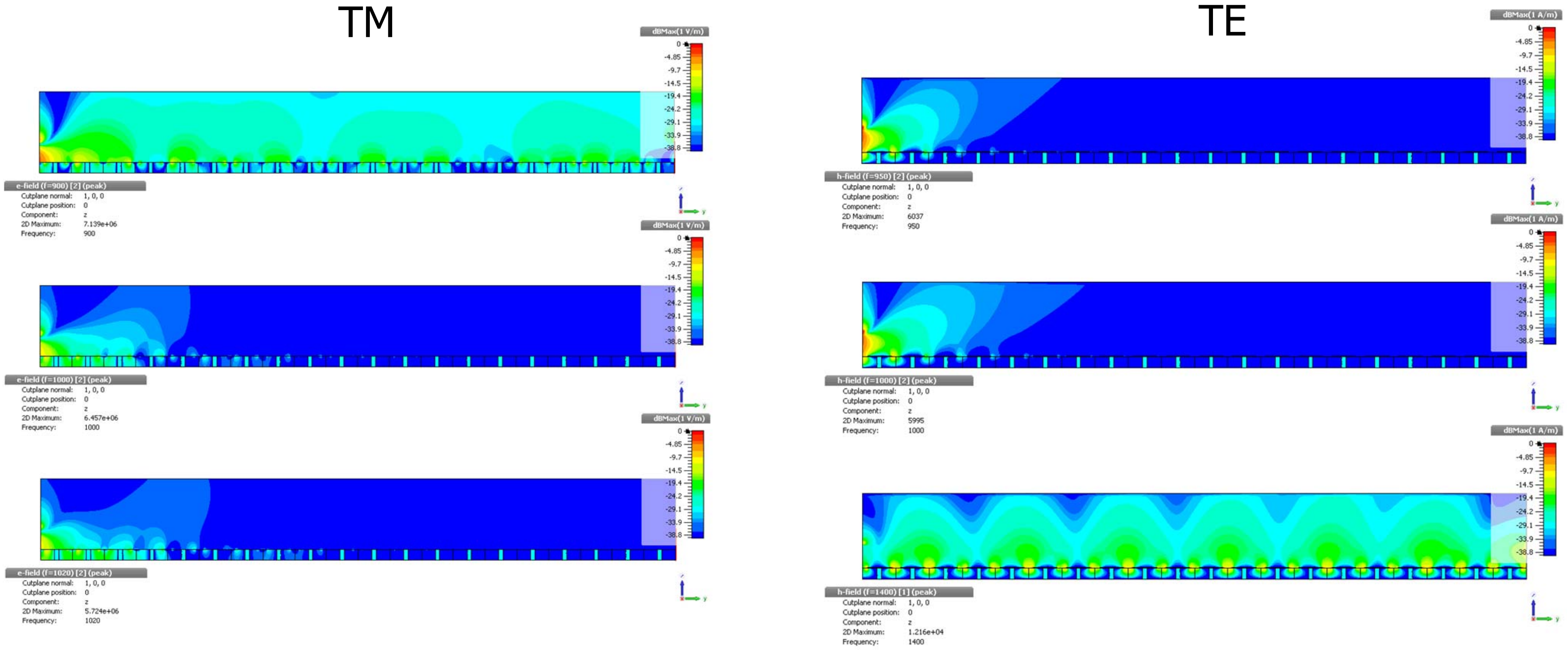
THz metamaterials: Design of the mushroom

Dimensions of the one Cell:
D = 27.38 µm, P = 19.38 µm,
R = 4 µm, G = 4 µm
GaAs with h = 10 µm, t_AU = 200 nm,
t_Pt = 40 nm, t_Ti = 30 nm





Results #1



e-field (f=900) [2] (peak)
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: z
2D Maximum: 7.139e+06
Frequency: 900

e-field (f=1000) [2] (peak)
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: z
2D Maximum: 6.457e+06
Frequency: 1000

e-field (f=1020) [2] (peak)
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: z
2D Maximum: 5.724e+06
Frequency: 1020

h-field (f=950) [2] (peak)
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: z
2D Maximum: 6037
Frequency: 950

h-field (f=1000) [2] (peak)
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: z
2D Maximum: 5995
Frequency: 1000

h-field (f=1400) [1] (peak)
Cutplane normal: 1, 0, 0
Cutplane position: 0
Component: z
2D Maximum: 1.216e+04
Frequency: 1400

950 GHz :TM waves in propagation, TE waves in cutoff
1000 GHz: both the TM and TE waves in cut off (waves do not propagate)
1200 GHz: (TM waves in cutoff, TE waves in propagation
Confirm the results of the dispersion analysis.

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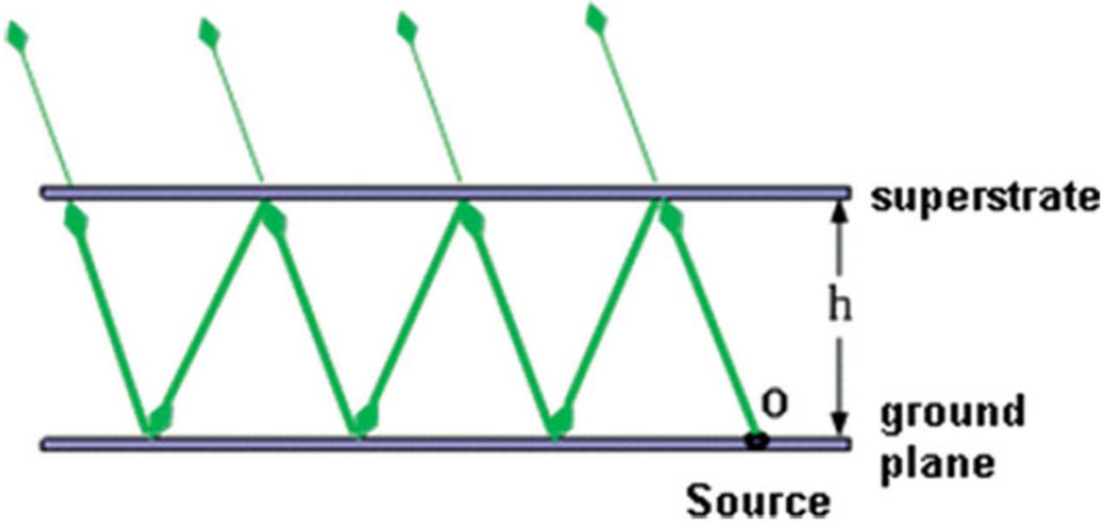
Superstrate: Reduction of the cavity



$$h = \frac{\varphi_1 + \varphi_2}{\pi}\frac{\lambda}{4} + N\frac{\lambda}{2} \quad N = 0, 1, 2, \ldots,$$

PEC: φ = 180 Deg

N = 1

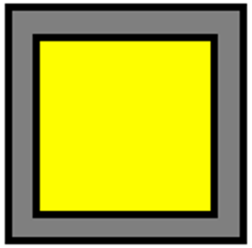
h = λ/2

AMC/EBG: φ ≠ 180 Deg

N = 0, 1

h = λ/120

V1

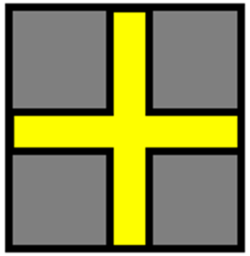


φ = -180 Deg

φg = 180 Deg

h = λ/2

V2



φ = -78 Deg

φg = 120 Deg

h = λ/120

Dimmensions: V1 » V2

Conclusion

- Disadvantages of my proposal:

  Losses, Efficiency, Complicated design, Production.

- Advantages of my proposal:

  Complete planar structure, Circular polarization, High gain, reduced mutual coupling, wide axial ratio band.

Thank you for your attention

I would like to thank prof. Hartnagel for his great help with my work.

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INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

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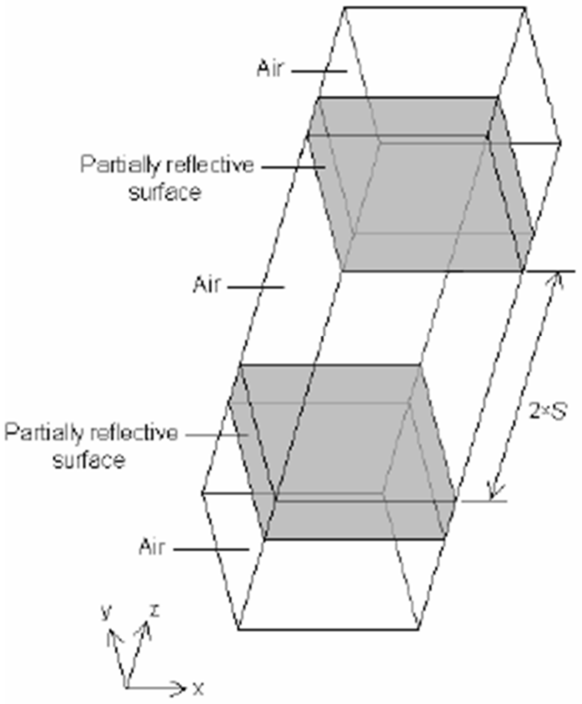
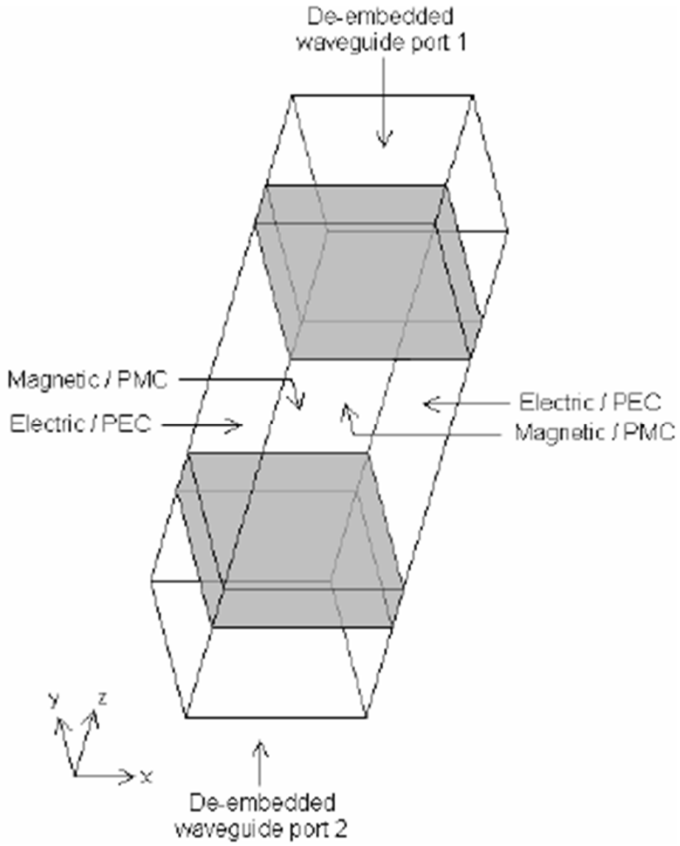
Superstrate: Boundary conditions





EBG: Boundary conditions