Analysis and Design of Left-Handed Metamaterial Lenses Using Ansoft HFSS

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Introduction: Left-Handed Metamaterials

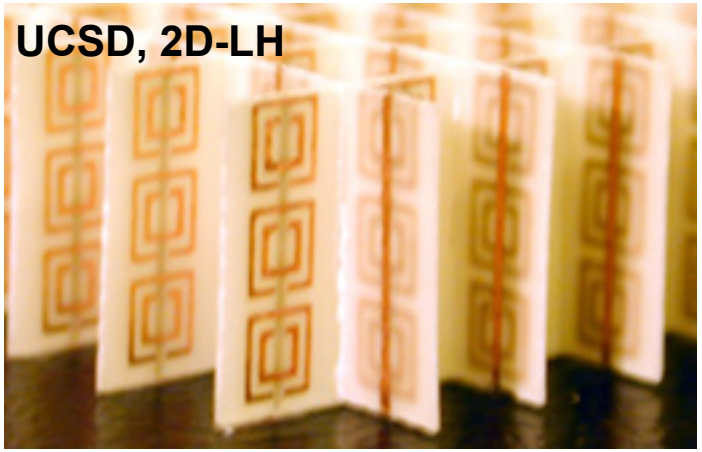
Historical Milestones

- **1968** : theoretical analysis of hypothetical LH materials by **Veselago**
- **1996/9** : introduction of electric (ε<0) / magnetic (μ<0) plasmon by **Pendry**
- **2000** : experimental demonstration of LH structure by **Smith**

LH definition: → **materials with** $\varepsilon < 0$ and $\mu < 0 \Rightarrow n < 0$ and $v_p - \| v_g$

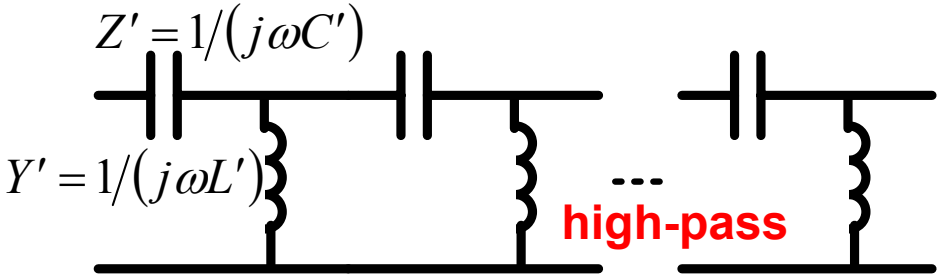
→ **unit-cell << λ →** **effective / macroscopic / homogeneous**

Resonant Structure Approach



- **approach**: no simple/rigorous analysis & no design method
- **structures**: RESONANT ⇨ lossy & narrow bandwidth & highly dispersive

Transmission Line Approach

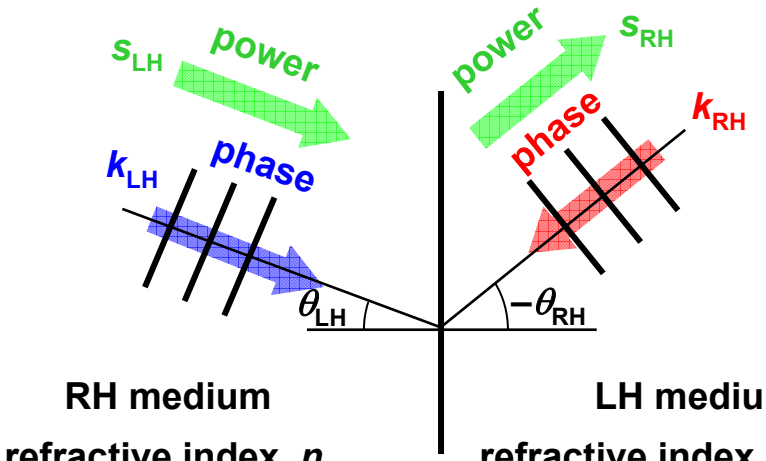


"BACKWARD WAVES"

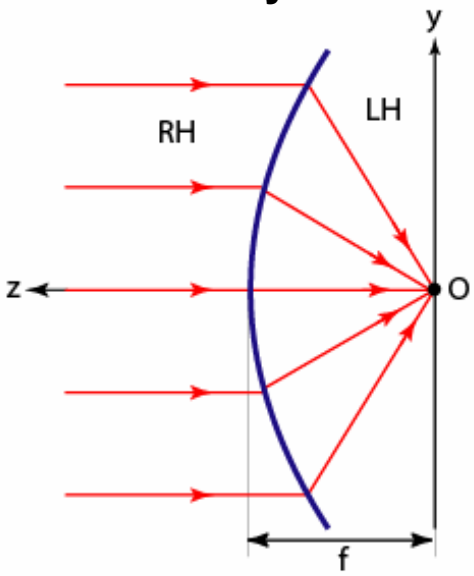
(e.g. Brillouin, Pierce)

- **approach**: Transmission line analysis & circuit design methods
- **structures**: ***NON*-RESONANT** ⇨ low loss & broad bandwidth & moderate dispersion

Negative Refractive Index Lenses

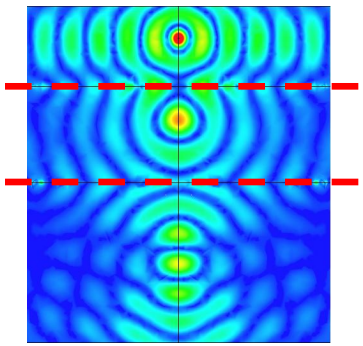


Plane Wave ↔ Cylindrical Wave

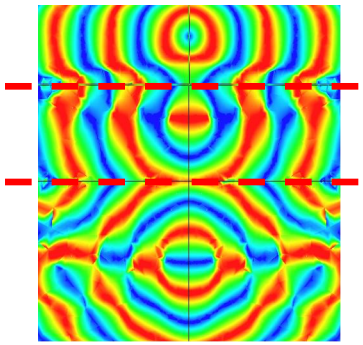


HFSS Simulations: Effective Medium (ε < 0, μ < 0)

flat lens

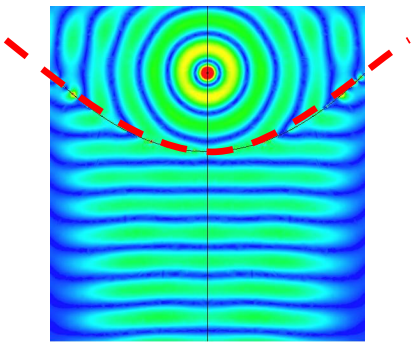


magnitude

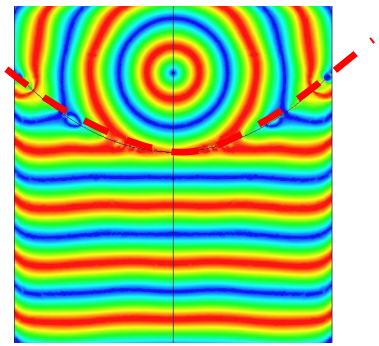


phase

parabolic lens



magnitude

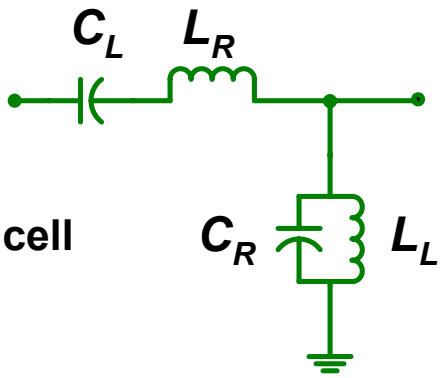


phase

Practical Realization of LHMs

Composite Right/Left-Handed TL

1-D unit cell



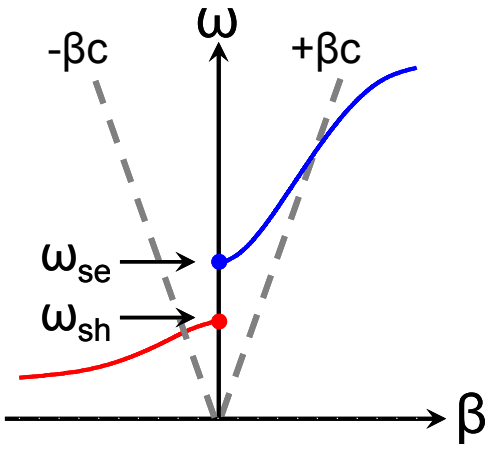
CRLH metamaterial includes

LH and unavoidable

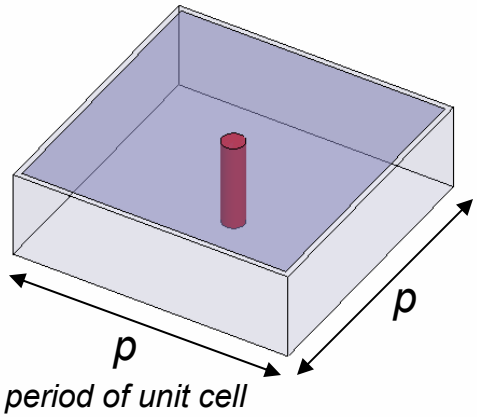
RH parasitic effects.

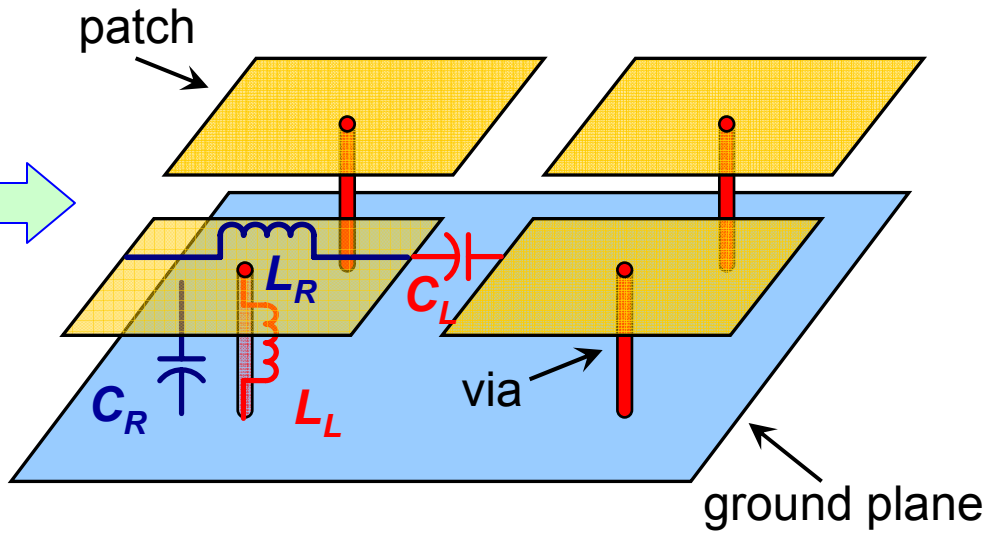
LH at low frequencies

RH at high frequencies



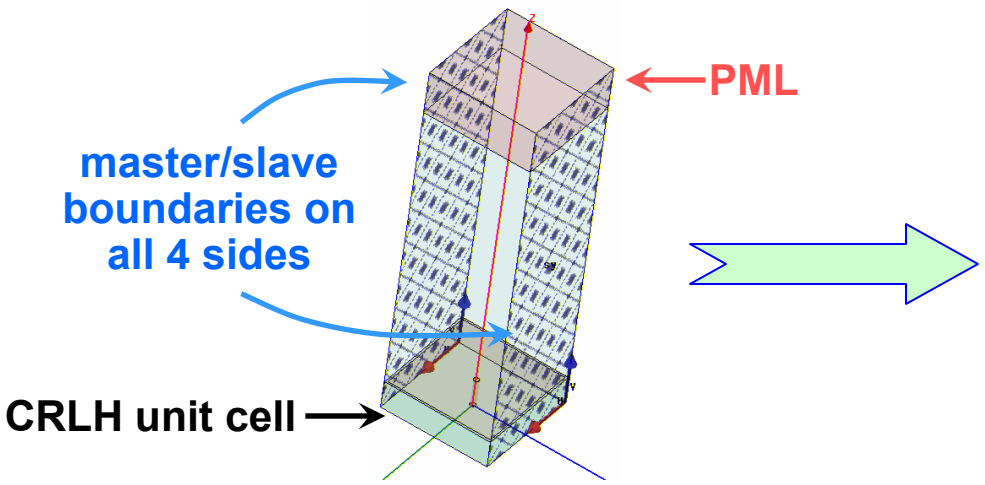
2-D unit cell



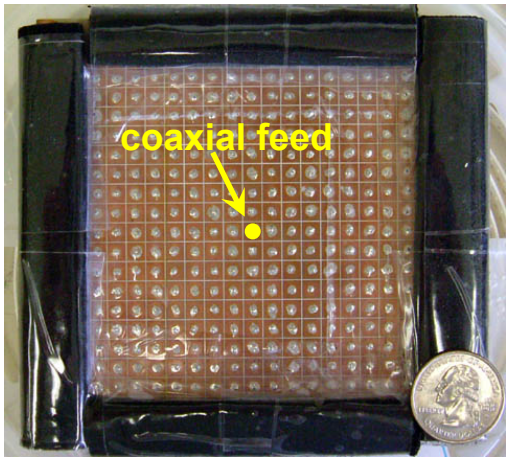


HFSS Characterization of 2-D CRLH TL

HFSS Eigenmode Simulation w/PBCs

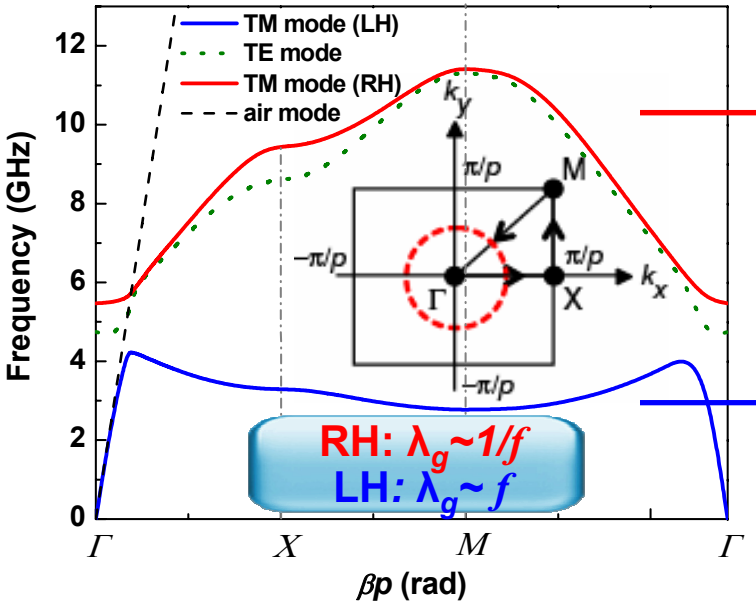


17x17 Mushroom Array

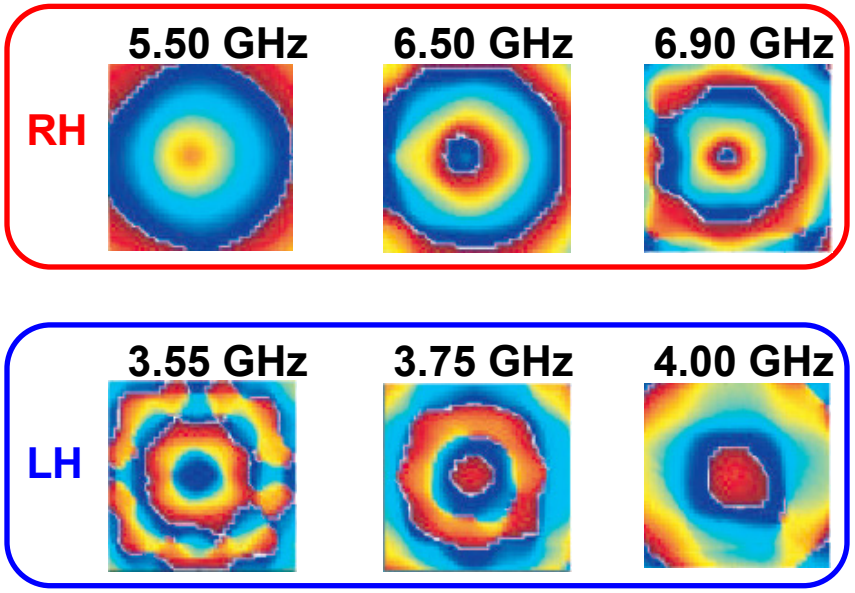


Dispersion Diagram (HFSS)

(p=5.0 mm, g=1.0 mm, h=1.27 mm, ε_R=10.2)

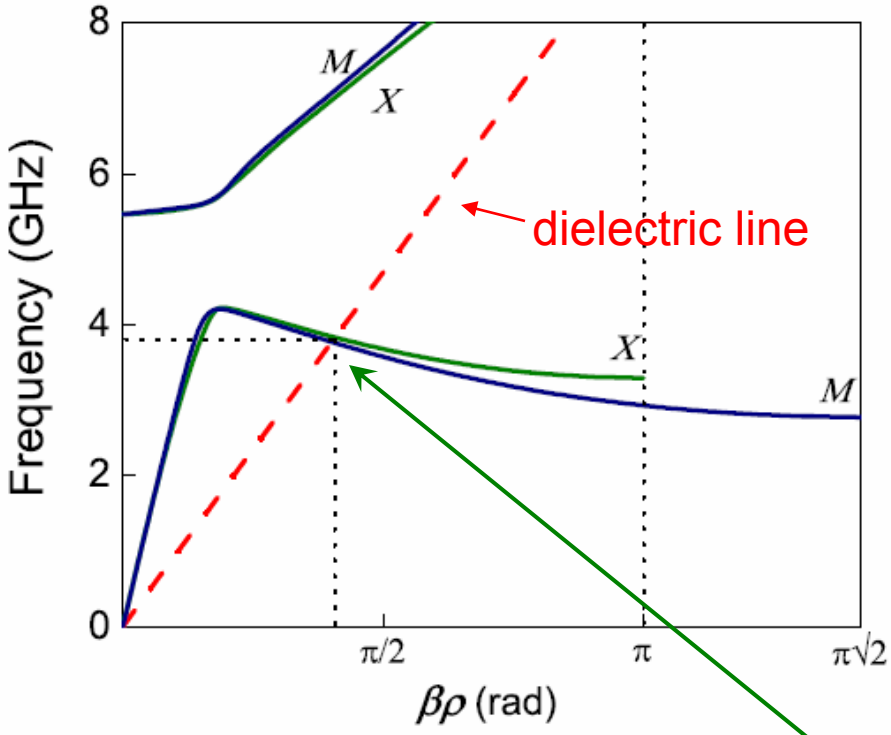


Measured E-Field Phase Atop 17x17 Array

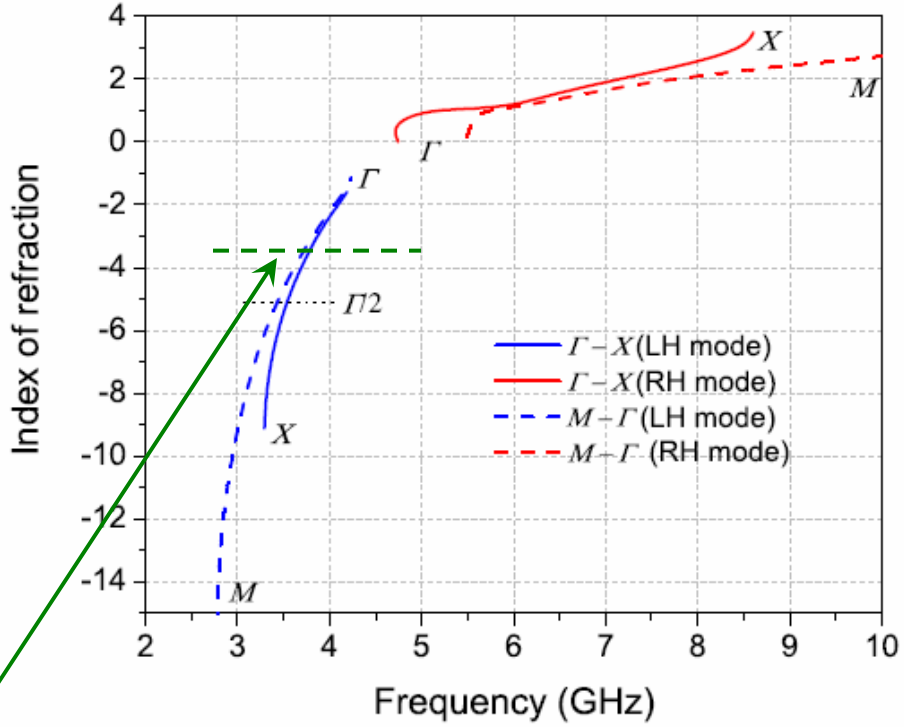


RH/LH Interface Matching Conditions

Dispersion Diagram



Refractive Index



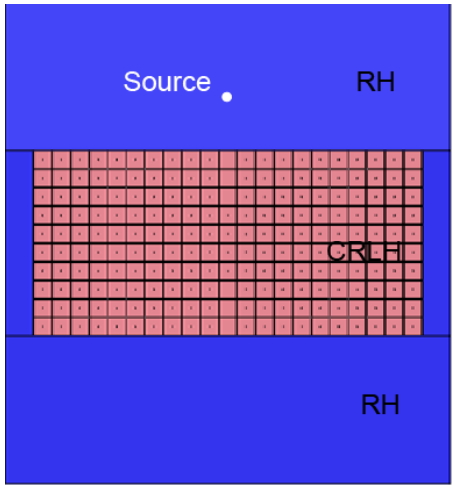
n_{CRLH} = -3.2 @ f = 3.77 GHz

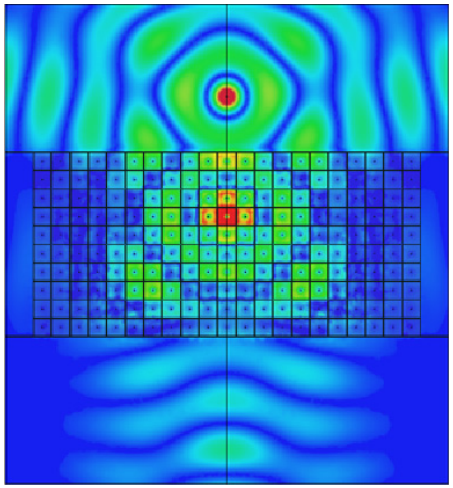
need n_{RH} = - n_{CRLH}=3.2

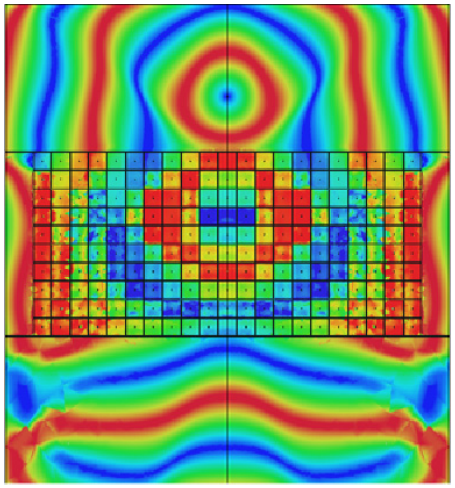
HFSS Simulation of NRI Lenses

magnitude

phase

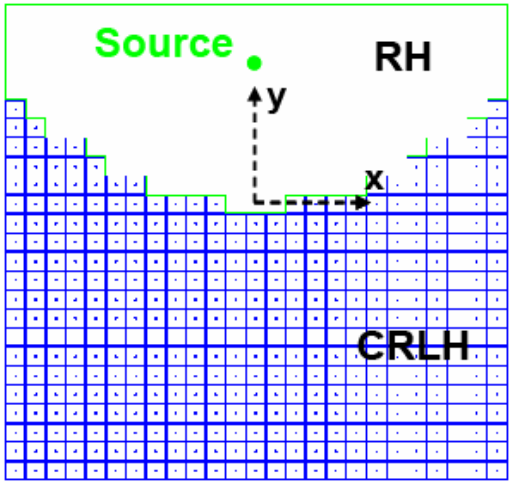


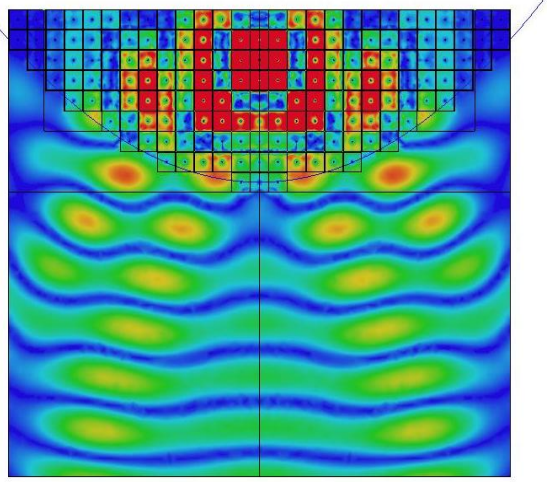


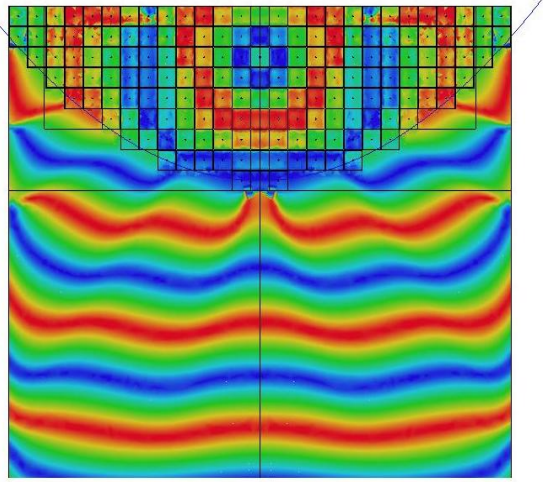


magnitude

phase

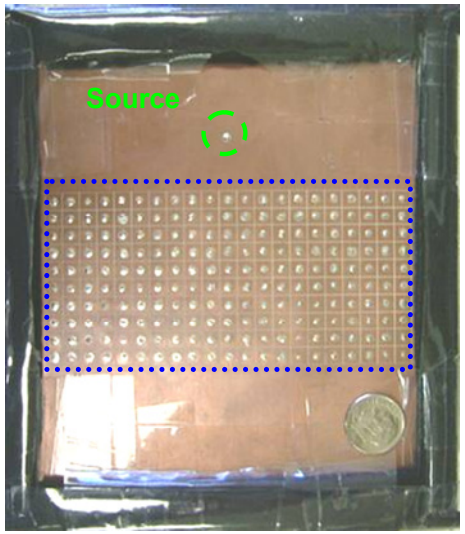






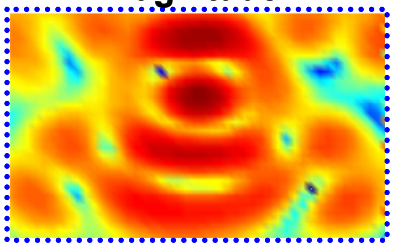
* CRLH and RH regions interchanged for simulation

Measured Results

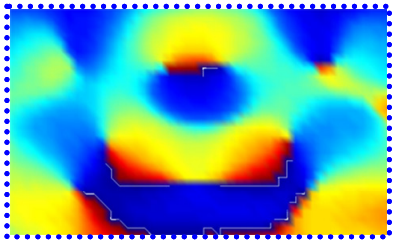


f_0 =3.79 GHz

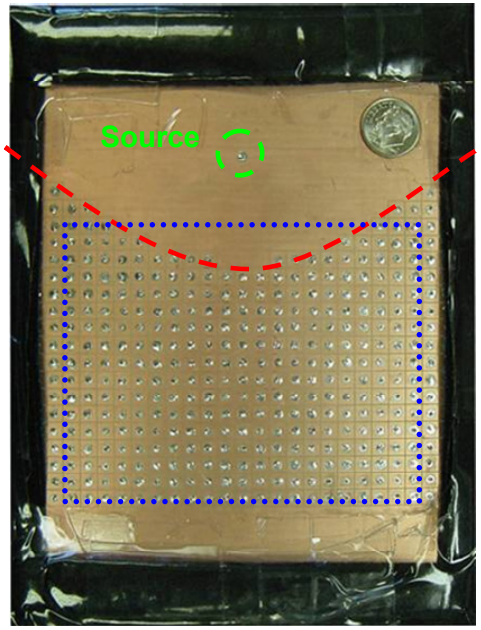
Magnitude



Phase

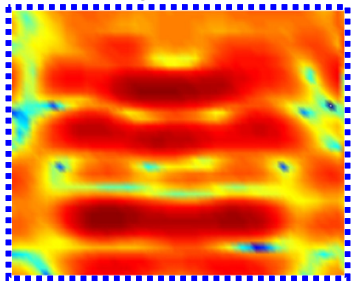


Mushrooms (21x10 cells)
*** Entire structure built on ε_R=10.2 substrate**

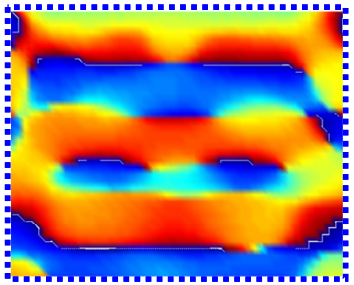


f_0 =3.77 GHz

Magnitude



Phase



~ Mushrooms (23x16 cells) in outlined area