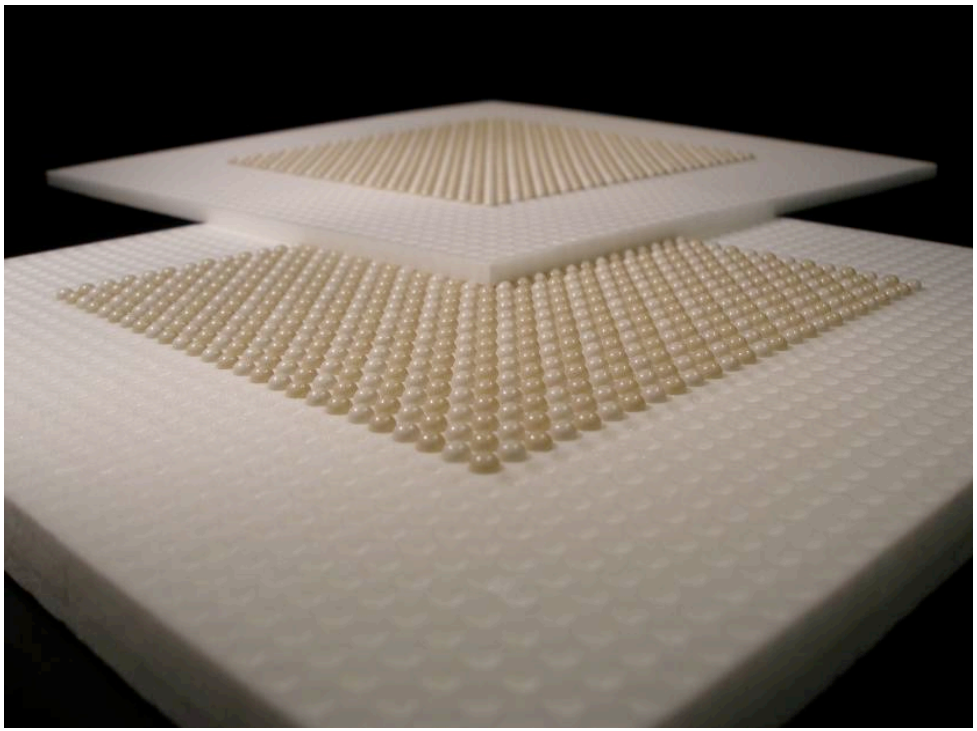
SAND2009-6502C

METAMATERIAL SCIENCE & TECHNOLOGY

EXPERIMENTAL REALIZATION OF LOW LOSS, ISOTROPIC DNG MATERIALS

J.F. Carroll III, J.H. Loui, P.G. Clem, and M.B. Sinclair



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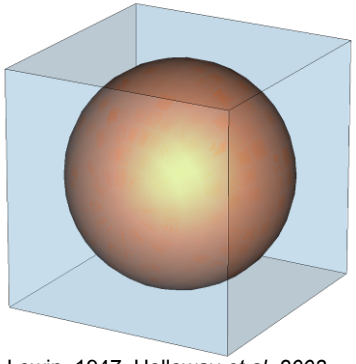
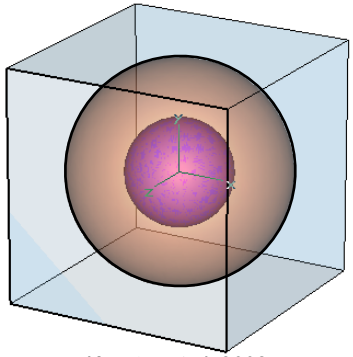
ISOTROPIC DNG UNIT-CELL TOPOLOGIES



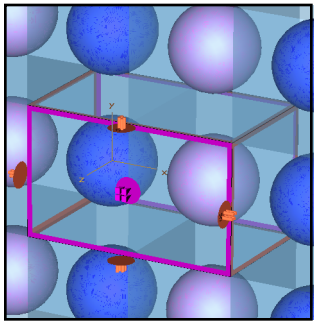
Lewin, 1947, Holloway *et al. 2003*

- $\varepsilon_r = \mu_r$
- Effective Medium
- Isotropic
- Simulation



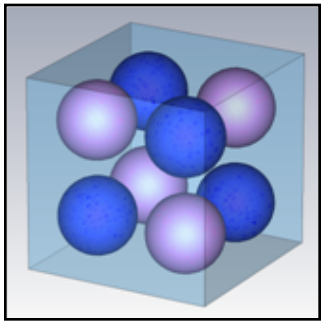
Kuester *et al. 2008*

- $\mu_r = 1$
- $\varepsilon_{r\ core} > \varepsilon_{r\ clad}$
- Isotropic
- Simulation



Ahmadi *et al. 2008*

- $\mu_r = 1$
- $\varepsilon_{r1} \neq \varepsilon_{r2}$
- Anisotropic
- Simulation



Vendik *et al. 2006 & this work*

- $\mu_r = 1$
- $\varepsilon_{r1} \neq \varepsilon_{r2}$
- Isotropic
- Simulation & Experiment

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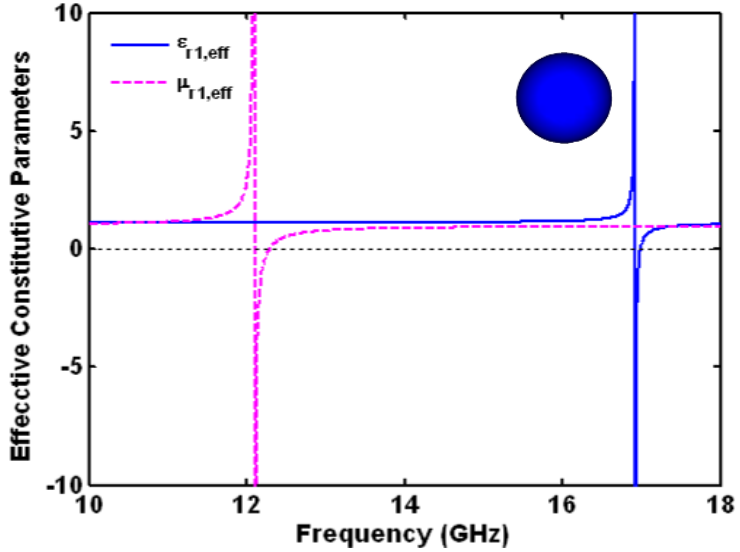
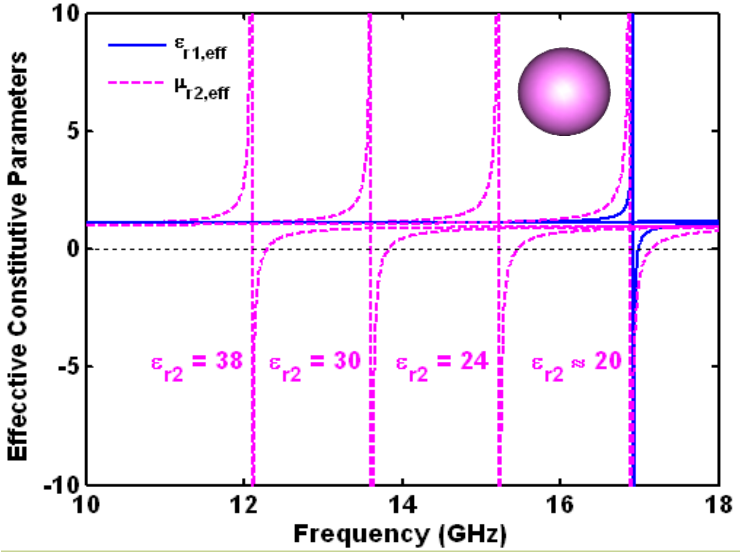
NaCl Structure Design & Material Selection

- Designed DNG response by overlapping electric and magnetic resonances ~17GHz





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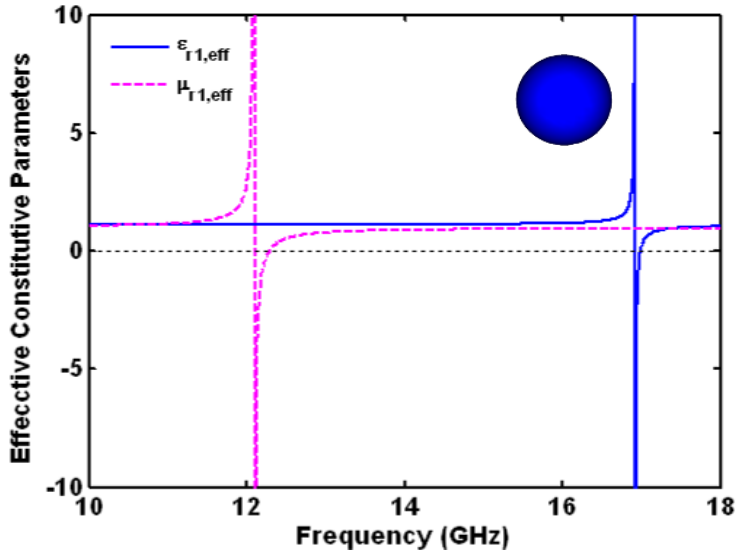

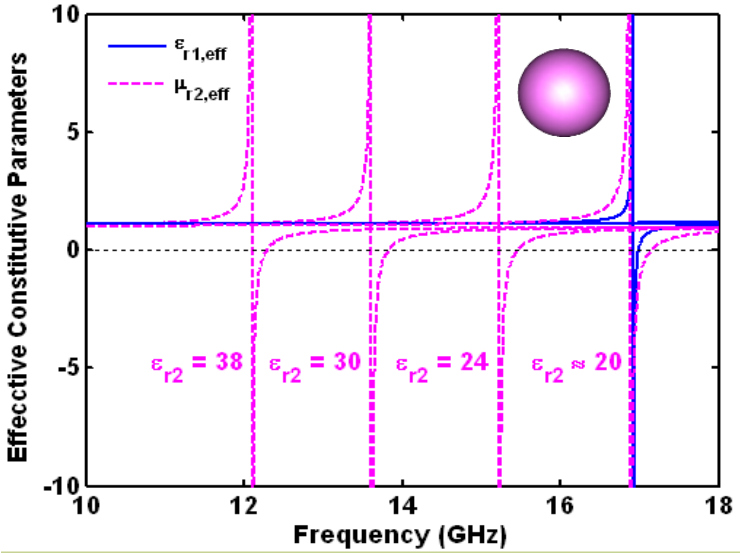

Material composition	ε_r	tan δ ($\bullet 10^{-4}$)
Al_2O_3	10	3
$Mg_xCa_{1-x}TiO_3$	20	9
$Ba[Sn_x(Mg_{0.33}Ta_{0.67})_{1-x}O_3$	25	2
$Ba(Zn_{0.33}Ta_{0.67})O_3$	30	9
$(Zr_xSn_{1-x})TiO_4$	38	5
$Ba_2Ti_9O_{20}$	39	5
$CaTiO_3$-$NdAlO_3$	45	5
$BaNd_2Ti_4O_{12}$	77	5
$(Ba,Pb)Nd_2Ti_4O_{12}$	90	5
TiO_2	100	3
$CaTiO_3$	170	30
$SrTiO_3$	270	50

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PHYSICAL SPHERE PROPERTIES

Sphere A – $(Zr,Sn)TiO_4$	Sphere B – $(Mg,Ca)TiO_3$
• Weight: 0.168 g +/- 0.001 g	• Weight: 0.127 g +/- 0.002 g
• Diameter: 0.400 cm +/-0.000 cm	• Diameter: 0.398 cm +/-0.000 cm
• % Relative density: >97%	• % Relative density: >99%

All spheres as polished to < 10 micron sphericity

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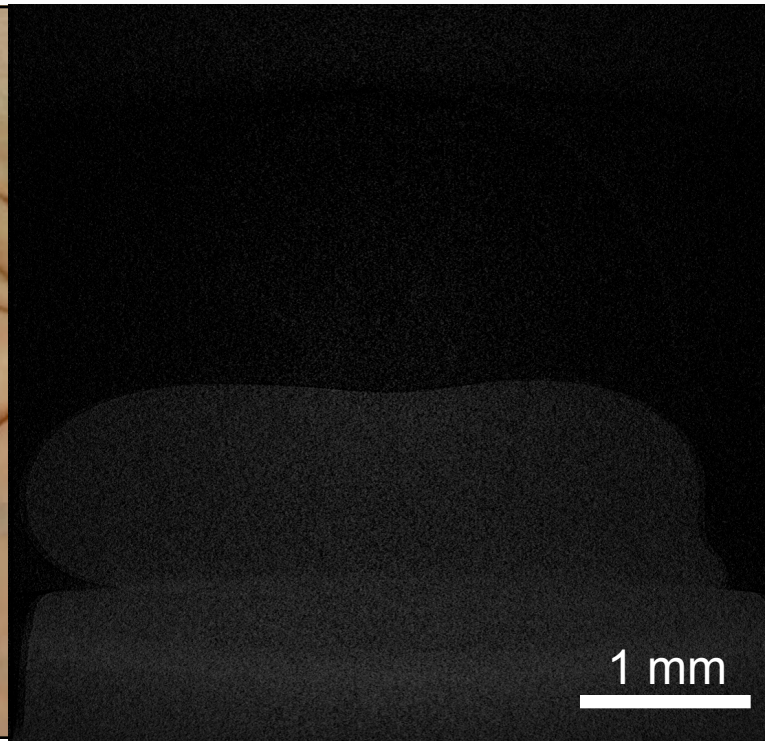
PHYSICAL SPHERE PROPERTIES



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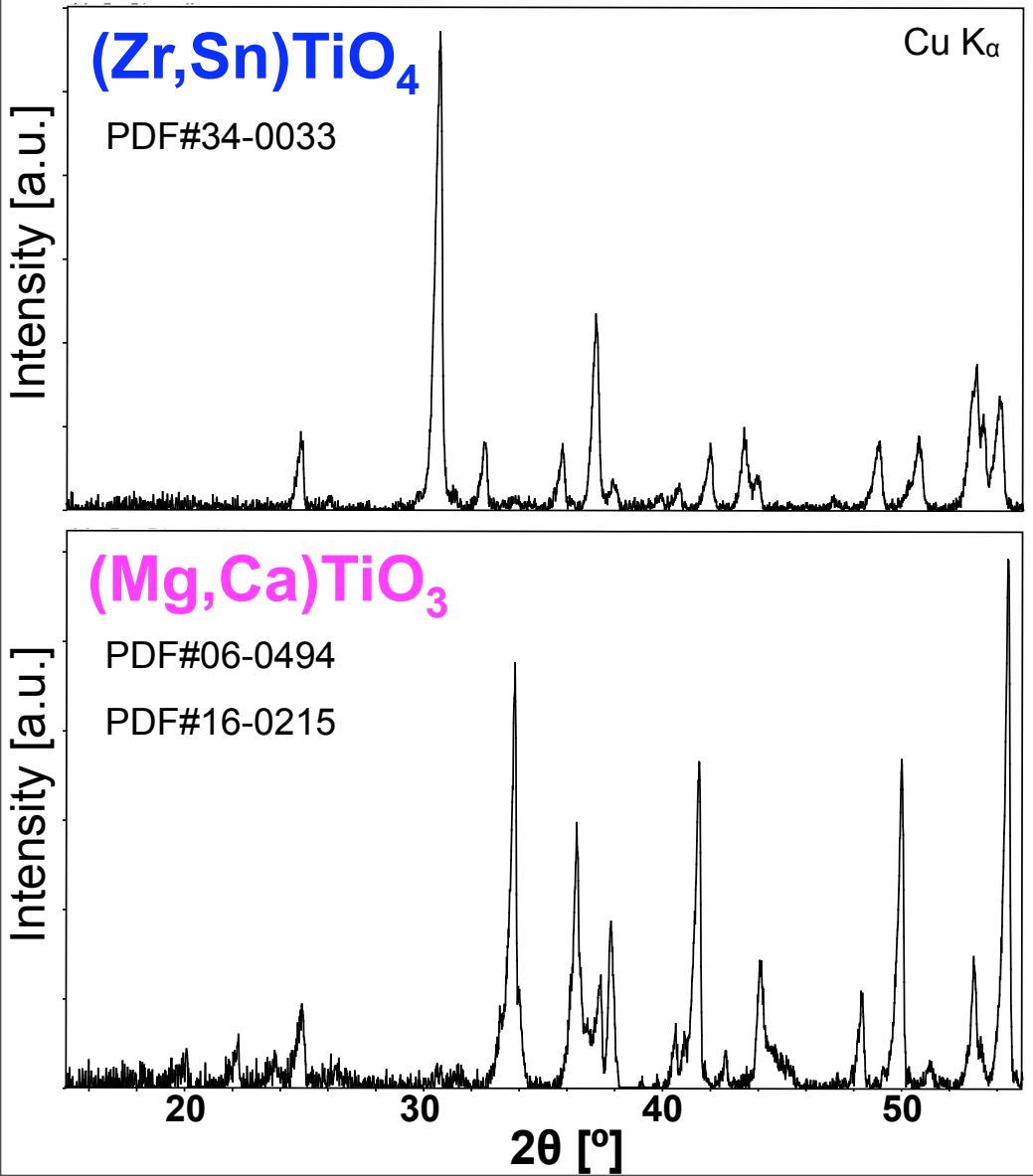
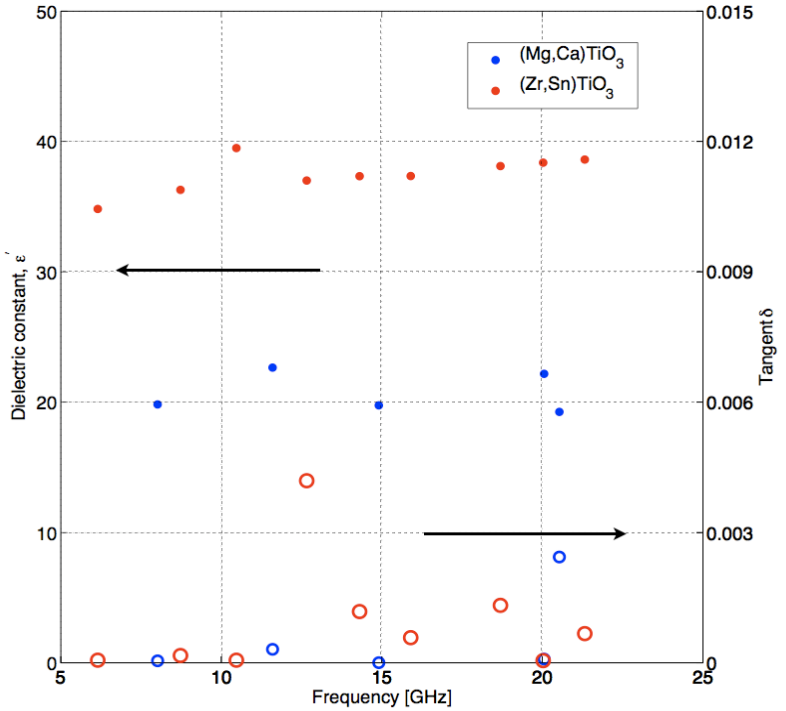
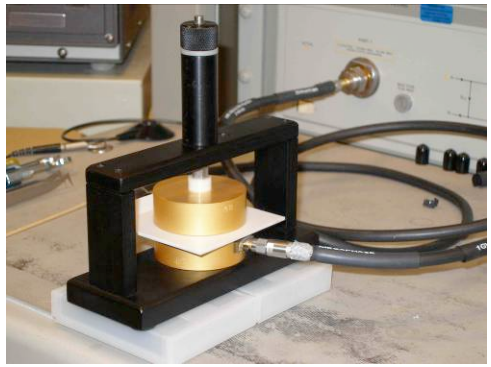
STRUCTURE - PROPERTY RELATIONSHIPS







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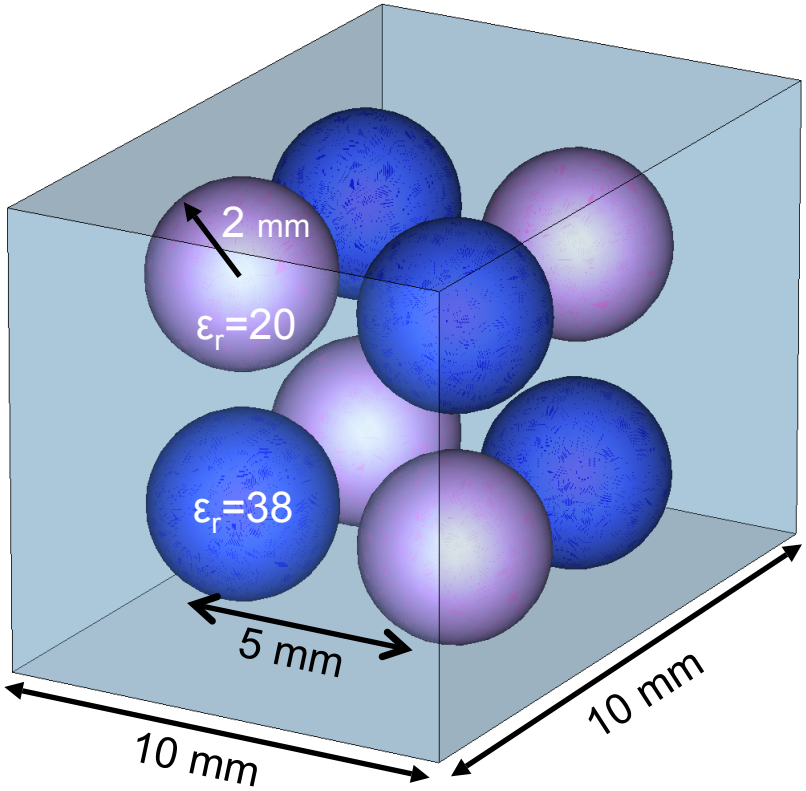
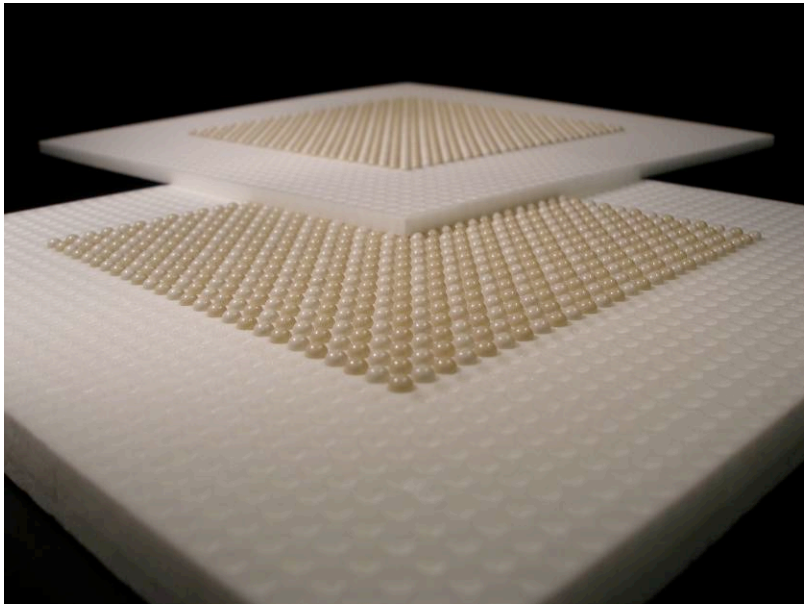
UNIT-CELL PARAMETERS & CONSTRUCTION

Unit Cell Parameters





Sphere A: $(Zr,Sn)TiO_4$ - darker tint

Sphere B: $(Mg,Ca)TiO_3$ - lighter tint

Array size: 26 x 26

Foam support structure, 3 layers

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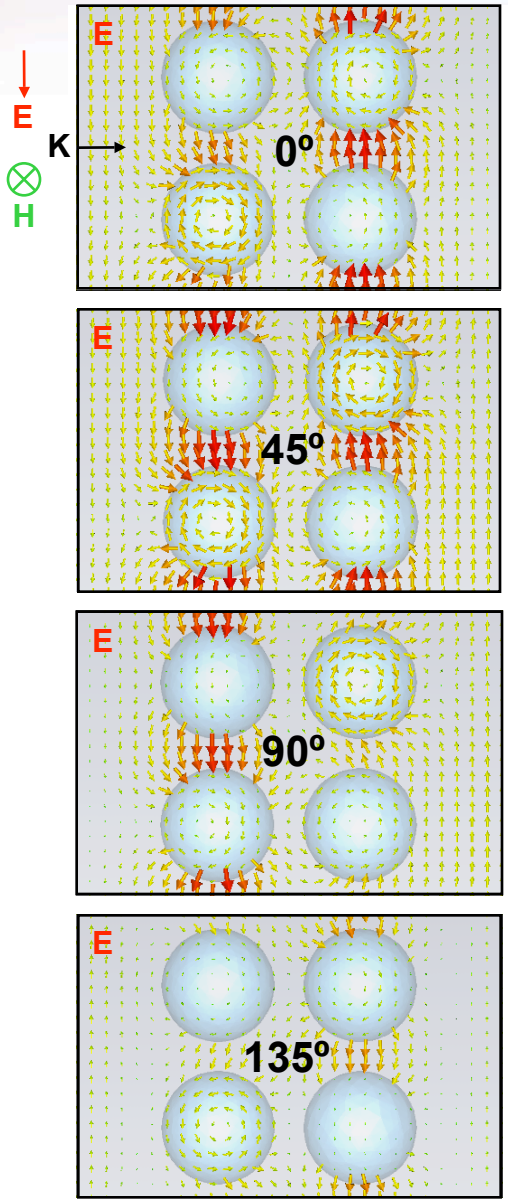
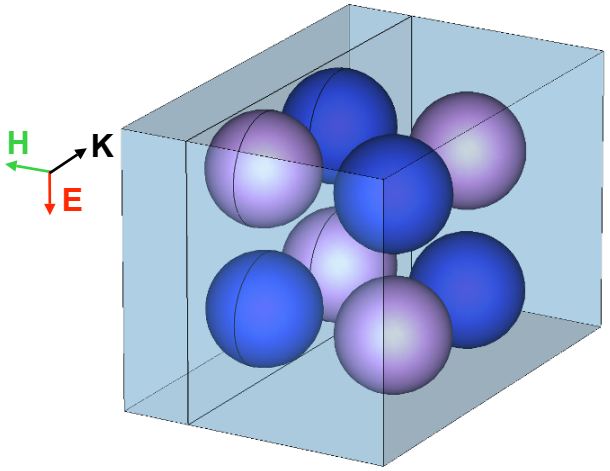
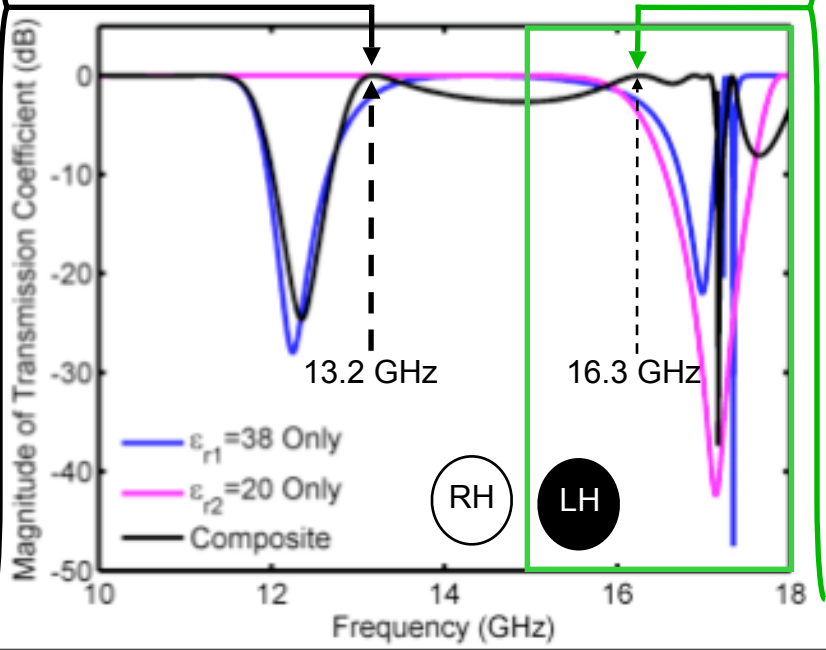
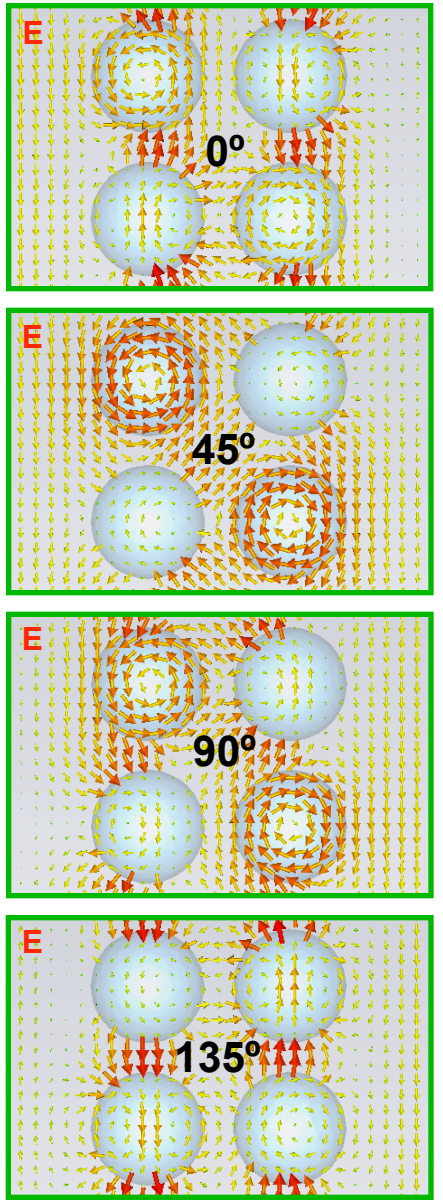
GEOMETRY & PHASE FIELD ANALYSIS





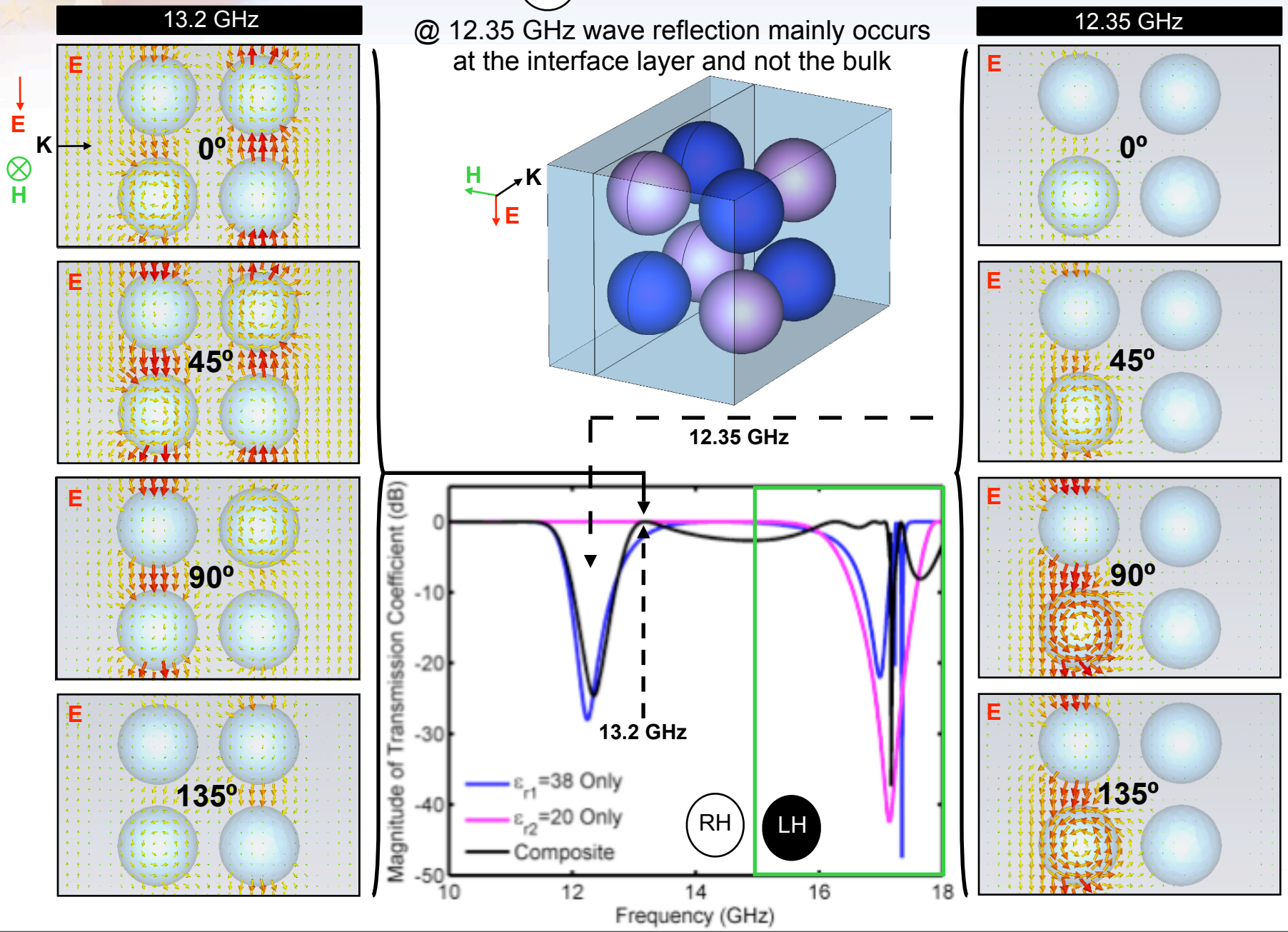
E-field Polarized Opposite of Excitation for LH Propagation @ 16.3 GHz





RH FEATURES

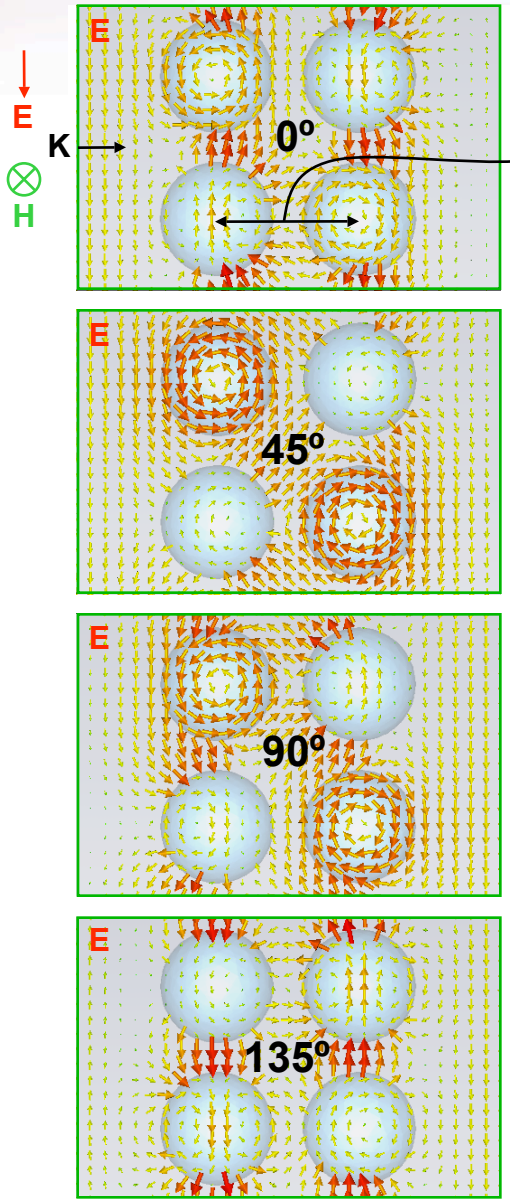
@ 12.35 GHz wave reflection mainly occurs at the interface layer and not the bulk



LH Features & Index

16.3 GHz

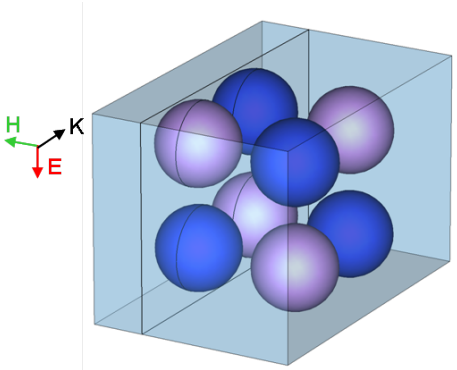
16.9 GHz



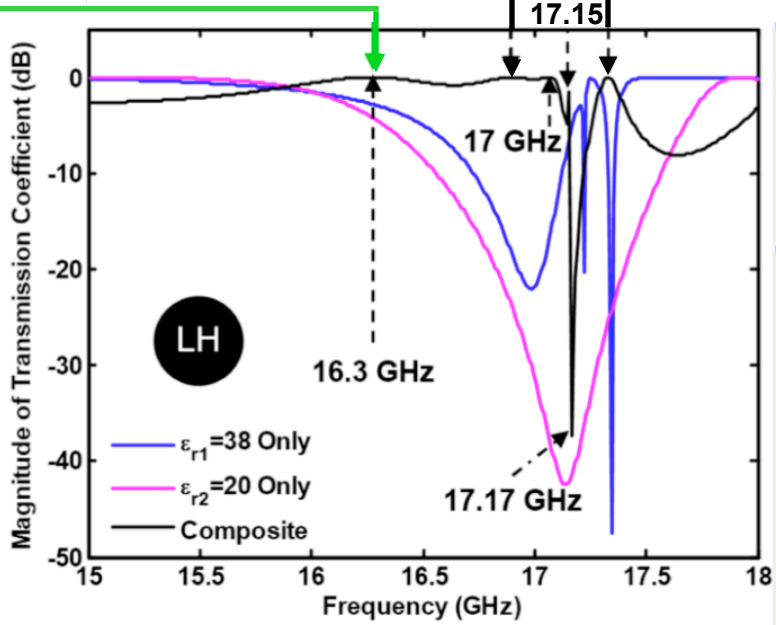
$\lambda_o/2$ @16.3 GHz = 9.2 mm

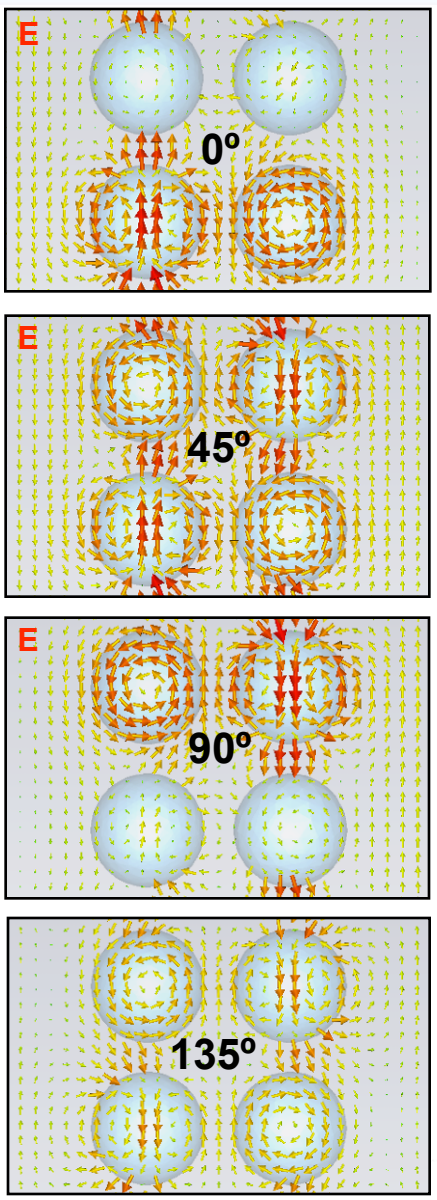
$\lambda_g/2$ = 5 mm

$n = \lambda_o/\lambda_g = -1.84$

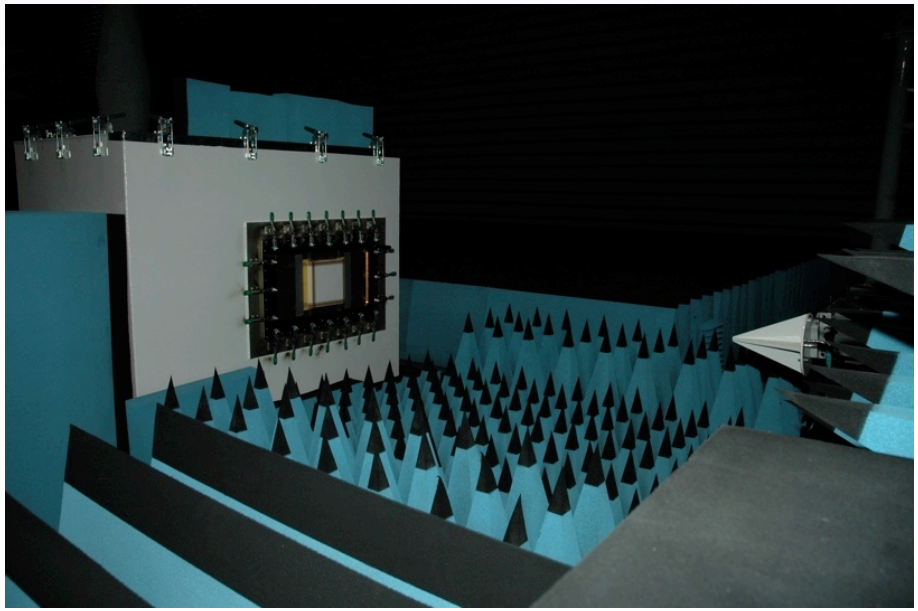


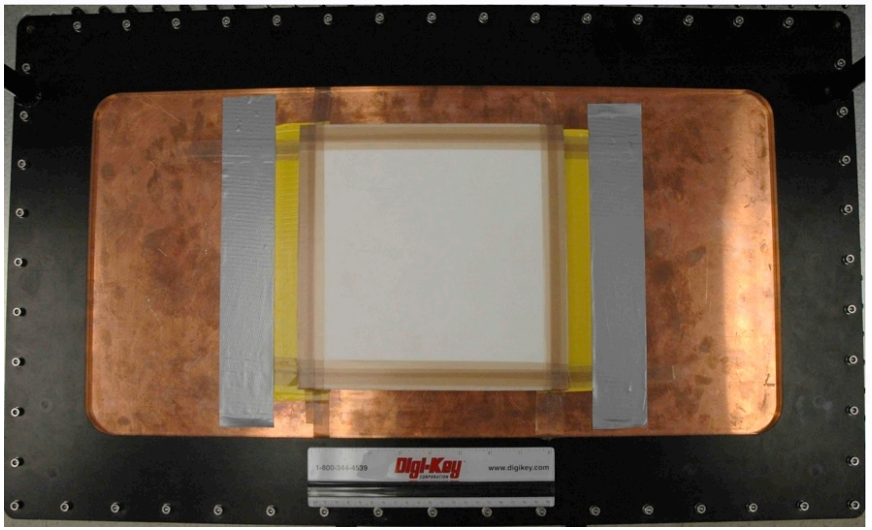
Different Modal Profile





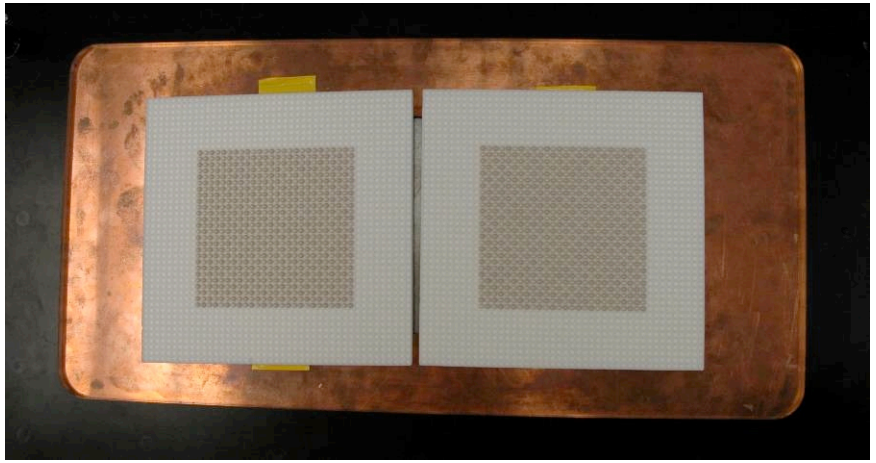
FACILITY FOR ADVANCED RADAR MEASUREMENTS (FARM)





7 Inch x 7 Inch Aperture

- Agilent PNA E8362B 10MHz - 20GHz
- TEMCO Dual Polarized Log Periodic
- BW: 2-20 GHz
- Transmitter inside the box
- Thru and isolation calibration with time-gating at normal incidence



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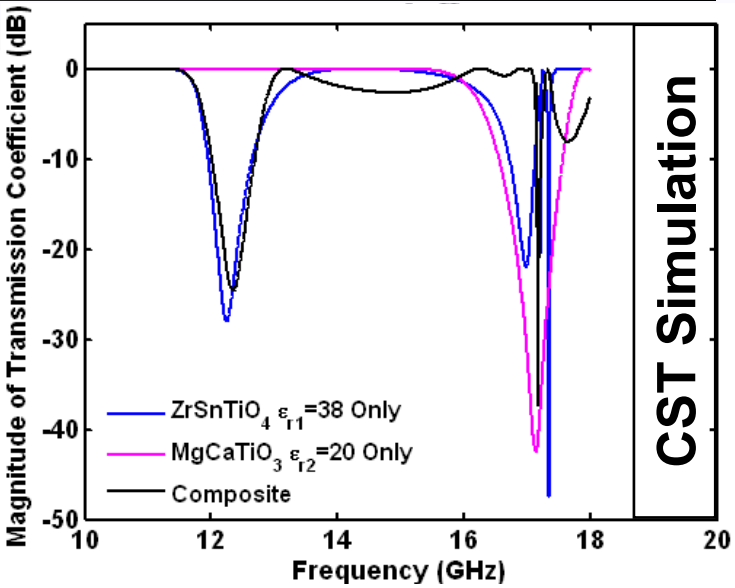
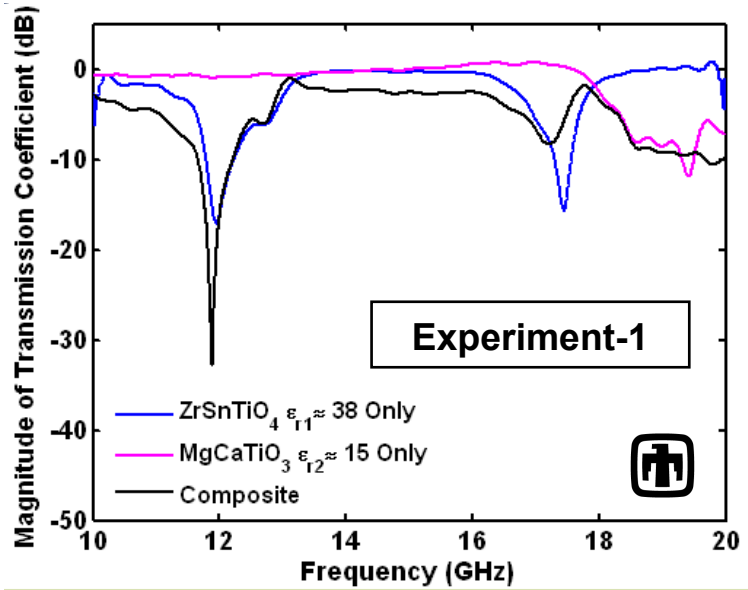
EXPERIMENTAL RESULTS

- Experiment-1 offered unconvincing evidence of DNG propagation due to $\varepsilon_{r2} << 20$





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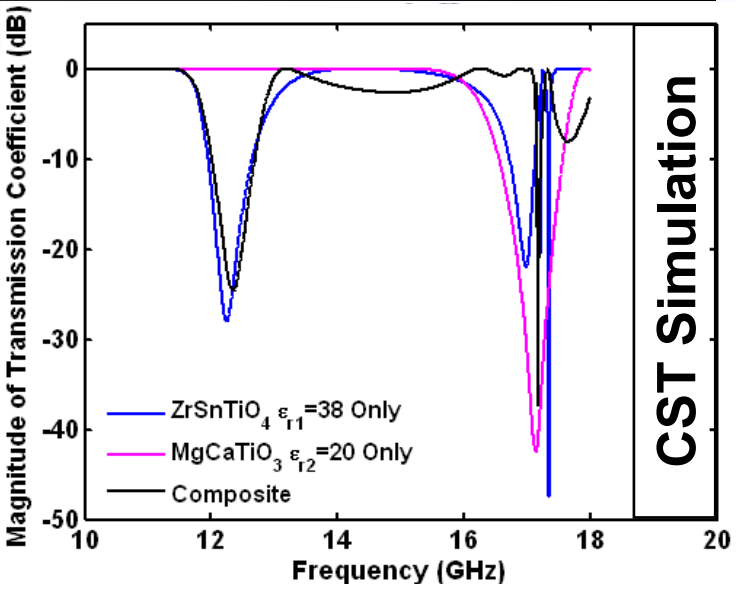
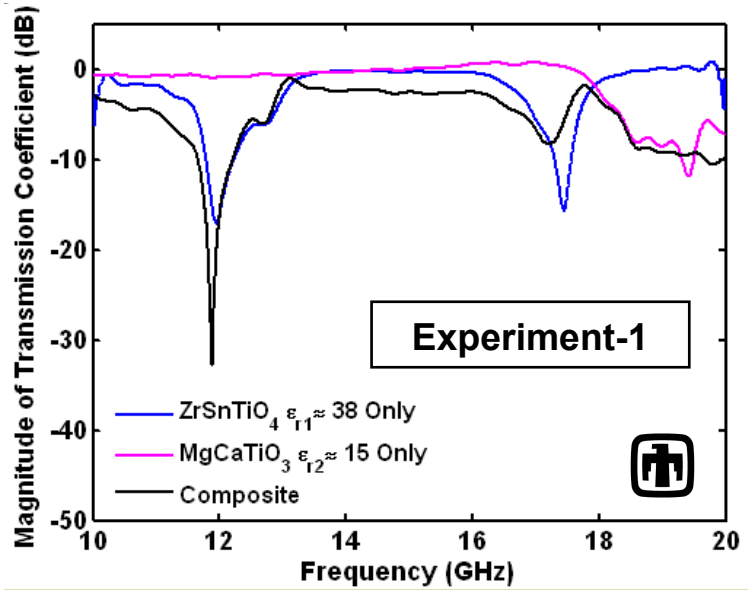
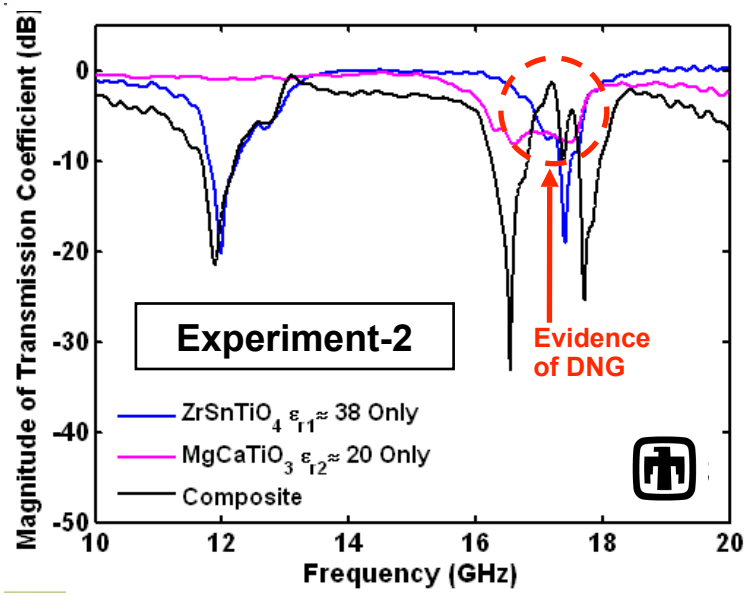
EXPERIMENTAL RESULTS

- Experiment-1 offered unconvincing evidence of DNG propagation due to $\varepsilon_{r2} << 20$
- Experiment-2 contained $(Mg,Ca)TiO_3$ spheres with the desired $\varepsilon_{r2} \sim 20$
- DNG transmission peaks occurred where band-stops of the two spheres overlapped with similar magnitude

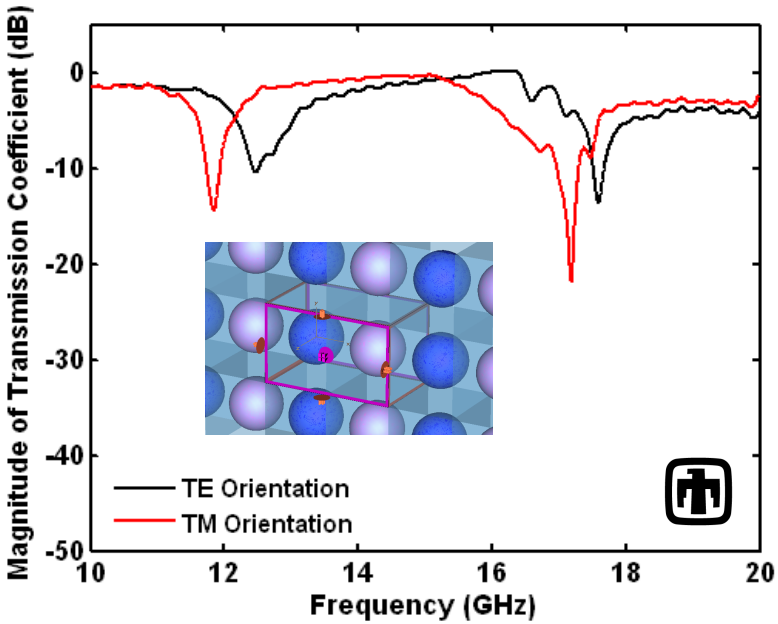






ISOTROPIC DNG VALIDATION

Two-Sphere Unit-cell



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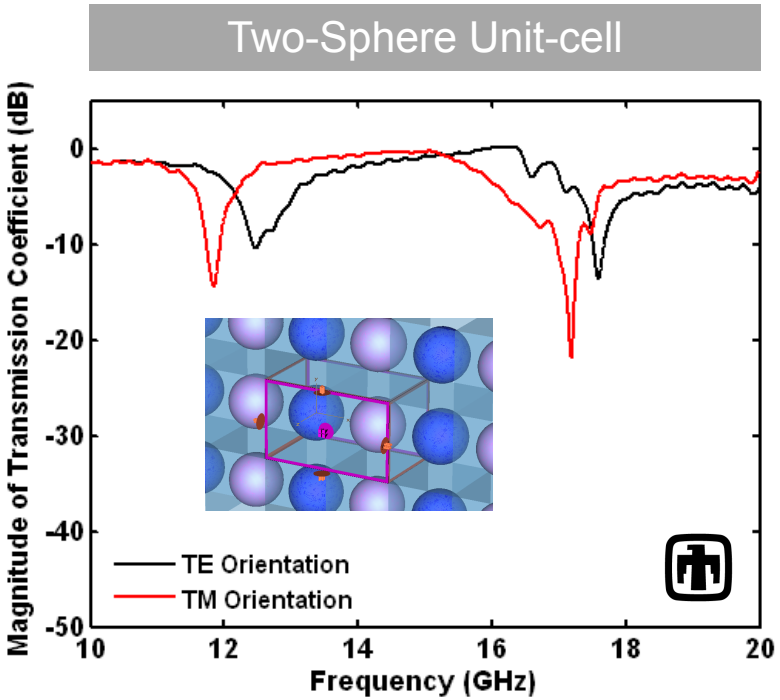
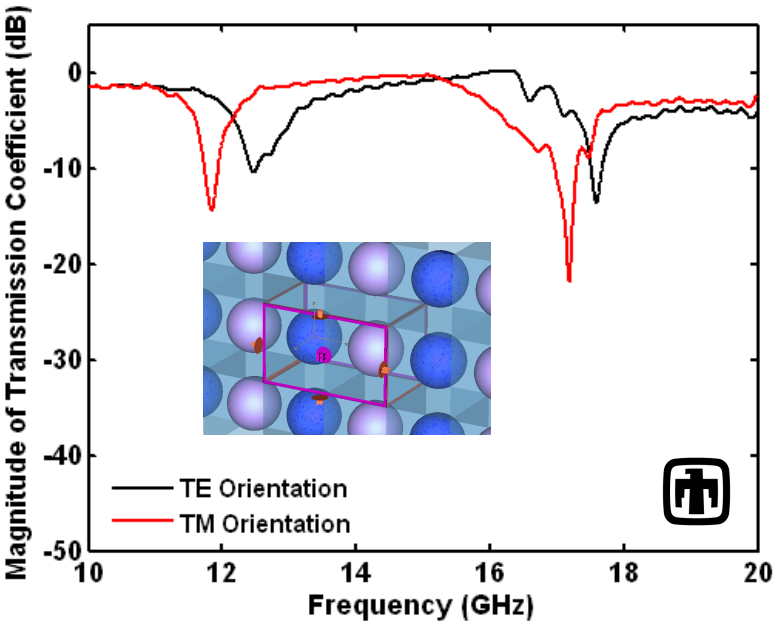


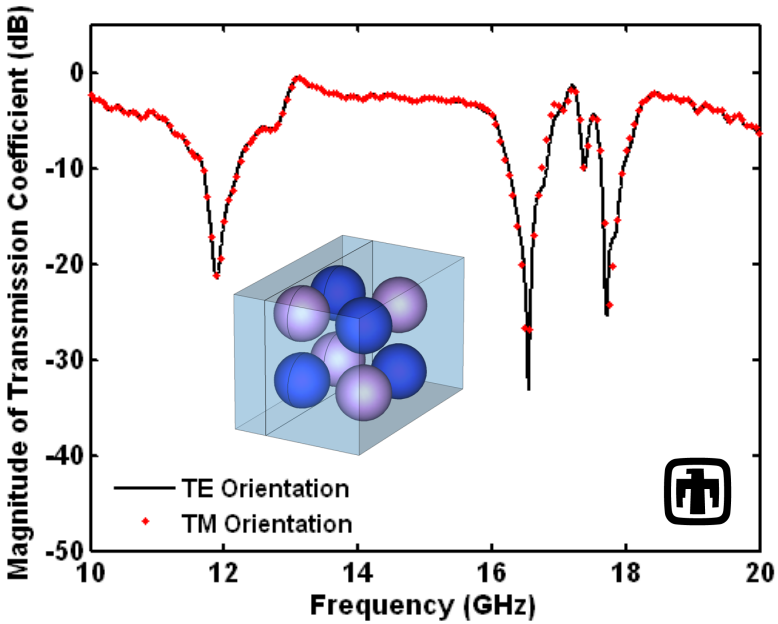
- Two-sphere unit-cell (left) only exhibit DNG for TE and not TM polarized waves

ISOTROPIC DNG VALIDATION

Two-Sphere Unit-cell



Eight-Sphere NaCl Unit-cell



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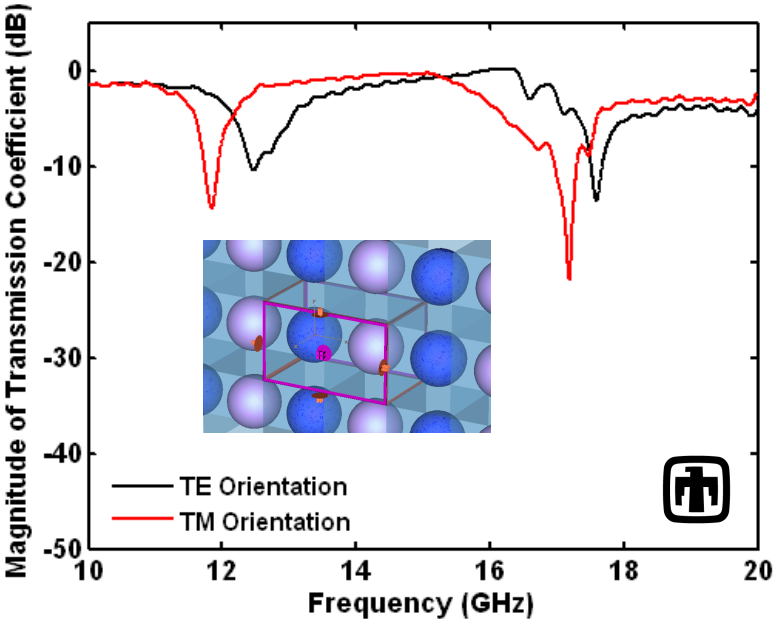
ISOTROPIC DNG VALIDATION

Two-Sphere Unit-cell



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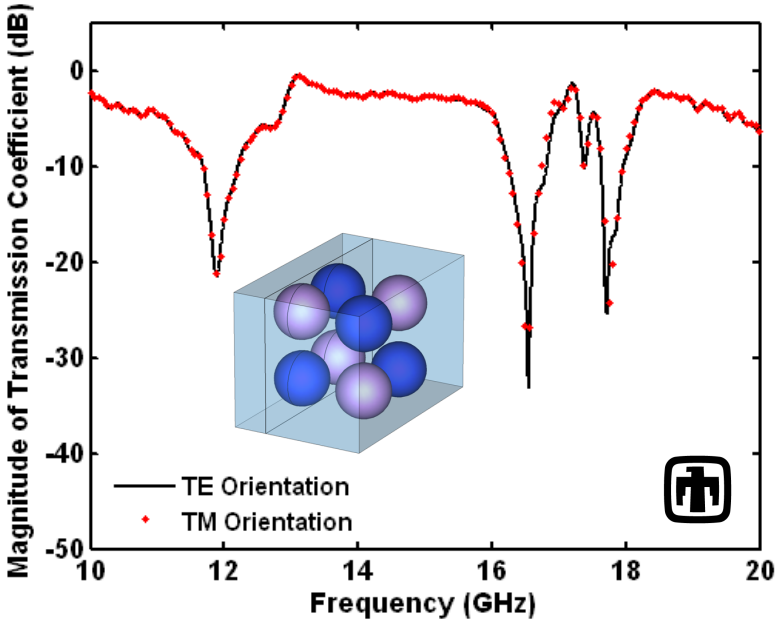

- Two-sphere unit-cell (left) only exhibit DNG for TE and not TM polarized waves
- Eight-sphere unit-cell (top) exhibit DNG for both TE and TM polarized waves

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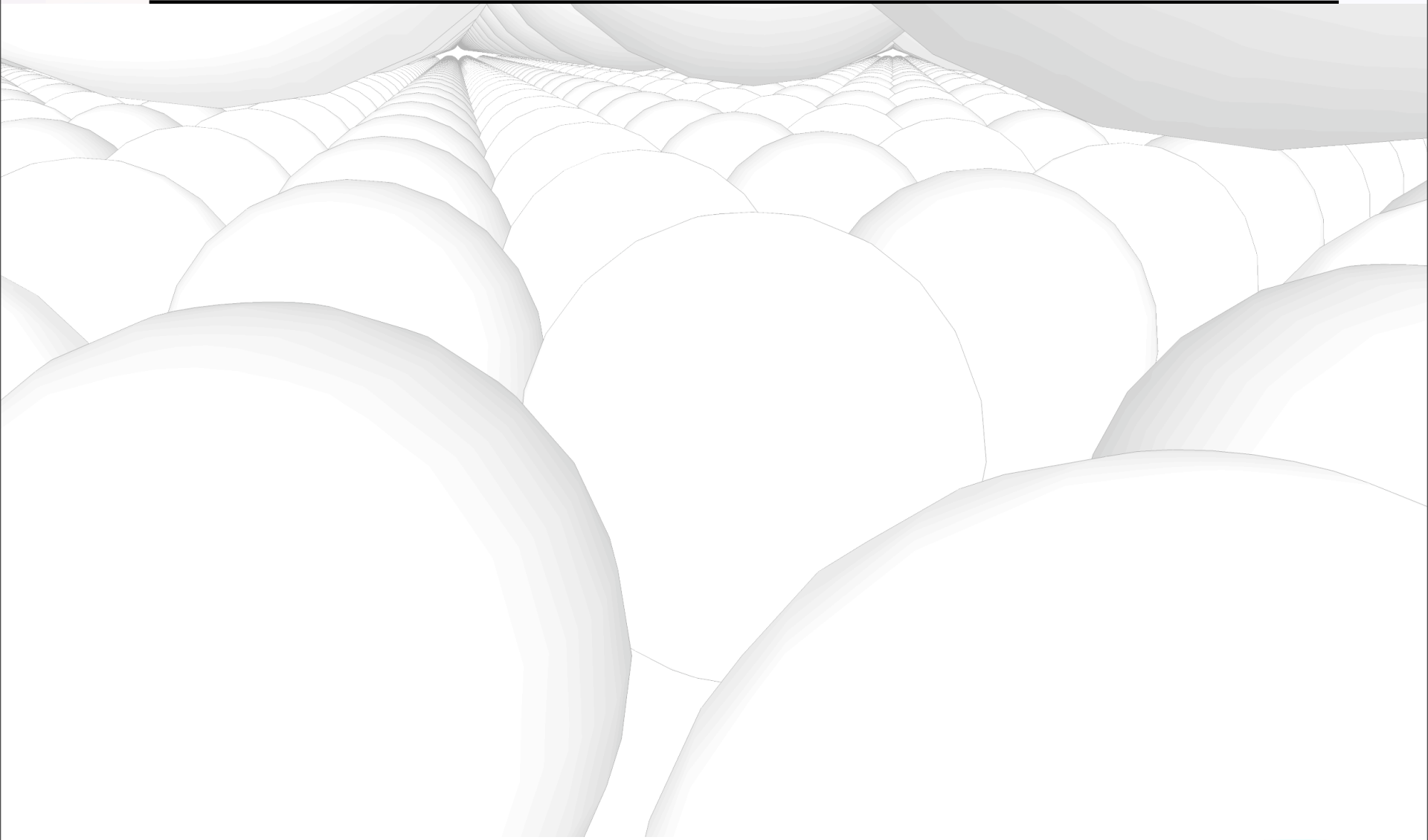
Conclusion, Future Work, & Acknowledgments



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Conclusion, Future Work, & Acknowledgments

Conclusions:

- Numerically and experimentally demonstrated isotropic DNG propagation for NaCl cubic lattice of bi-spheres
- Multi-mode DNG propagation would likely affect determination of effective refractive index

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Gaussian-Beam Variable Angle Measurement System Online

Future Work:

- Variable angle, off-normal incidence
- Role of packing density on DNG properties

Acknowledgments:

- Thank Dr. Billy Brock for helpful discussions and usage of time-domain gating code
- Thank E.D. Branson, A.W. Cook, K.F. Fenton, and Edward Powell for assisting in sample preparation and DNG measurement.

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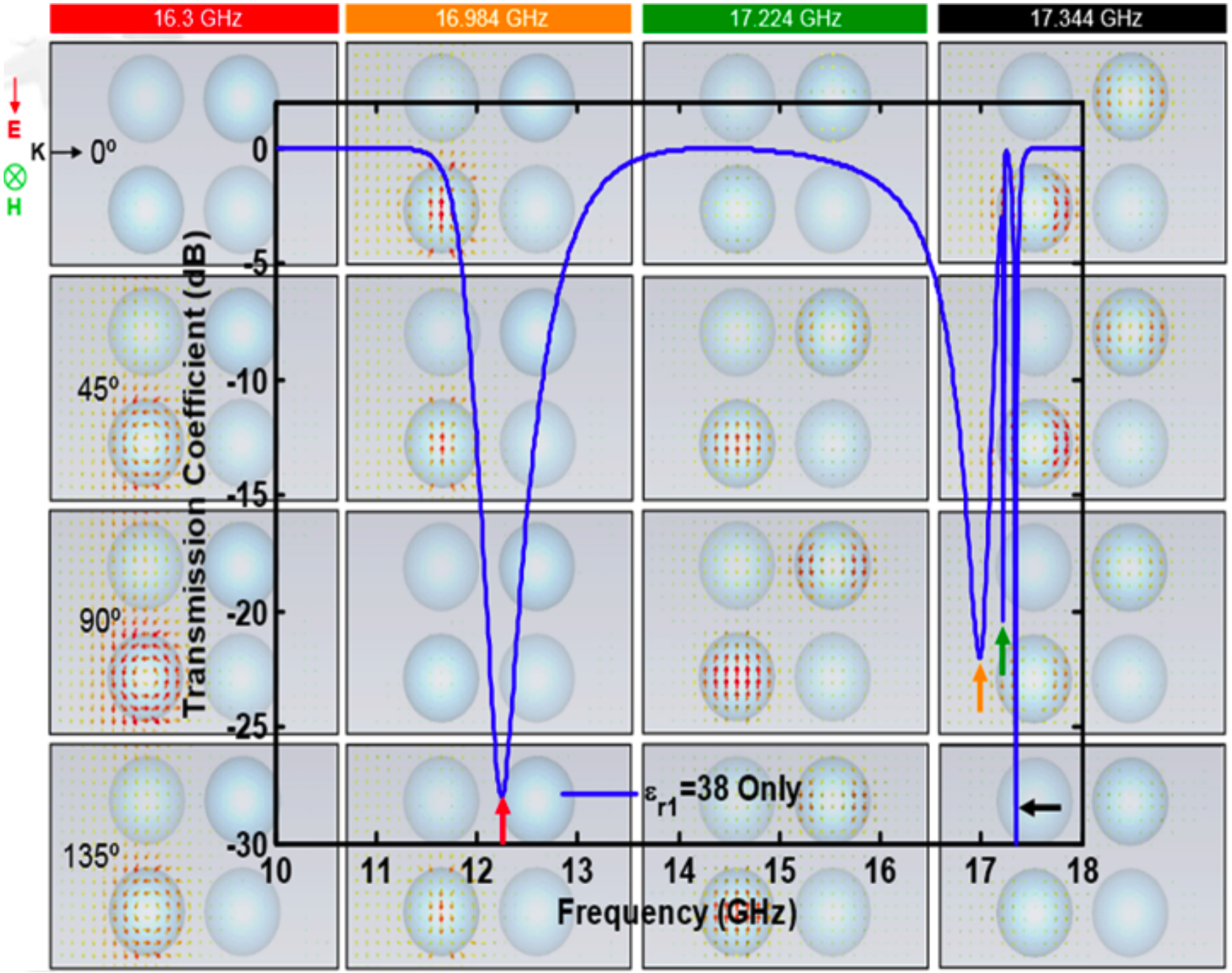
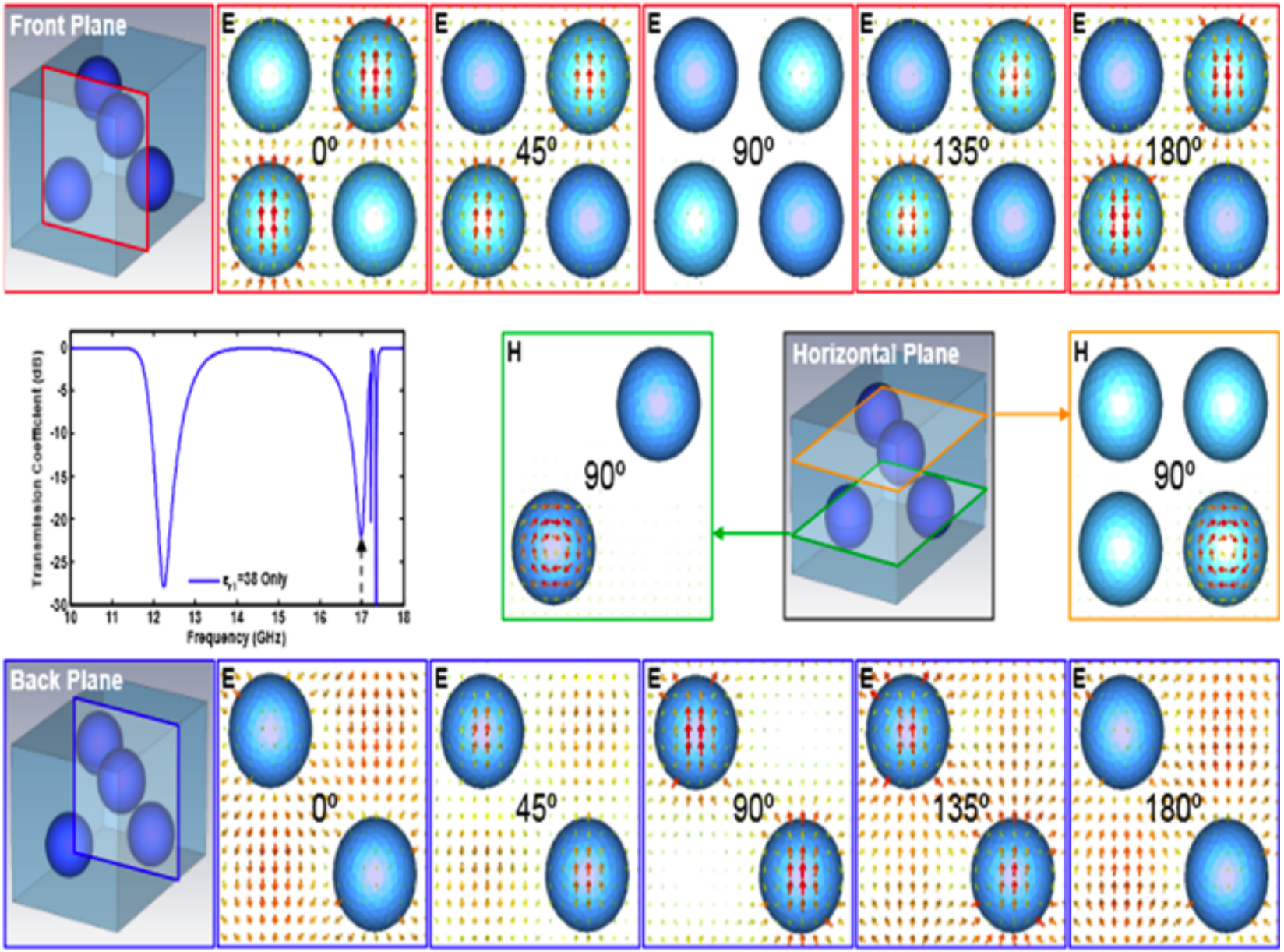
Backup Slides


16.3 GHz
16.984 GHz
17.224 GHz
17.344 GHz
E
H
K
0°
45°
90°
135°
0
-5
-10
-15
-20
-25
-30
Transmission Coefficient (dB)
10
11
12
13
14
15
16
17
18
Frequency (GHz)
ε_{r1}=38 Only

ELECTRICAL RESONANCE AT 17 GHZ, ε_r = 38 SPHERES



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