European School of Antennas

Applications of FSS based EBG surface

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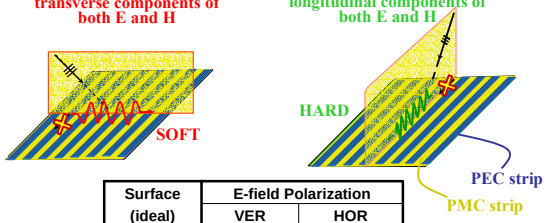
Artificially hard and soft surfaces
Relized by using printed dipoles and slots

PEC, PMC, Vs. SOFT and HARD

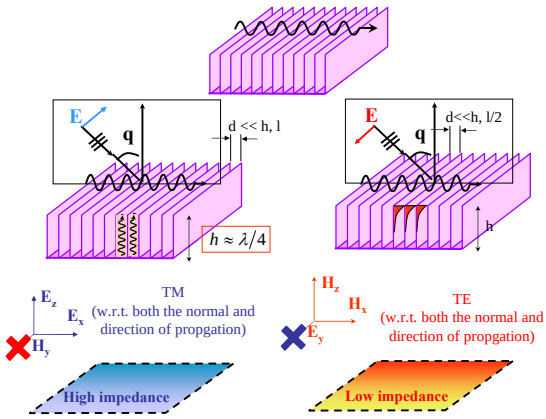
Imposes vanishment of the transverse components of both E and H

Imposes vanishment of the longitudinal components of both E and H

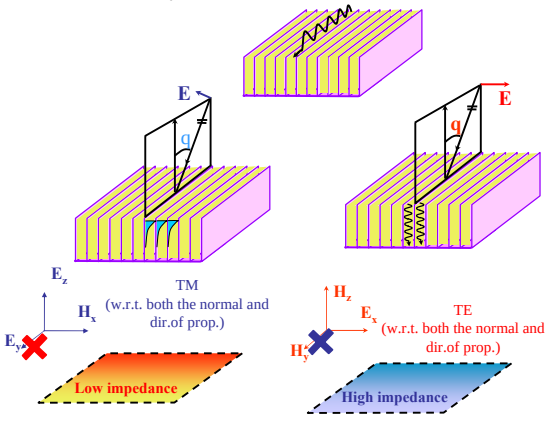


Surface (ideal)	E-field Polarization	
	VER	HOR
PEC	GO	STOP
PMC	STOP	GO
SOFT	STOP	STOP
HARD	GO	GO
EBG	STOP	STOP

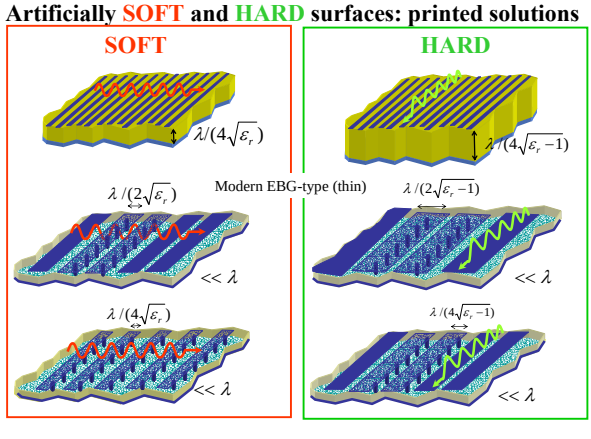
Artificially SOFT surfaces: classical solution

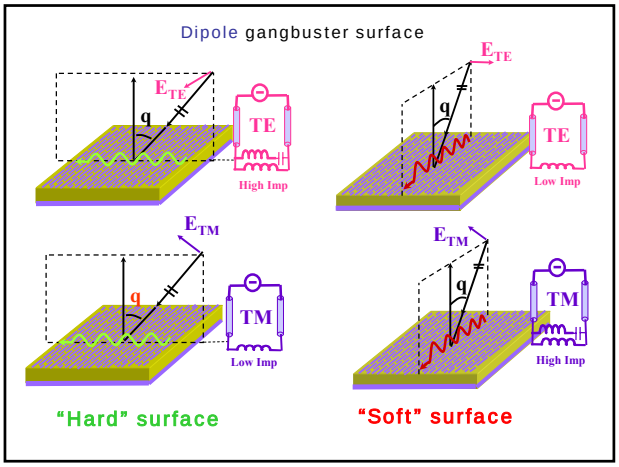


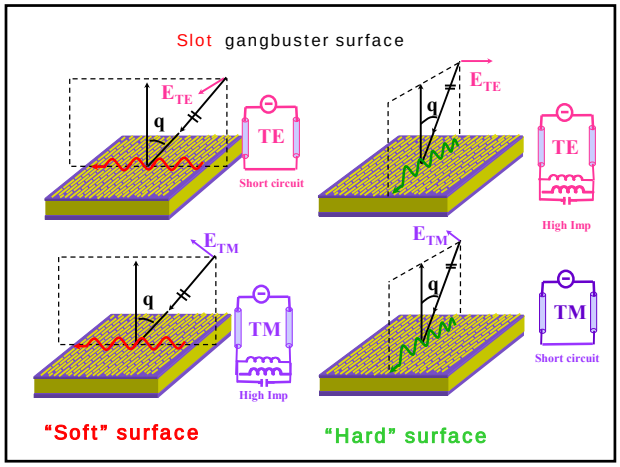
Artificially HARD surfaces: classical solution

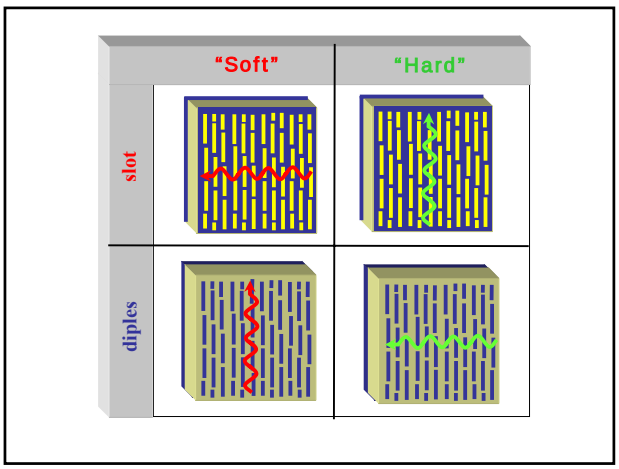


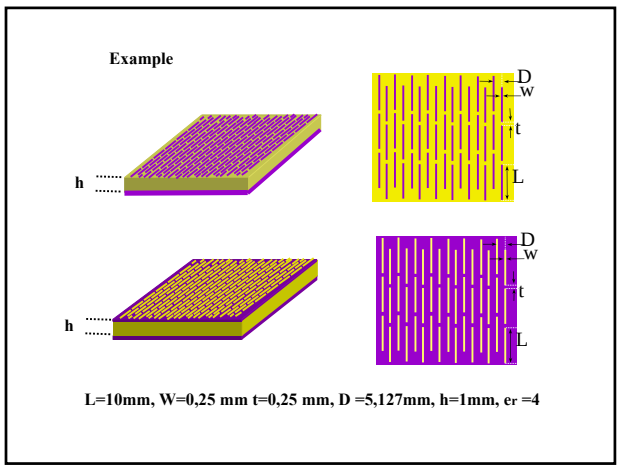
Artificially SOFT and HARD surfaces: printed solutions

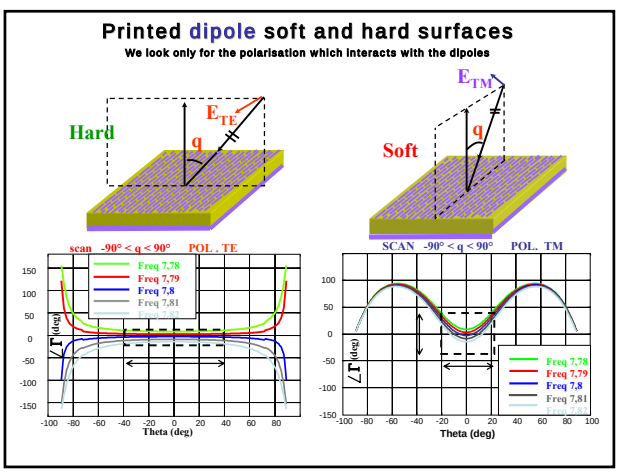


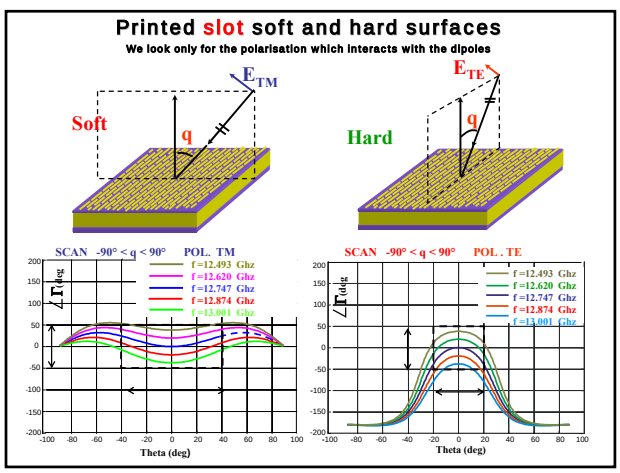

Dipole gangbuster surface
E_{TE}
q
TE
High Imp
E_{TE}
q
TE
Low Imp
E_{TM}
q
TM
Low Imp
E_{TM}
q
TM
High Imp
"Hard" surface
"Soft" surface


Slot gangbuster surface
E_{TE}
q
TE
Short circuit
E_{TE}
q
TE
High Imp
E_{TM}
q
TM
High Imp
E_{TM}
q
TM
Short circuit
"Soft" surface
"Hard" surface

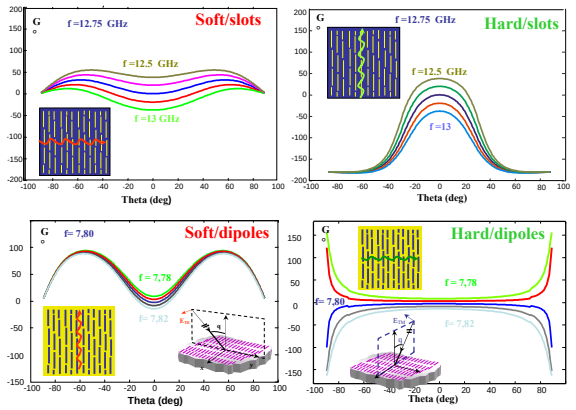

"Soft"
"Hard"
slot
diples


Example
h
D
W
t
L
h
D
W
t
L
L=10mm, W=0,25 mm t=0,25 mm, D =5,127mm, h=1mm, εr =4

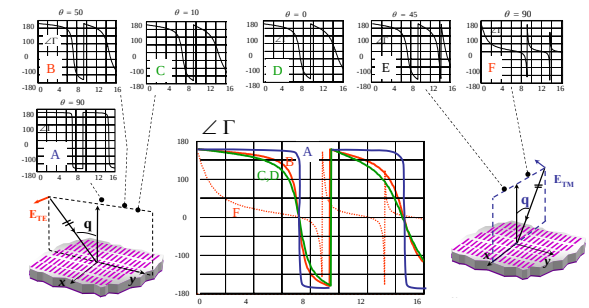

Printed dipole soft and hard surfaces
We look only for the polarisation which interacts with the dipoles
Hard
E_{TE}
q
Soft
E_{TM}
q
scan -90° < q < 90° POL. TE
Freq 7,78
Freq 7,79
Freq 7,8
Freq 7,81
∠Γ (deg)
Theta (deg)
SCAN -90° < q < 90° POL. TM
Freq 7,78
Freq 7,79
Freq 7,8
Freq 7,81
∠Γ (deg)
Theta (deg)


Printed slot soft and hard surfaces
We look only for the polarisation which interacts with the dipoles
Soft
E_{TM}
q
Hard
E_{TE}
q
SCAN -90° < q < 90° POL. TM
f=12.493 Ghz
f=12.620 Ghz
f=12.747 Ghz
f=12.874 Ghz
f=13.001 Ghz
∠Γ (deg)
Theta (deg)
SCAN -90° < q < 90° POL. TE
f=12.493 Ghz
f=12.620 Ghz
f=12.747 Ghz
f=12.874 Ghz
f=13.001 Ghz
∠Γ (deg)
Theta (deg)

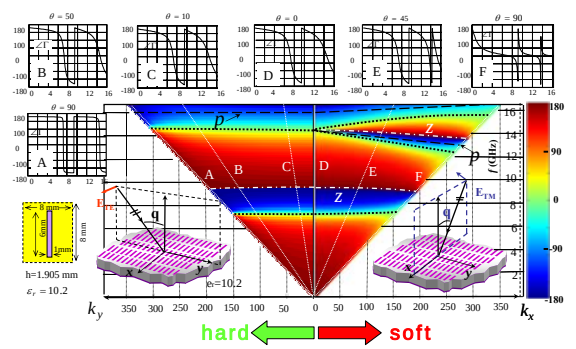
Phase of the ref. coeff. w.r.t. the incidence angle



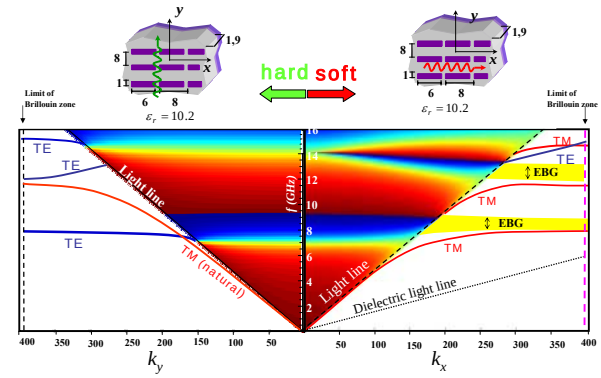
Phase of the ref. coeff. w.r.t. the frequency



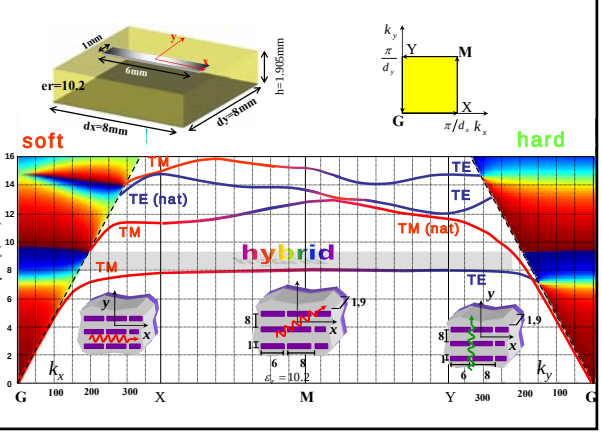
Phase of the reflection coefficient (dipoles)



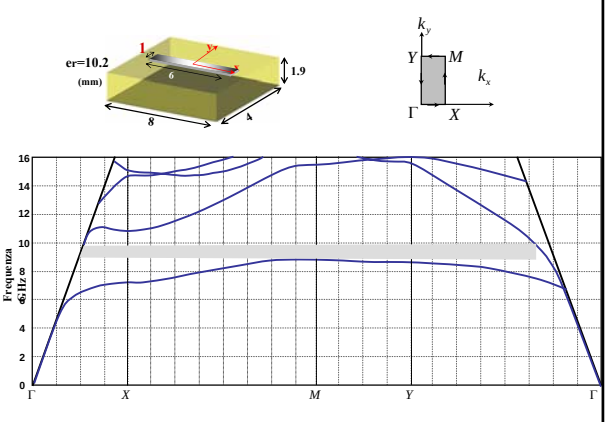
Dispersion diagrams-principal planes

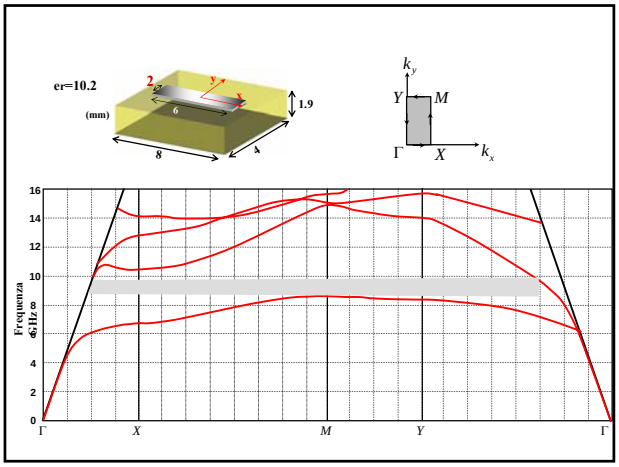


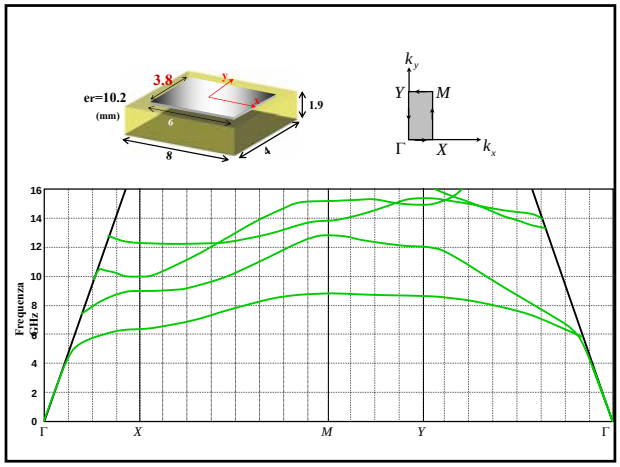
Dispersion diagram- oblique propagation

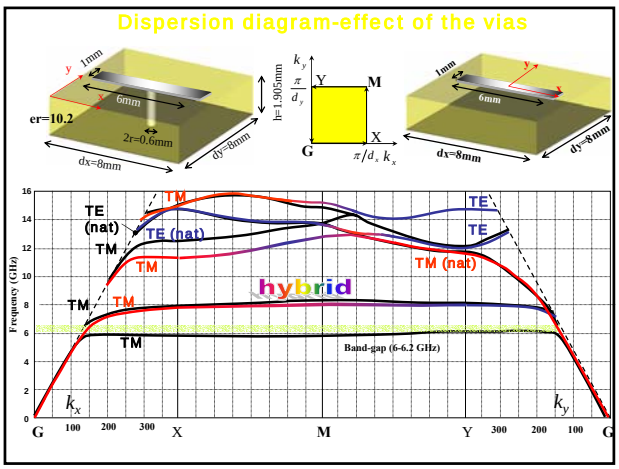


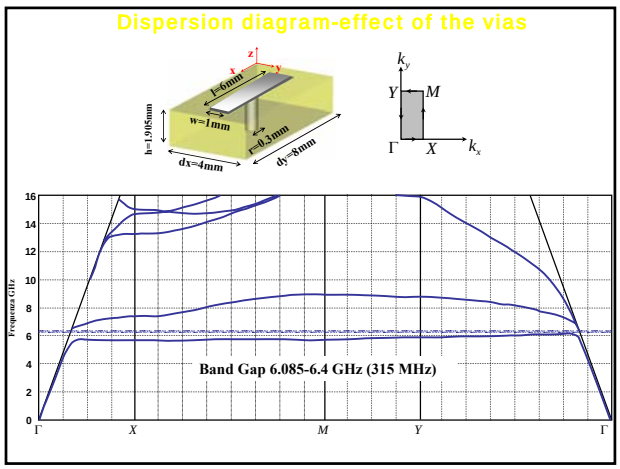
No vias-no larger dipole

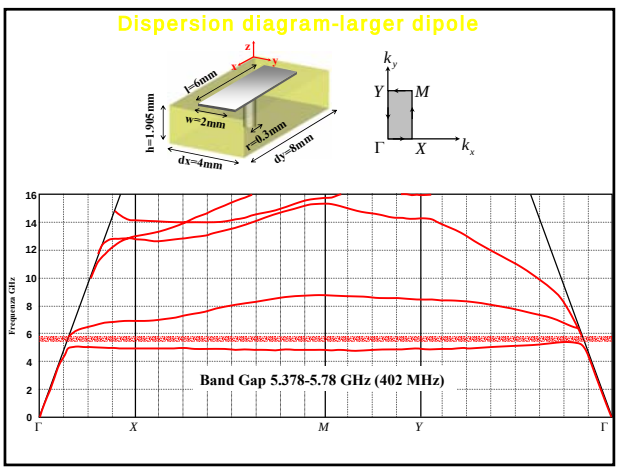


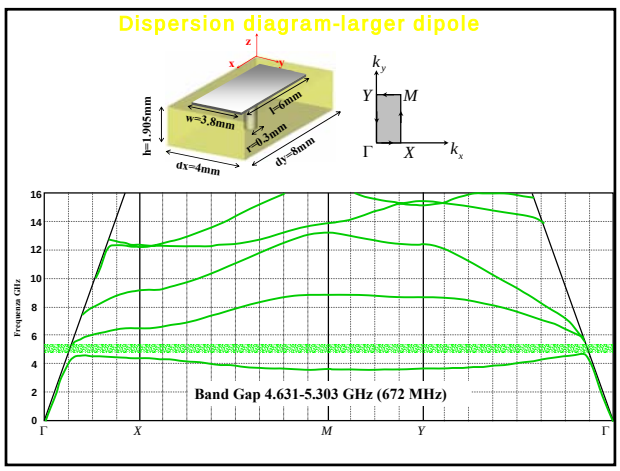

er=10.2
(mm)
2
6
8
4
1.9
Frequenza GHz
Γ X M Y Γ


er=10.2
(mm)
3.8
6
8
4
1.9
Frequenza GHz
Γ X M Y Γ

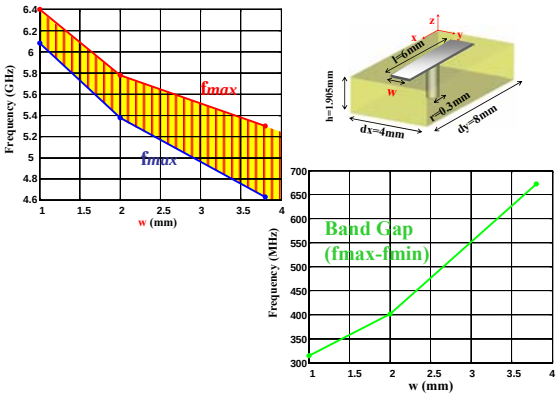

Dispersion diagram-effect of the vias
er=10.2
6mm
2r=0.6mm
dx=8mm
dy=8mm
h=1.905mm
TE
(nat)
TM
TE (nat)
TM (nat)
hybrid
Band-gap (6-6.2 GHz)
Frequency (GHz)
G X M Y G


Dispersion diagram-effect of the vias
l=6mm
w=1mm
r=0.3mm
dx=4mm
dy=8mm
h=1.905mm
Band Gap 6.085-6.4 GHz (315 MHz)
Frequenza GHz
Γ X M Y Γ


Dispersion diagram-larger dipole
l=6mm
w=2mm
r=0.3mm
dx=4mm
dy=8mm
h=1.905mm
Band Gap 5.378-5.78 GHz (402 MHz)
Frequenza GHz
Γ X M Y Γ

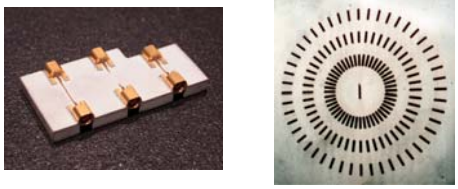

Dispersion diagram-larger dipole
l=6mm
w=3.8mm
r=0.3mm
dx=4mm
dy=8mm
h=1.905mm
Band Gap 4.631-5.303 GHz (672 MHz)
Frequenza GHz
Γ X M Y Γ

Dispersion diagram-effect of the vias



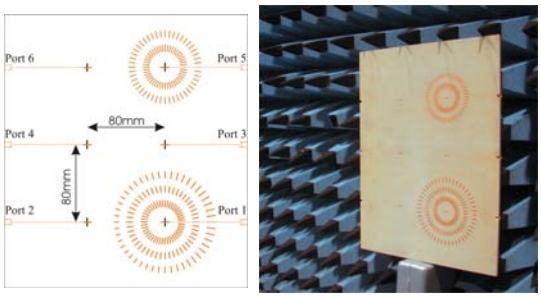
Prototype

- Dielectric from Rogers TMM10i (ε_r = 9.8 ± 0.25)
- Central Frequency = 5.5 GHz
- Feeding Coax. and Micro-strip
- Completely Planar Structure

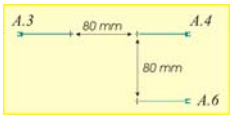


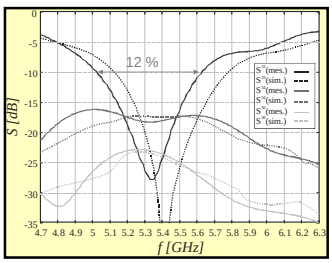
Courtesy of TNO Physics and Electronics Laboratory - The Netherlands

The Panel and Port Definitions

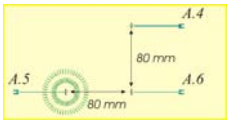


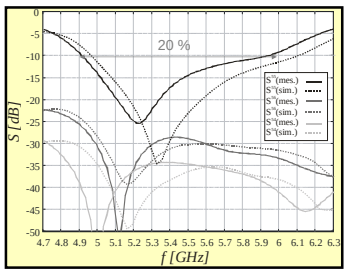
Antennas without EBG's



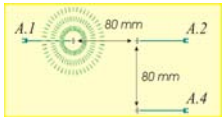


Antenna + 2 rings

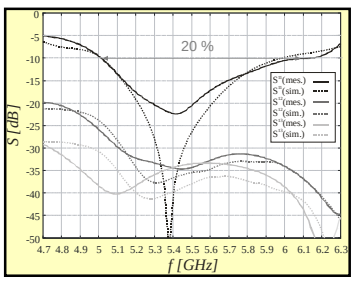




Antenna + 3 rings

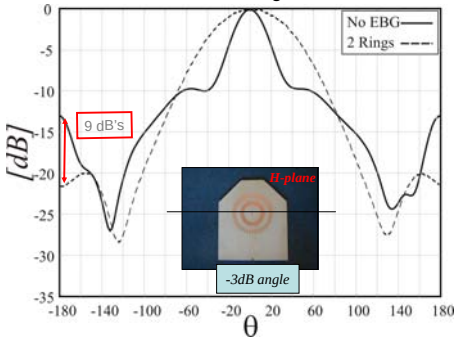


Dipole was slightly ruined
Frequency centered !!

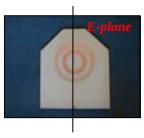


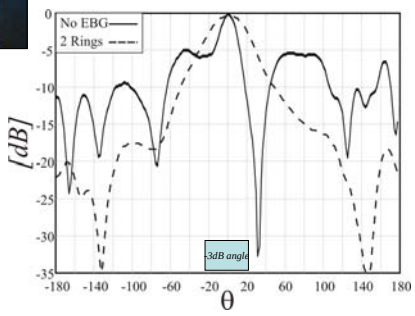
Radiation Patterns

Radiation Pattern (H plane)
Two Rings

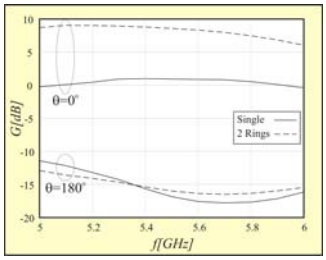


Radiation Pattern (E-plane)
Two rings





Efficiency Improvement



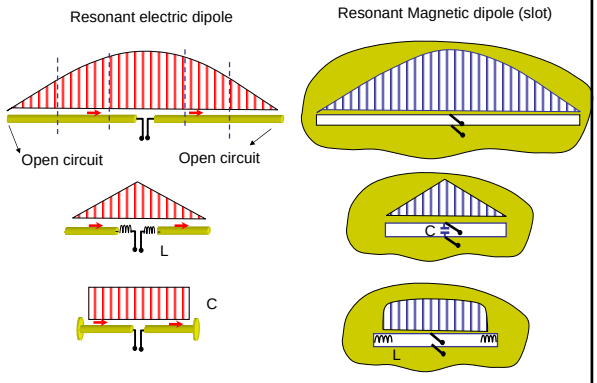
3D simulations

Gain enhancement is significant (note infinite slab)

Front to back ratio is greatly improved

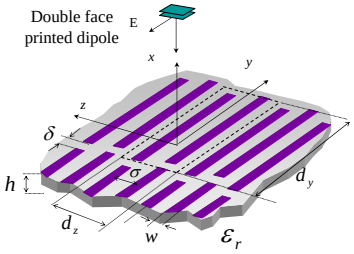
Examples

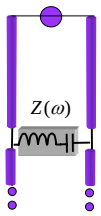
- Hard and soft waveguides
- Compact resonators (N. Engheta)
- Quasi TEM waveguide
- leaky wave antennas



Parameterizing with respect to k

Double face printed dipole





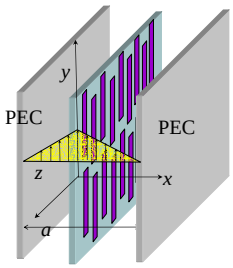
k_z =kcosq

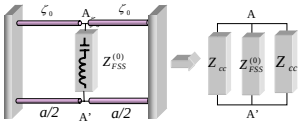
Z=z/cosq

Geometry for a dipole-FSS printed on a grounded dielectric slab. *h*=0.508 mm, *w*=0,25 mm, d_y =10mm, d= 0,2 mm, d_z =0,5 mm, relative permittivity ε_r = 4.5.

$$Y_S(\omega)=\frac{\omega C}{1-\left(\omega/\omega_0\right)^2}$$

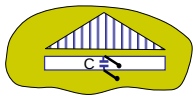
Metamaterial sheet inside a parallel plate waveguide



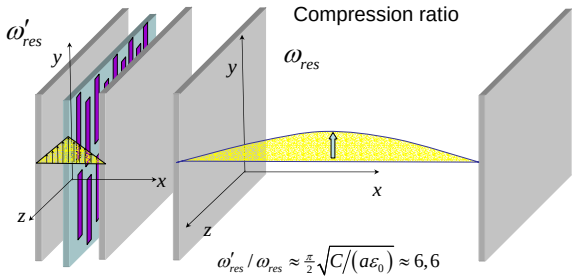


$$\frac{\omega_{res}C}{1-\left(\omega_{res}/\omega_0\right)^2}=\frac{2}{\xi_0\tan\left(\frac{1}{2c}a\omega_{res}\right)}$$

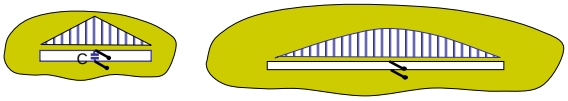
$$\omega_{res}\approx 1\Big/\sqrt{\tfrac{1}{4}C\mu_0 a+1/\omega_0^2}$$



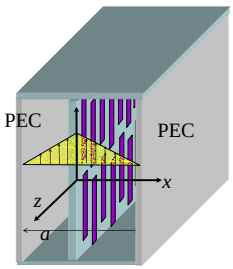
Compression ratio

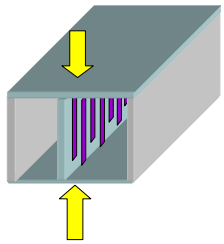


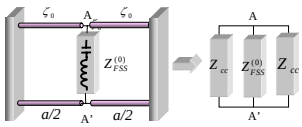
$$\omega'_{res}/\omega_{res}\approx\tfrac{\pi}{2}\sqrt{C/(a\varepsilon_0)}\approx 6{,}6$$



Rectangular Waveguide



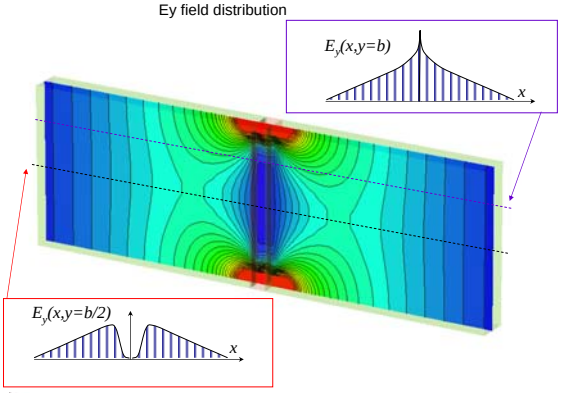




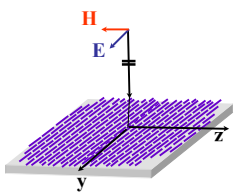
$$\frac{\omega_c C}{1-\left(\omega_c/\omega_0\right)^2}=\frac{2}{\xi_0\tan\left(\frac{1}{2c}a\omega_c\right)}$$

Waveguide cut-off

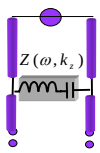
Ey field distribution



Parameterizing with respect to k

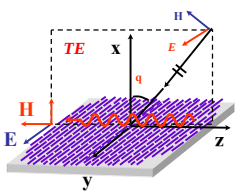


$$Z_S(\omega,\theta)=\frac{\omega C}{1-\left(\omega/\omega_0\right)^2}$$



k_z =kcosq

Z =z/cosq



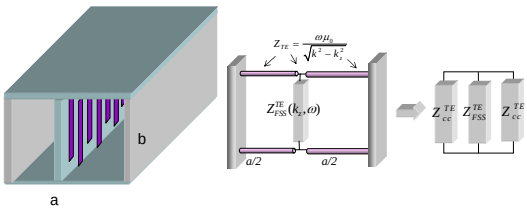
$k_z=k_0$ senq

$$\omega_p(k_z)=\omega_0+\eta c k_z$$

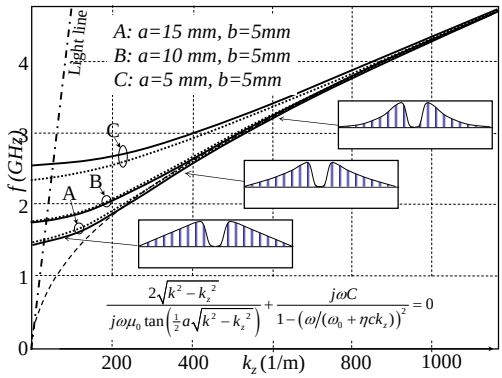
$$\frac{j\omega C}{1-\left(\omega/(\omega_0+\eta c k_z)\right)^2}=0$$

h = 5,5 X 10^{-3}

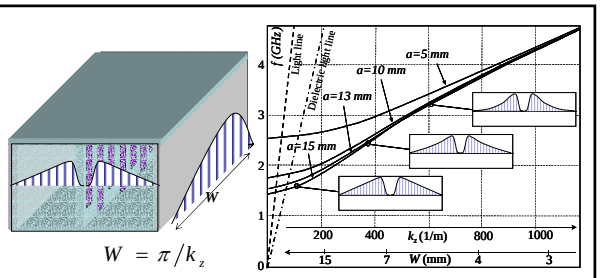
Waveguide dispersion equation



$$\frac{2\sqrt{k^2 - k_z^2}}{j\omega\mu_0 \tan\left(\frac{1}{2}a\sqrt{k^2 - k_z^2}\right)} + \frac{j\omega C}{1 - \left(\omega/(\omega_0 + \eta c k_z)\right)^2} = 0$$



$$\frac{2\sqrt{k^2 - k_z^2}}{j\omega\mu_0 \tan\left(\frac{1}{2}a\sqrt{k^2 - k_z^2}\right)} + \frac{j\omega C}{1 - \left(\omega/(\omega_0 + \eta c k_z)\right)^2} = 0$$



$$W = \pi / k_z$$

$$\frac{2\sqrt{\left(\frac{\pi}{W}\right)^2 - \left(\frac{\omega_{res}}{c}\right)^2}}{\omega_{res}\mu_0 \tanh\left(\frac{1}{2}a\sqrt{\left(\frac{\pi}{W}\right)^2 - \left(\frac{\omega_{res}}{c}\right)^2}\right)} = \frac{\omega_{res} C}{1 - \left(\omega_{res}/(\omega_0 + \eta c\pi/W)\right)^2}$$

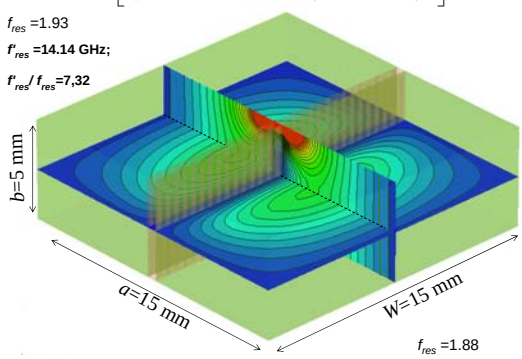
$$\omega_{res} = \left[\frac{1}{2\pi} WC\mu_0 \tanh\left(\frac{\pi}{2} a/W\right) + \left(\omega_0 + \eta c\pi/W\right)^{-2}\right]^{-1/2}$$

$$\omega_{res} = \left[\frac{1}{2\pi} WC\mu_0 \tanh\left(\frac{\pi}{2} a/W\right) + \left(\omega_0 + \eta c\pi/W\right)^{-2}\right]^{-1/2}$$

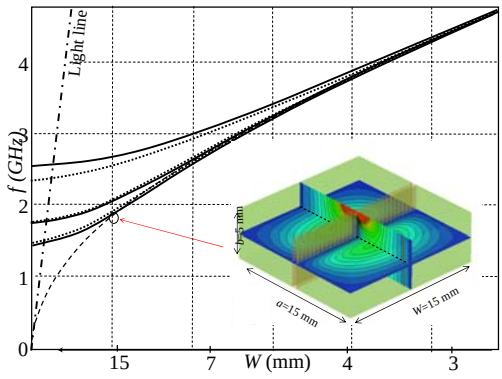
f_{res} =1.93

f'_{res} =14.14 GHz;

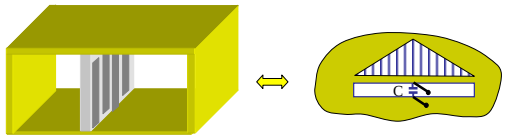
f'_{res} / f_{res} =7,32



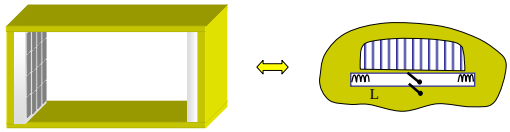
f_{res} =1.88



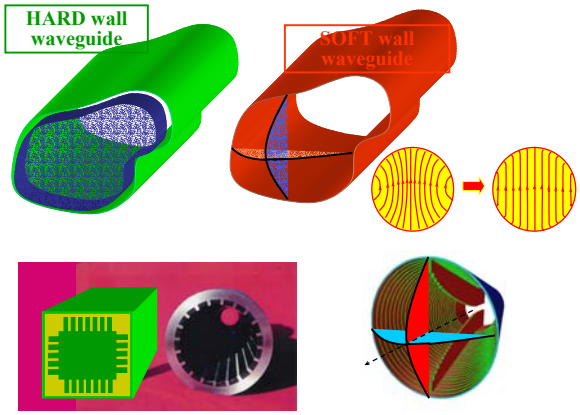
Frequency Selective Metamaterial Surfaces for Compact Cavity Resonator



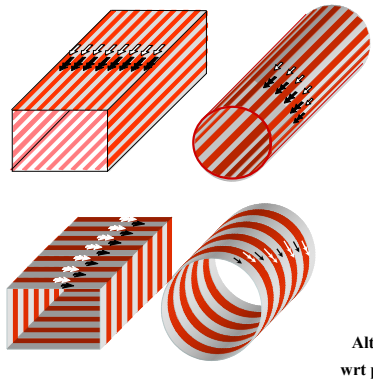
Quasi - TEM Waveguide by Using FSS Based Hard Surfaces



Waveguides with ideal sft and hard b.c. on the internal wall



Hard and Soft waveguide modes in terms of currents

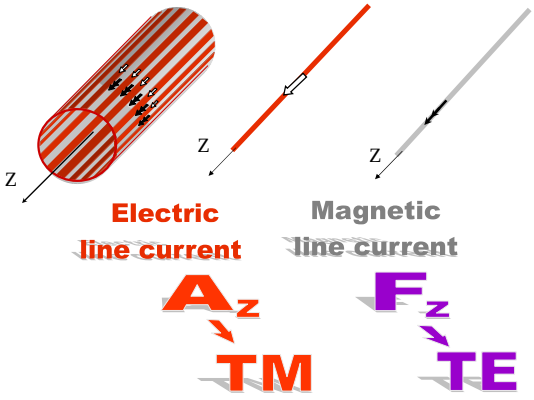


HARD longitudinal electric and magnetic currents

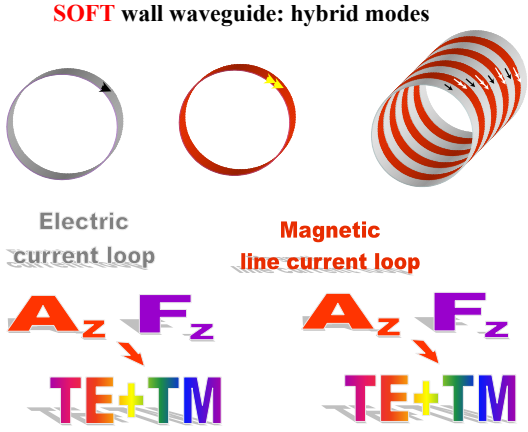
SOFT transverse electric and magnetic currents

Alternative process wrt potential approach

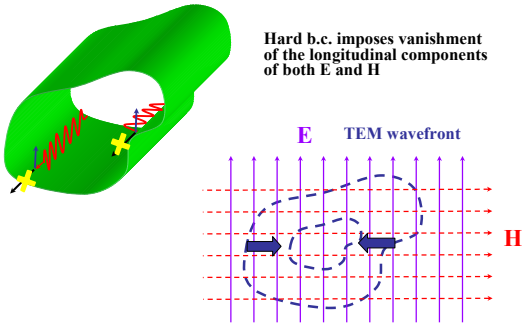
HARD waveguide: TE-TM decomposition



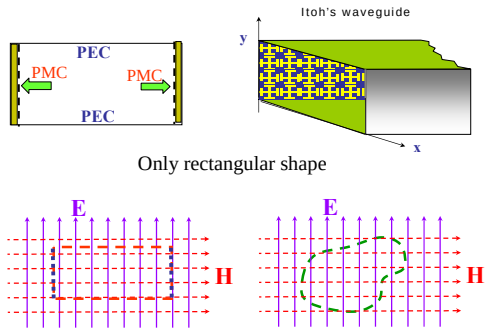
SOFT wall waveguide: hybrid modes



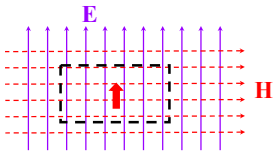
The "magic" of the hard-wall waveguide



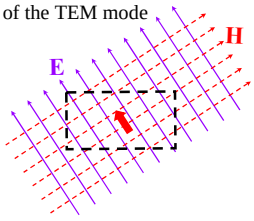
Quasi TEM mode: HARD-wall waveguide Vs PEC/PMC waveguide

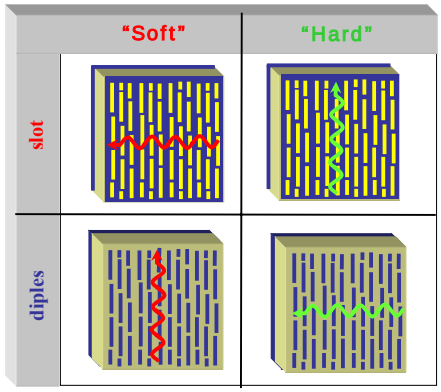


The “magic” of the hard-wall waveguide

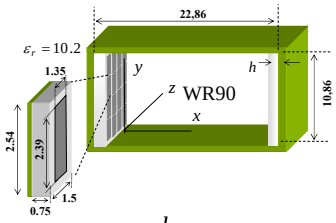


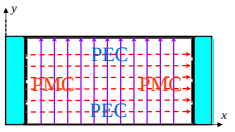
Arbitrary polarization of the TEM mode

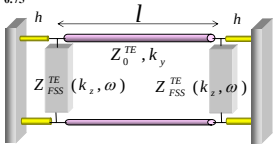




TEM wave propagation in rectangular waveguide



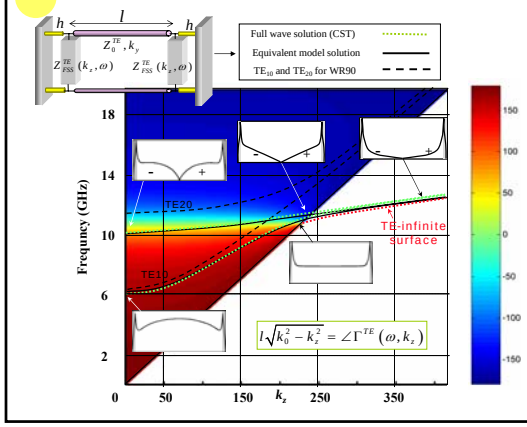


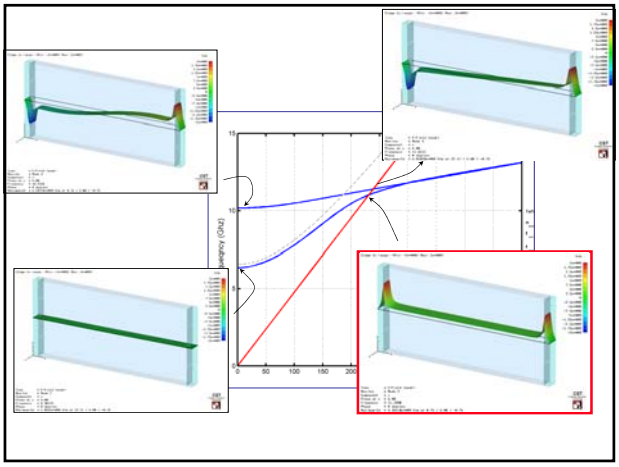


Dispersion equation

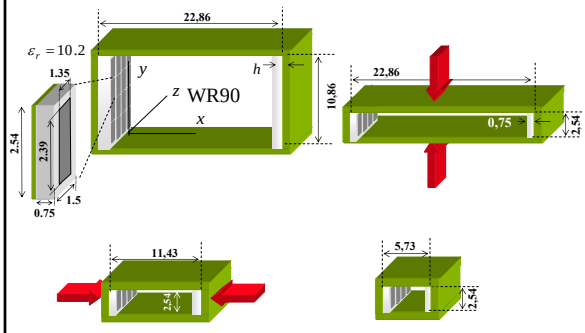
$$\tan\left(\sqrt{k_0^2 - k_z^2}\, l\right) = \tan\left(\angle\Gamma^{TE}(\omega, k_z)\right)$$

Dispersion Diagramm

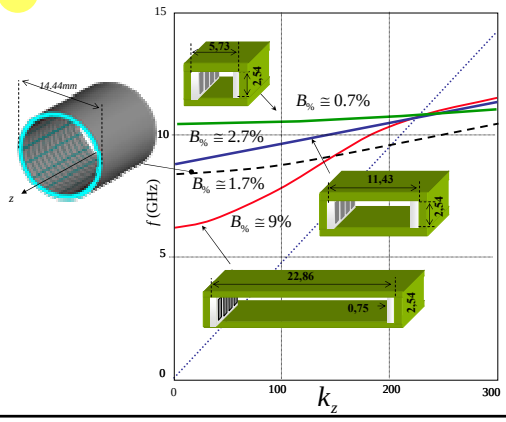




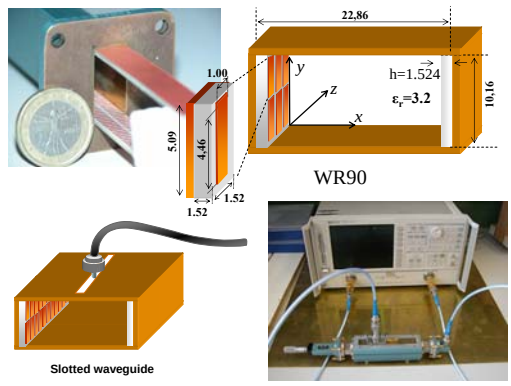
Compact Waveguide (1)

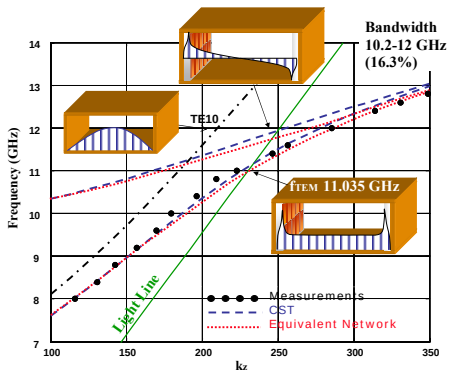


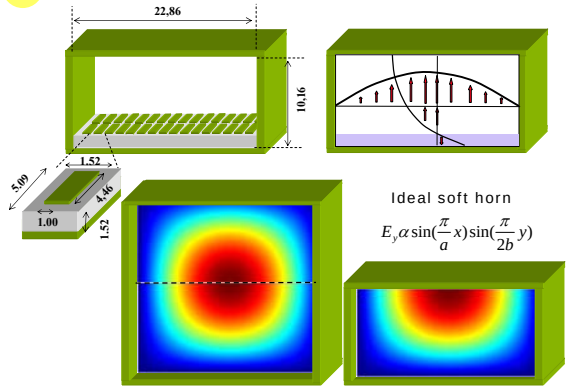
Compact Waveguide (1)

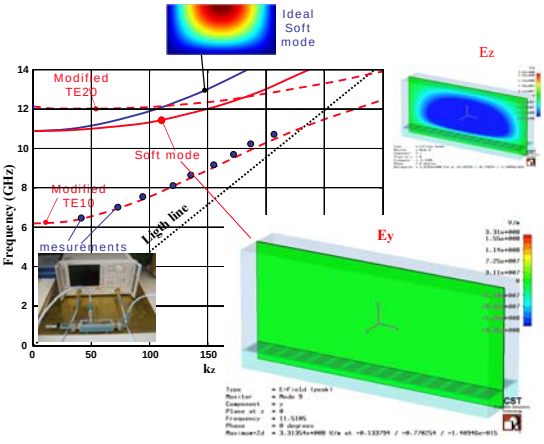


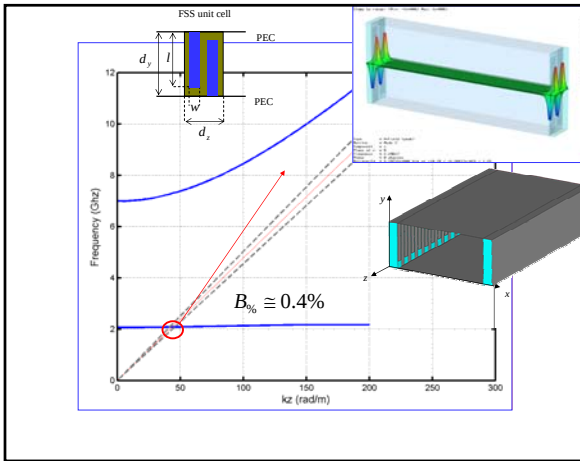
Measurements



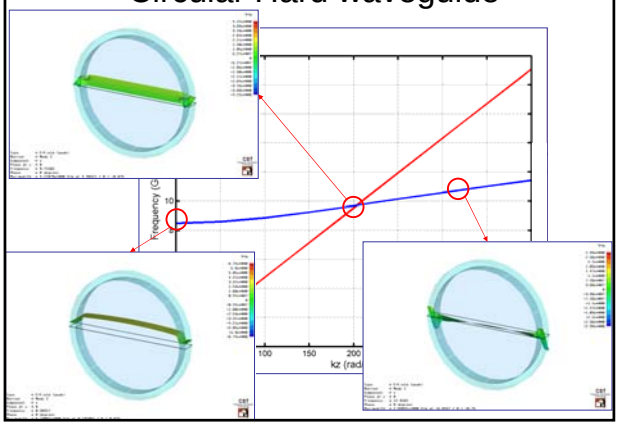




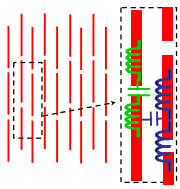




Circular Hard waveguide



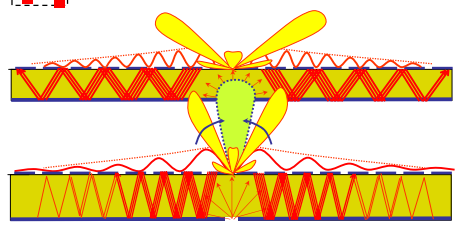
Basic idea for a leaky-wave antenna

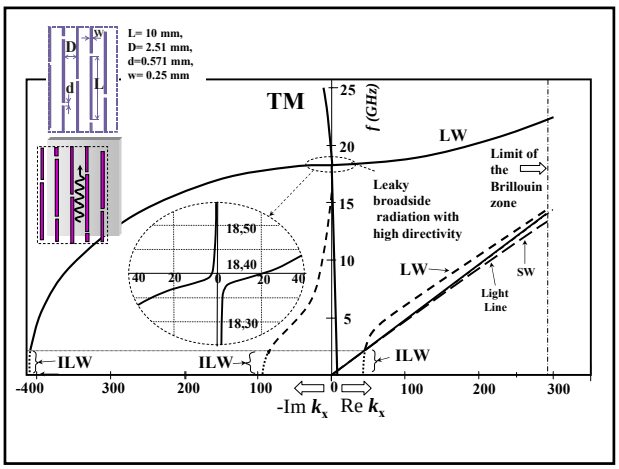


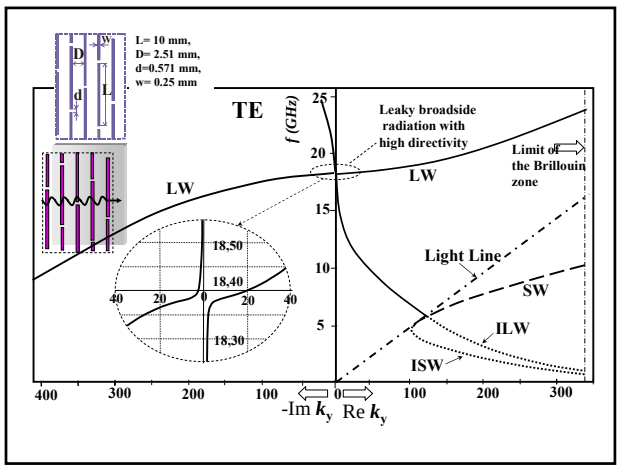
The effect of resonance of the FSS realizes at a certain frequency an “artificial short circuit

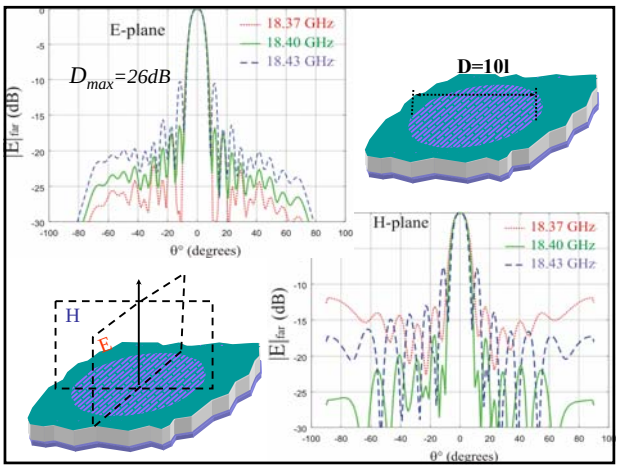
The short-circuits realizes a “parallel plate waveguide” which may support a leaky mode. The aperture realizes a conical beam radiation.

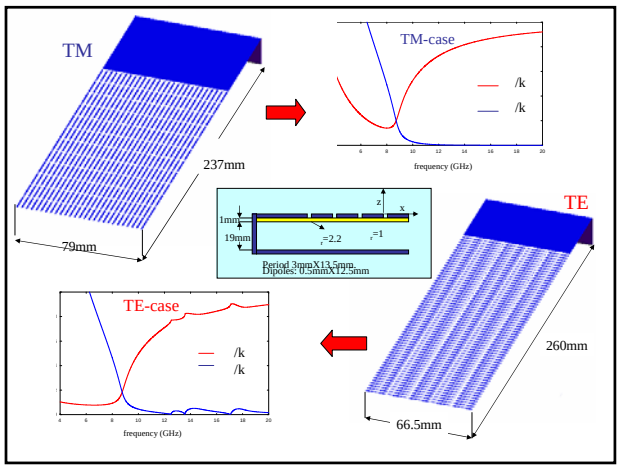
Chosing the right thickness of the slab realize a broadside beam.

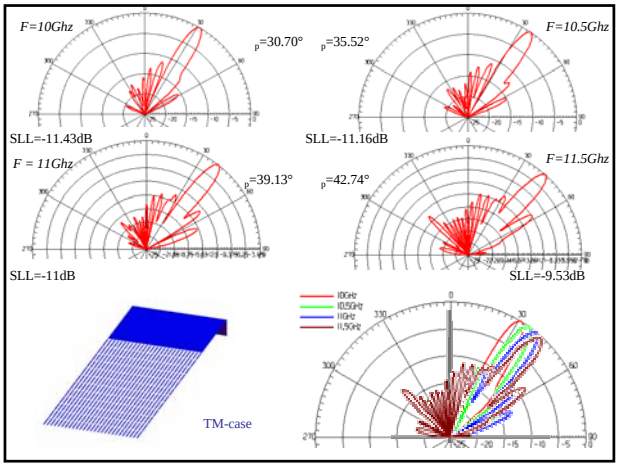


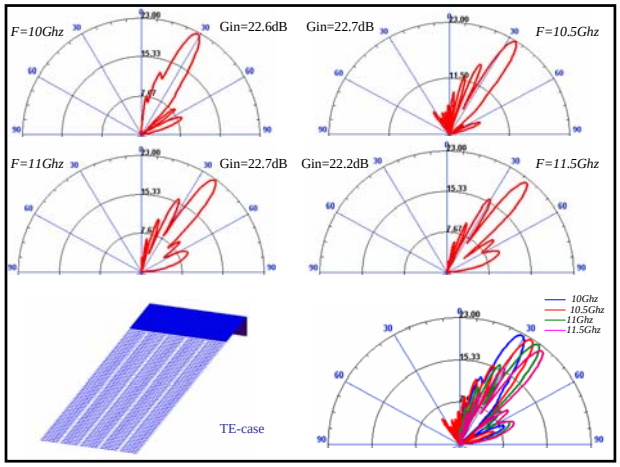




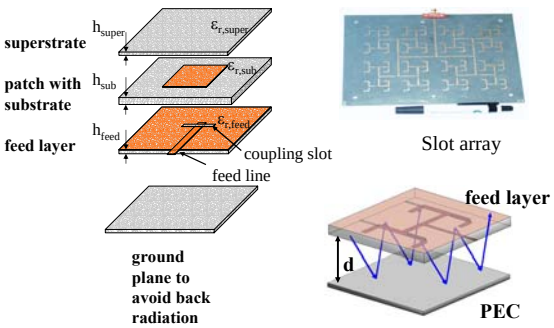


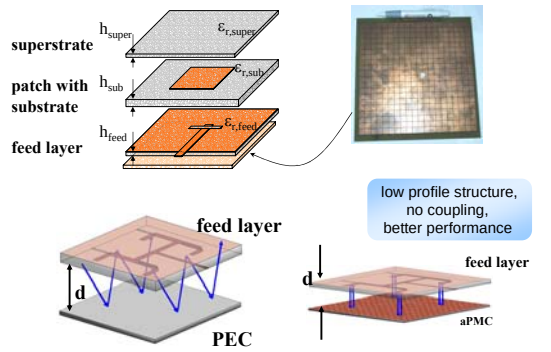




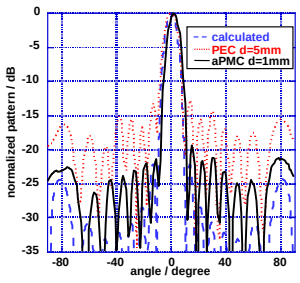


Use of artificial surfaces as a back screen





E-plane radiation pattern



E-plane radiation patterns at 13.5 GHz

side lobe suppression:
-23.0 dB calculated
-12.8 dB with PEC
-20.0 dB with aPMC

advantages of aPMC as antenna reflector:

⇨ **low side lobes**

⇨ **compact size**