Periodic Leaky-Wave Antennas for Orbital Angular Momentum Multiplexing System

Master Thesis
Final Presentation

Amar Al-Bassam

23.06.2014

ÉCOLE POLYTECHNIQUE MONTRÉAL

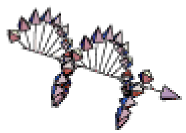
UNIVERSITÄT DUISBURG ESSEN

HFT

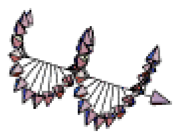
Outline

Orbital Angular Momentum

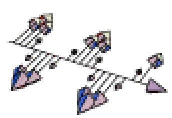
Spin Angular Momentum
Elliptical polarization



$s = +1$ Right-hand circular polarization

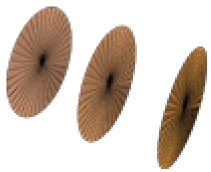


$s = -1$ Left-hand circular polarization

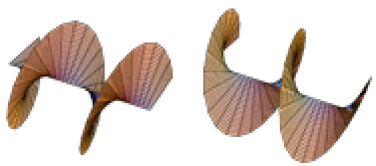


Photons cannot have zero spin. Linear polarization is combination of RHCP and LHCP

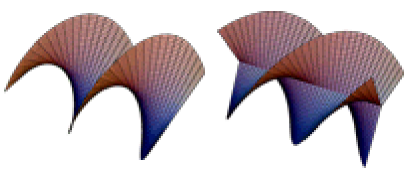
Orbital Angular Momentum
Helical phase-fronts



$m = 0$ Planar phase-front



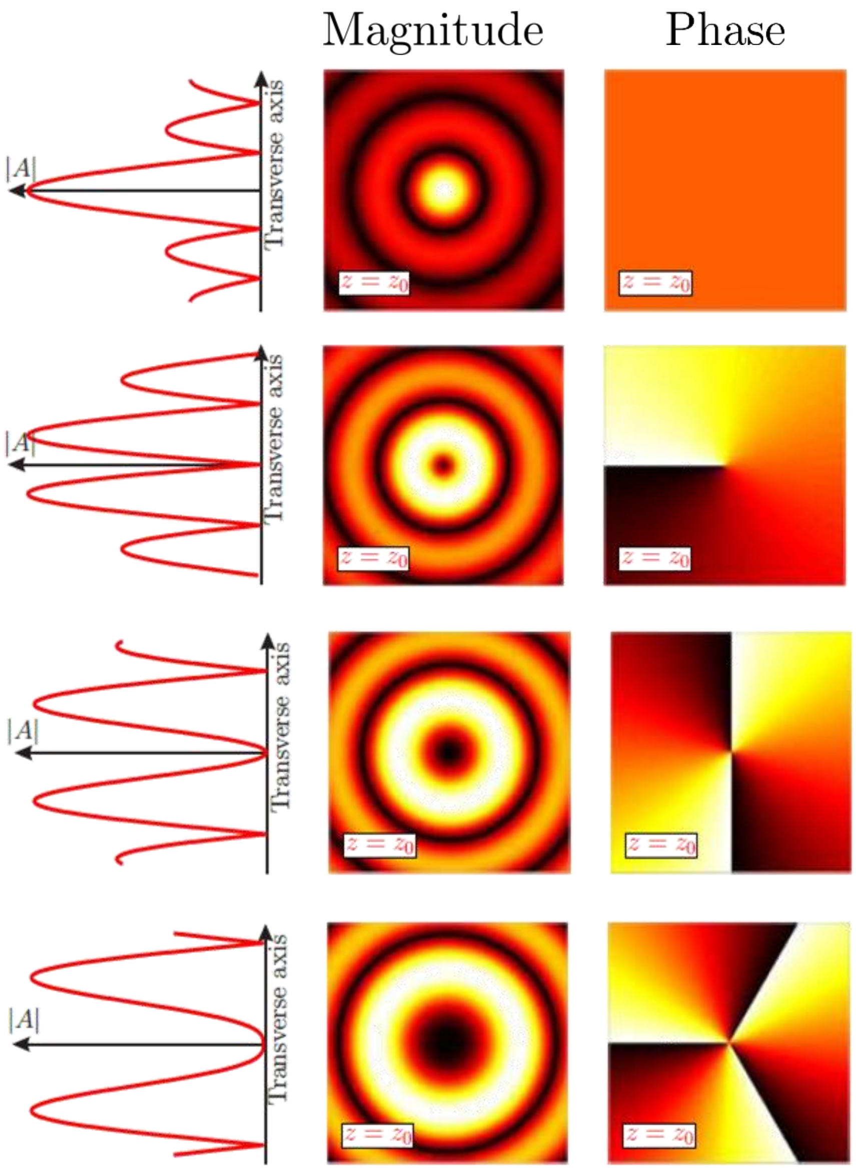
$m = \pm 1$ Right- and left-handed topological charges

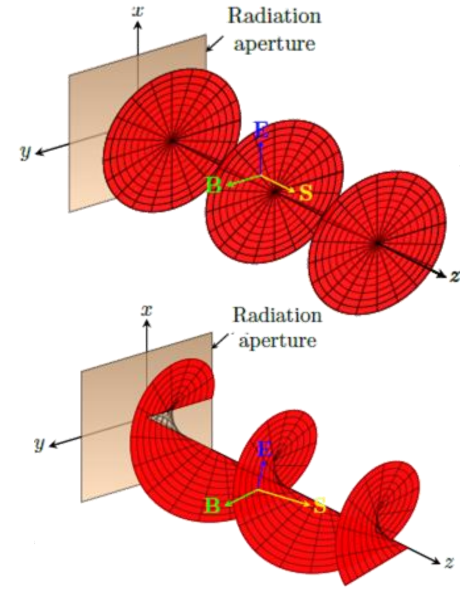


Higher order topological charges $m = 2{,}3$

Images courtesy of physics.gla.ac.uk/Optics

Magnitude & Phase of Vortex Beams





$m = 0$

$m = 1$

$m = 2$

$m = 3$

I. Introduction

II. Concept Of Generation

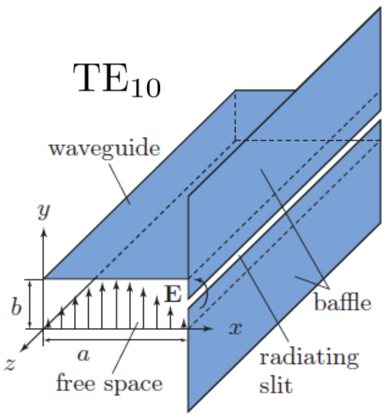
III. Electromagnetic Modeling

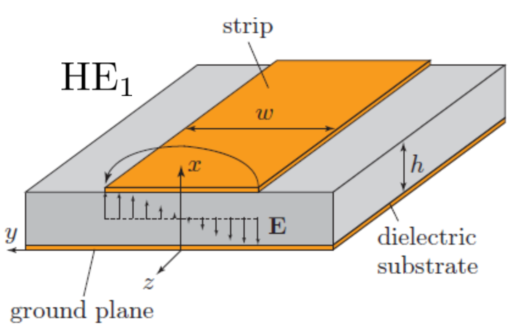
IV. Design & Experimental Results

❖ Conclusions & Questions

Leaky-Wave Antenna (LWA) Types

Uniform

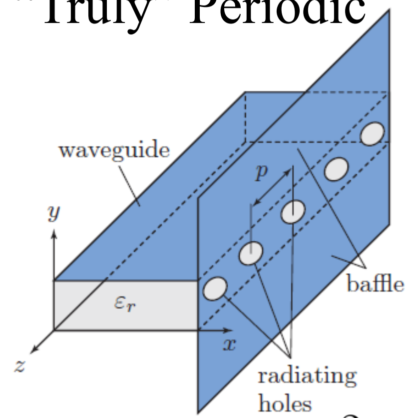




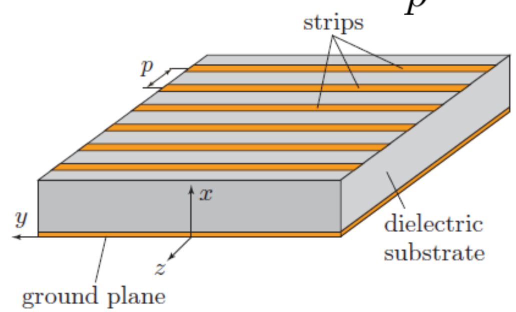
- invariant along propagation axis
- dominant or higher mode
- fast-wave mode
- $\beta = k_0\sqrt{\varepsilon_{re}} \Rightarrow \beta > 0$ $\Rightarrow \theta > 0$: FWD only

Periodic

"Truly" Periodic

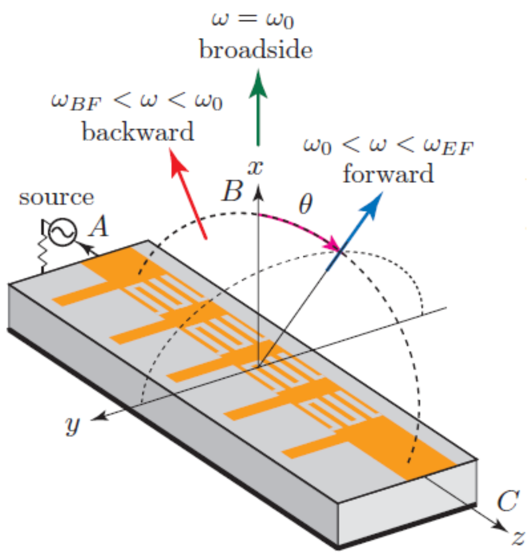


$$\beta_n(\omega) = \beta_0(\omega) + \frac{2\pi}{p}n$$



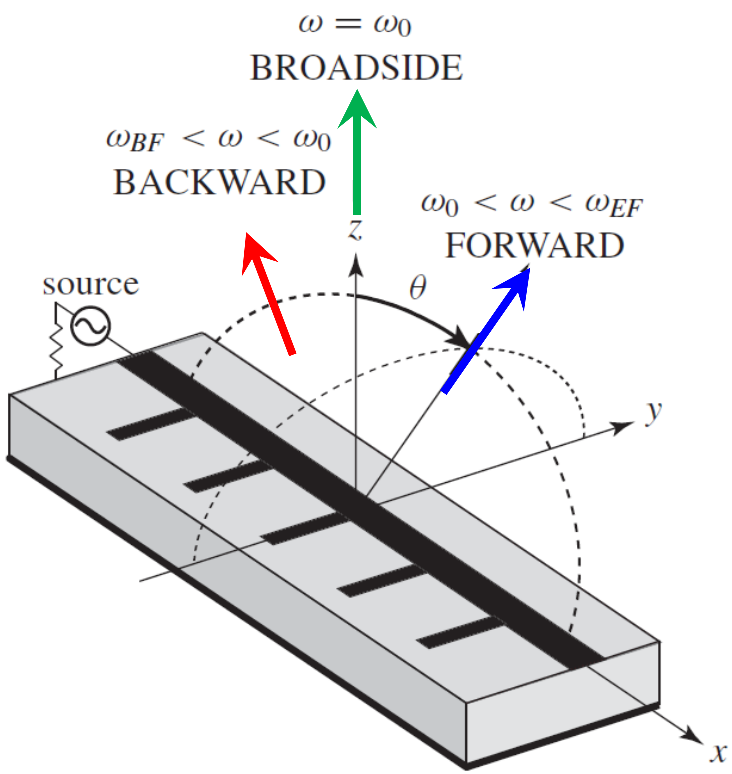
- periodic along propagation axis
- ∞ space harmonics (SH)
- using fast SH (β_0 slow), β_{-1}
- BWD and FWD

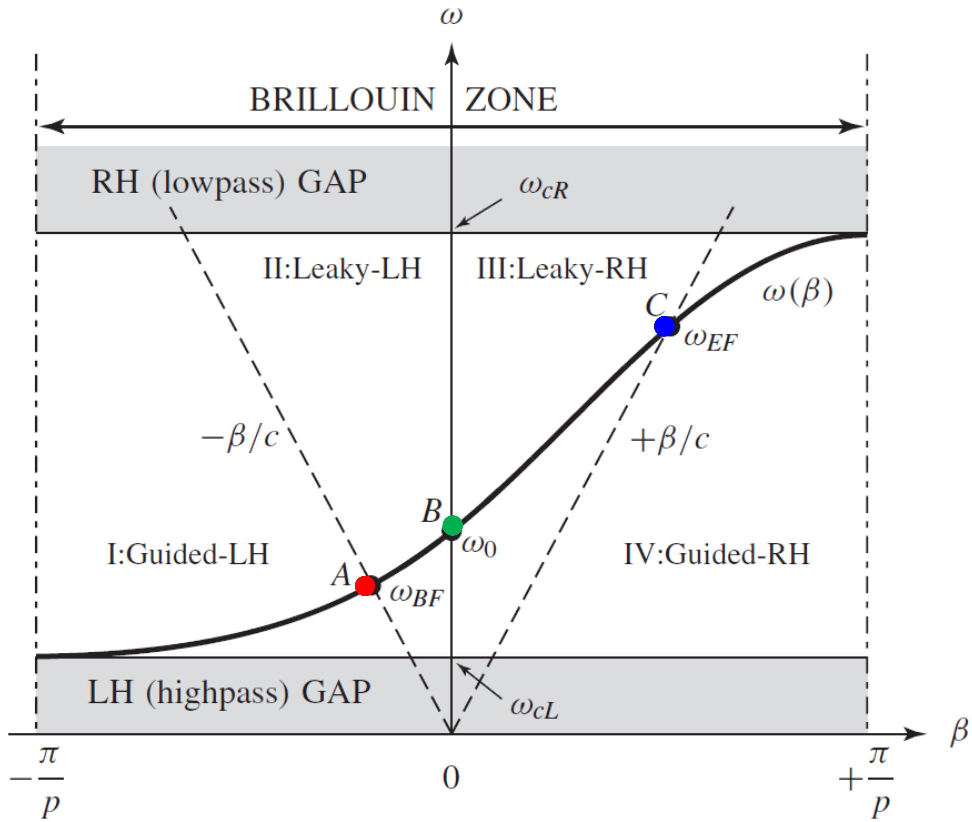
"Quasi"-Uniform



- CRLH
- topologically periodic, but electromagnetically uniform
- period << λ
- using fast SH: $n = 0$

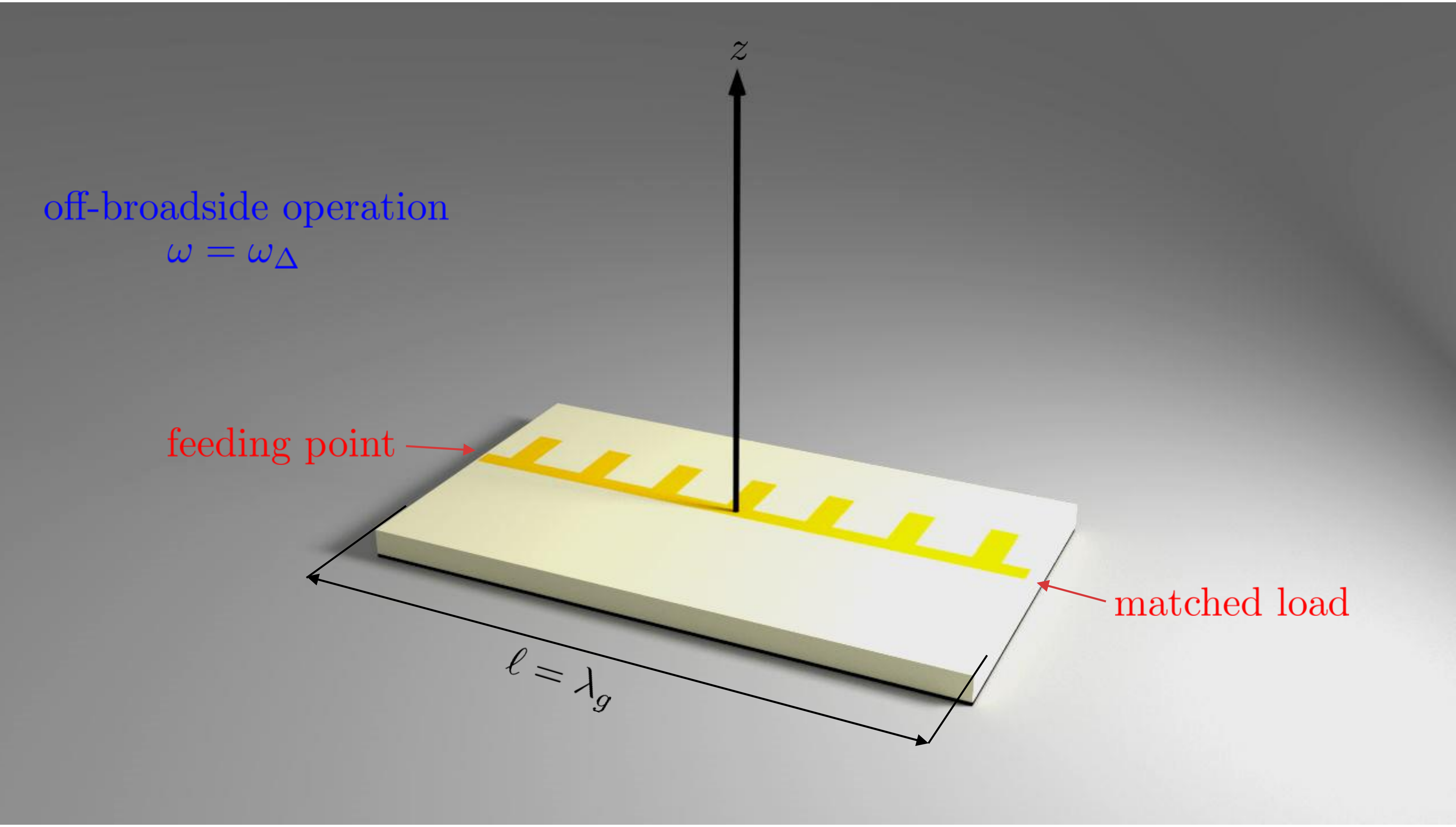
Full-Space Scanning





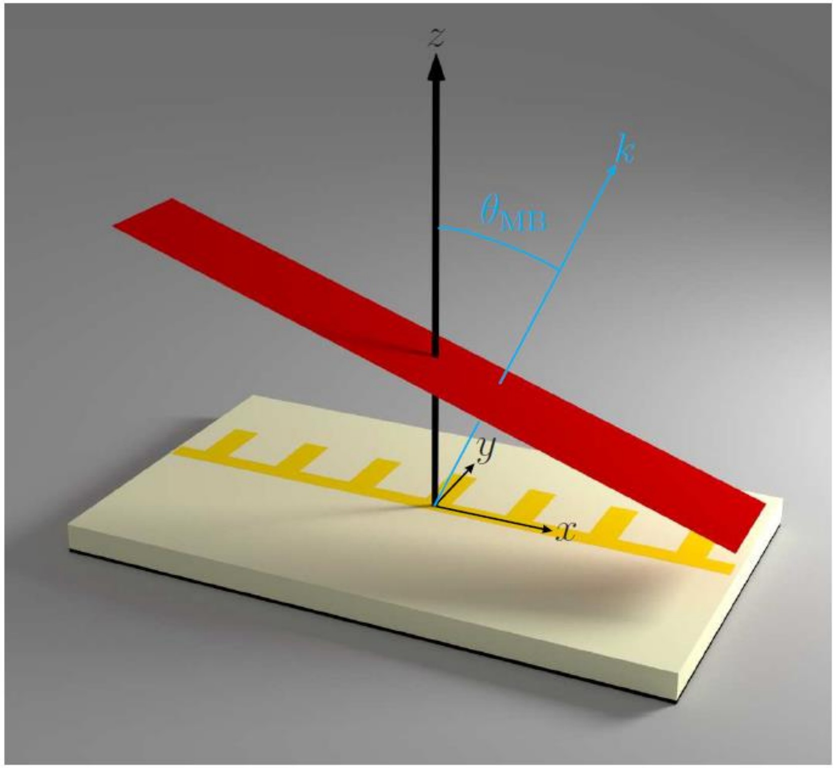
$$\text{scanning law} \rightarrow \theta_{\mathrm{MB}} = \arcsin \frac{\beta}{k_0}$$

Vortex Beam Generation Concept

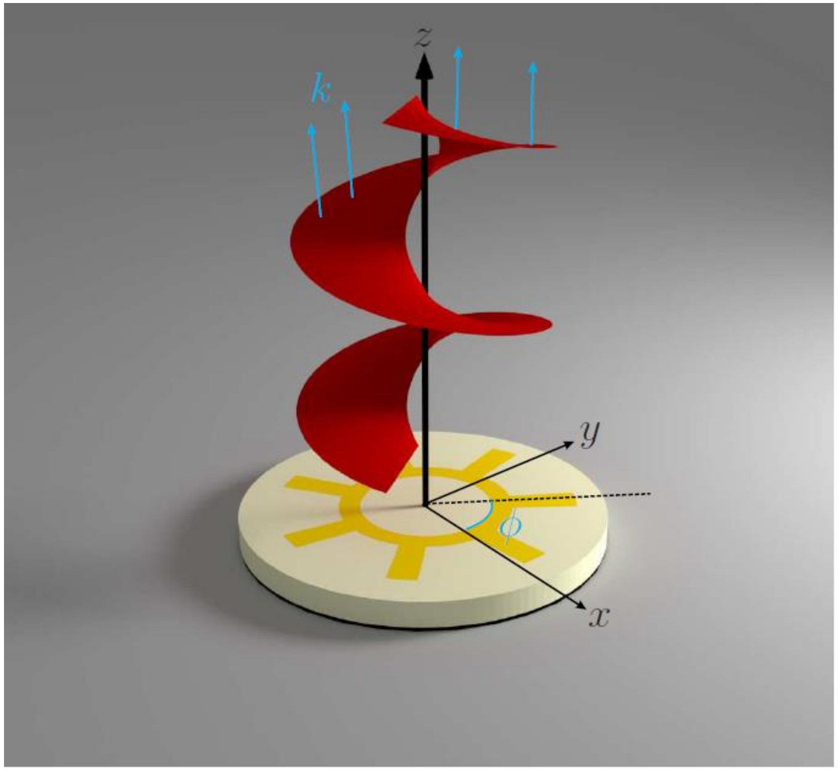


Phase Front of Linear & Circular LWA

tilted phase front



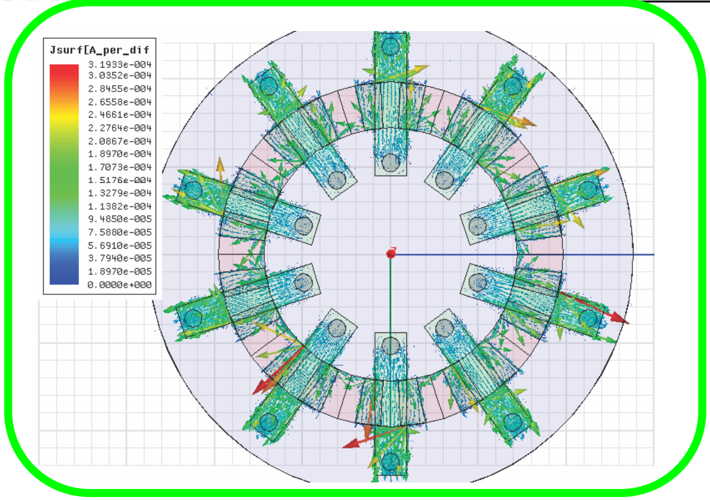
spiral phase front



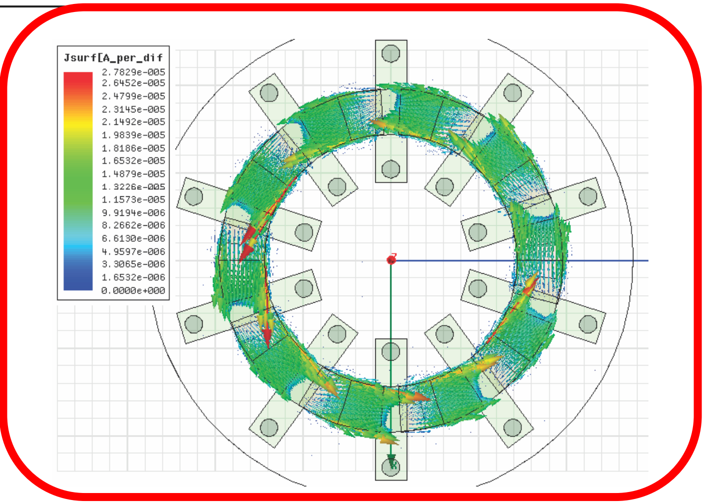
- Off-broadside operation
- Titled phase front by θ_{MB}

- Off-broadside operation
- Spiral phase front around propagation axis

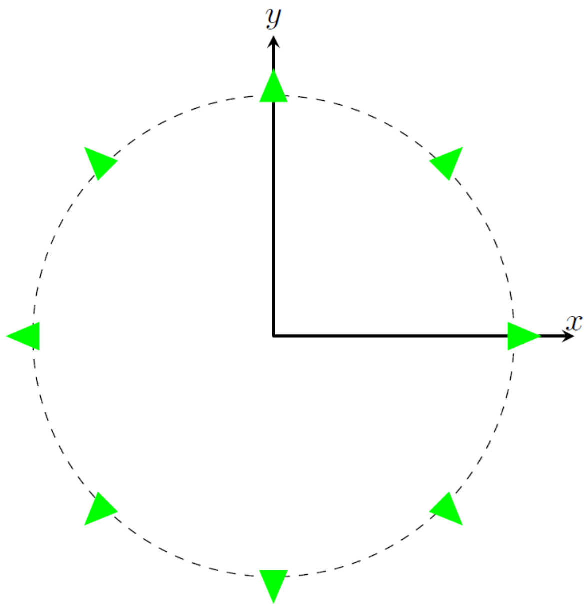
Surface Current Density

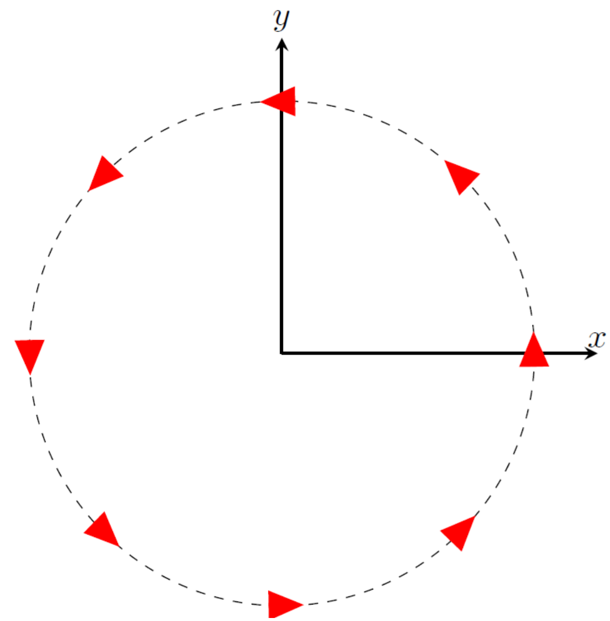


Radial current (Shunt Mode)



Azimuthal current (Series Mode)





**Eigenmode simulation in HFSS*

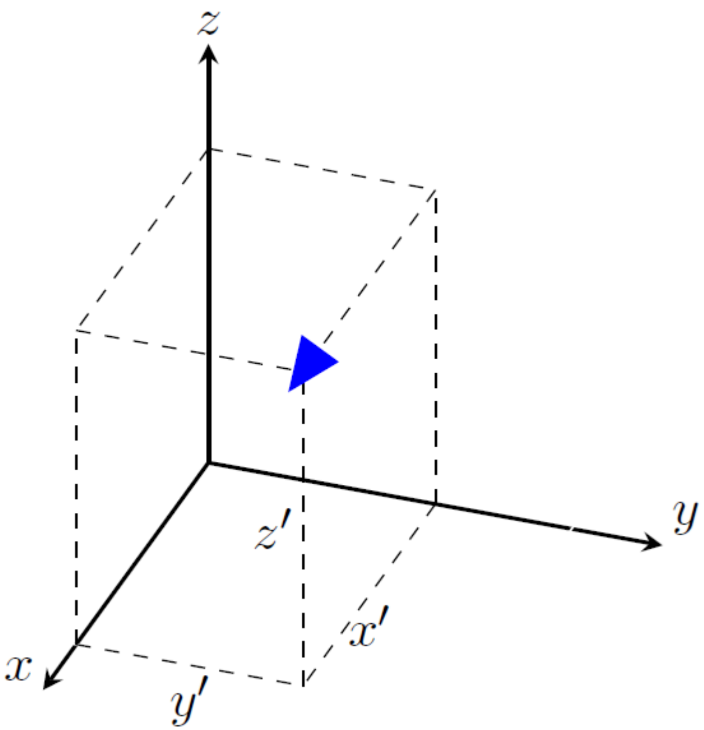
Dyadic Green's Function

Scalar Green's function

$$g(r', r) = \frac{e^{-jk_0|r-r'|}}{|r-r'|}$$

Dyadic Green's function

$$\bar{\bar{G}}_e(r', r) = (\bar{\bar{\mathbf{I}}} + \frac{1}{k_0^2}\nabla\nabla)g(r', r)$$



Electric field of an x-directed electric dipole

$$\underline{\vec{\mathbf{E}}}(r', r) = \frac{j\omega\mu_0\ell}{4\pi k_0^2} I_0(k_0^2\bar{\bar{\mathbf{I}}} + \nabla\nabla)g(r', r)\vec{e}_x$$

$$= \frac{j\omega\mu_0\ell}{4\pi k_0^2} I_0(k_0^2\bar{\bar{\mathbf{I}}} + \nabla\nabla)\frac{e^{-jk_0|r-r'|}}{|r-r'|}\vec{e}_x$$

$$|r-r'| = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}$$

R. E. Collin, *Field Theory of Guided Waves*, 2nd ed.

EM Modeling of Circular Array

Circular array of radially directed electric dipoles

$$\underline{\vec{\mathbf{E}}}^{\rho}(r', r) = \frac{j\omega\mu_0\ell}{4\pi k_0^2} I_0^{\rho} \sum_{n=0}^{N-1} (k_0^2 \bar{\bar{\mathbf{I}}} + \nabla\nabla) \frac{e^{-jk_0|r-r'|}}{|r-r'|} \left(\vec{e_x}\cos(n\phi') + \vec{e_y}\sin(n\phi')\right) e^{-n\underline{\gamma}\phi'}$$

Constant separation between elements

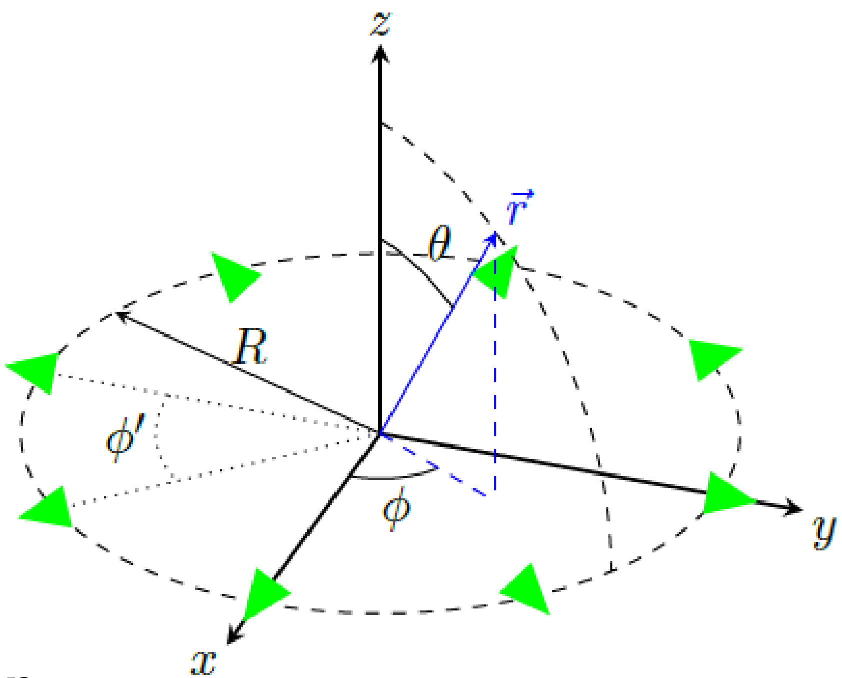
$$\phi' = \frac{2\pi}{N}$$

and constant radius

$$R = \sqrt{x'^2 + y'^2}$$

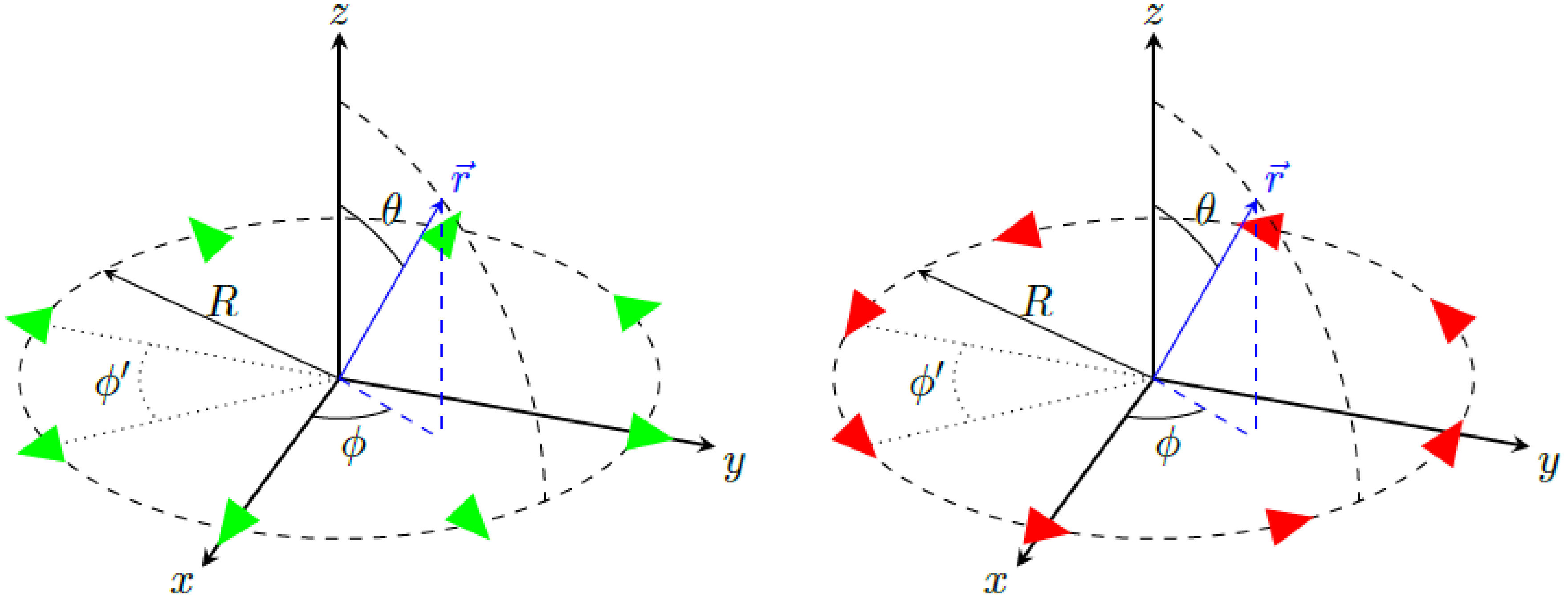
Propagation constant

$$\underline{\gamma} = \alpha - jm$$



Arbitrary magnitude and phase excitation

EM Modeling of CLWA



Electric field of each array

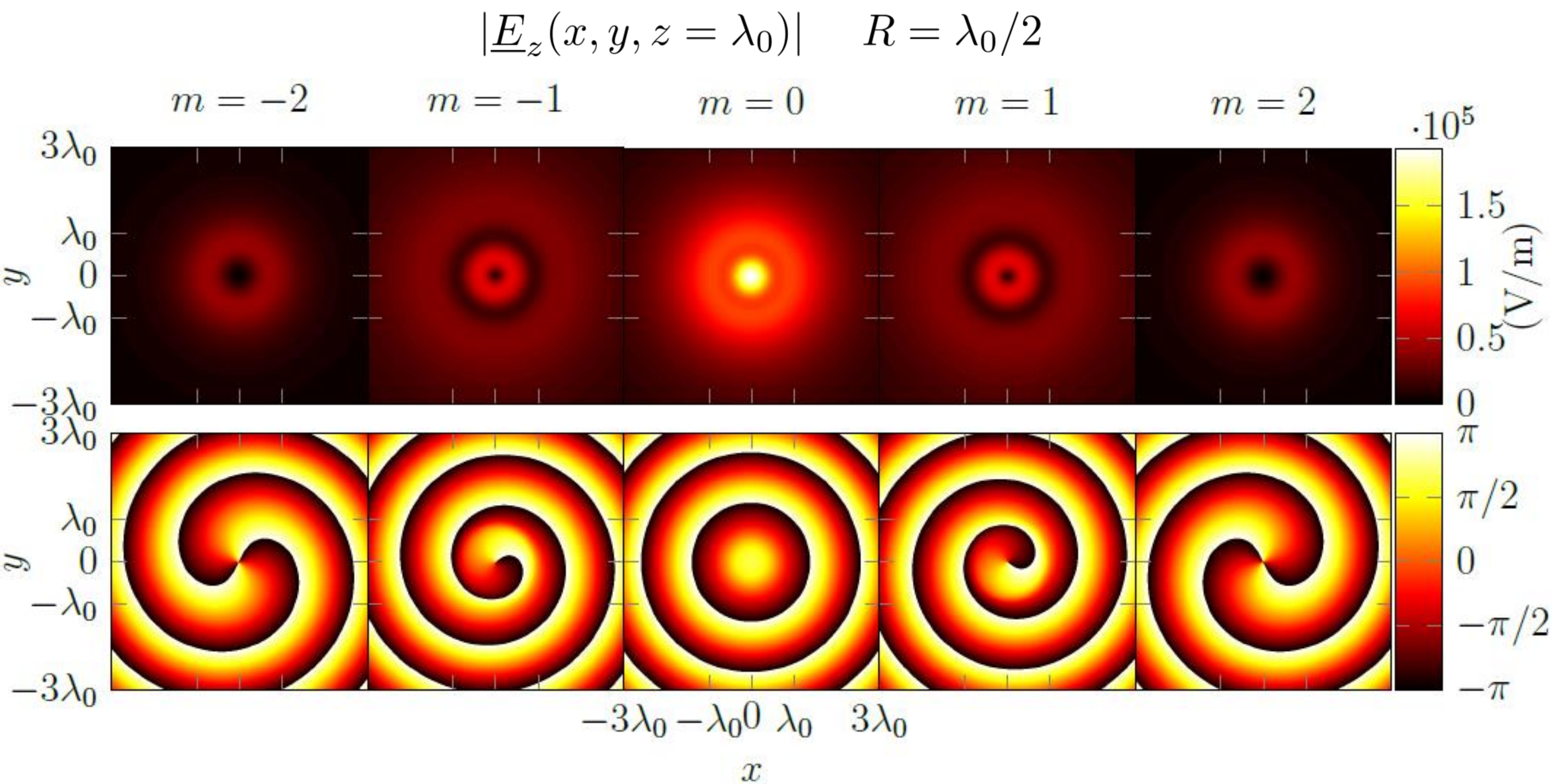
$$\begin{pmatrix} \vec{\underline{\mathbf{E}}}^{\rho} \\ \vec{\underline{\mathbf{E}}}^{\phi} \end{pmatrix}(r', r) = \frac{j\omega\mu_0\ell}{4\pi k_0^2}\begin{pmatrix} I_0^{\rho} \\ I_0^{\phi} \end{pmatrix}\sum_{n=0}^{N-1}(k_0^2\overline{\overline{\mathbf{I}}} + \nabla\nabla)\frac{e^{-jk_0|r-r'|}}{|r-r'|}\left(\begin{matrix}+\cos(n\phi') \\ -\sin(n\phi')\end{matrix}\vec{e_x} + \begin{matrix}\sin(n\phi') \\ \cos(n\phi')\end{matrix}\vec{e_y}\right)e^{\underline{\gamma} n\phi'}$$

Total Electric field

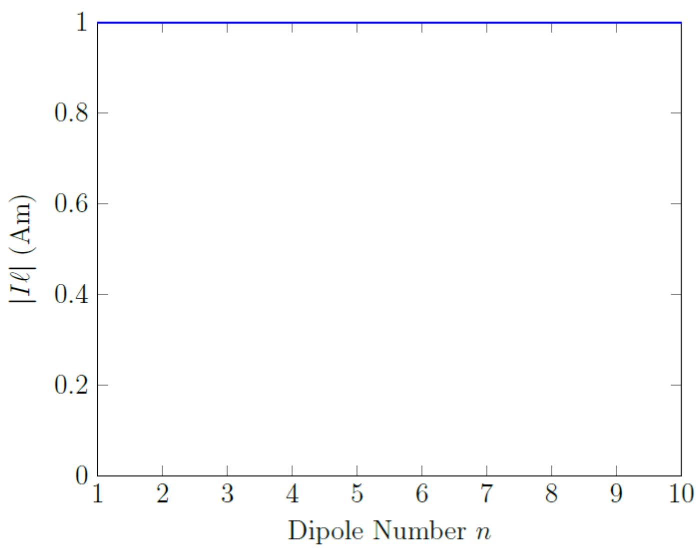
$$\vec{\underline{\mathbf{E}}} = \vec{\underline{\mathbf{E}}}^{\phi} \pm j\vec{\underline{\mathbf{E}}}^{\rho} \leftarrow \text{quadrature relation } (*)$$

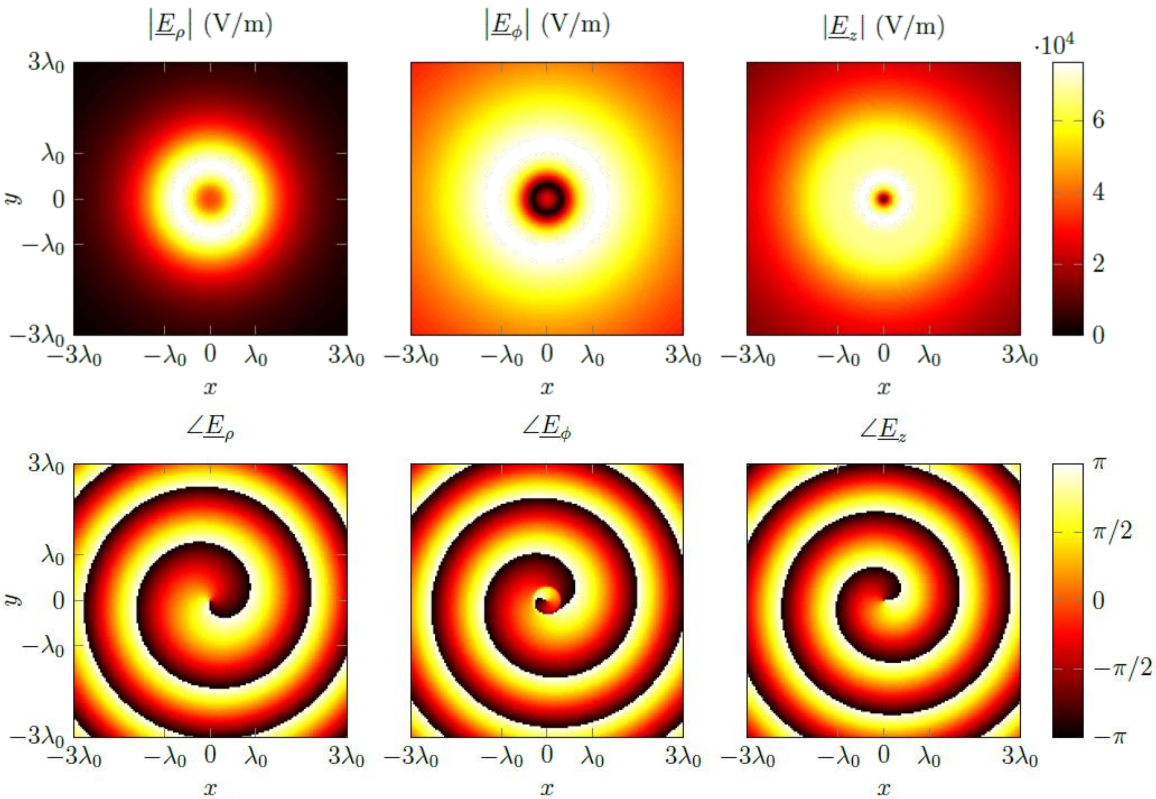
(*) S. Otto, Z. Chen, A. Al-Bassam, A. Rennings, K. Solbach and C. Caloz, "*Circular Polarization of Periodic Leaky-Wave Antennas with Axial Asymmetry: Theoretical Proof and Experimental Demonstration*," TAP 2014.

Numerical Results



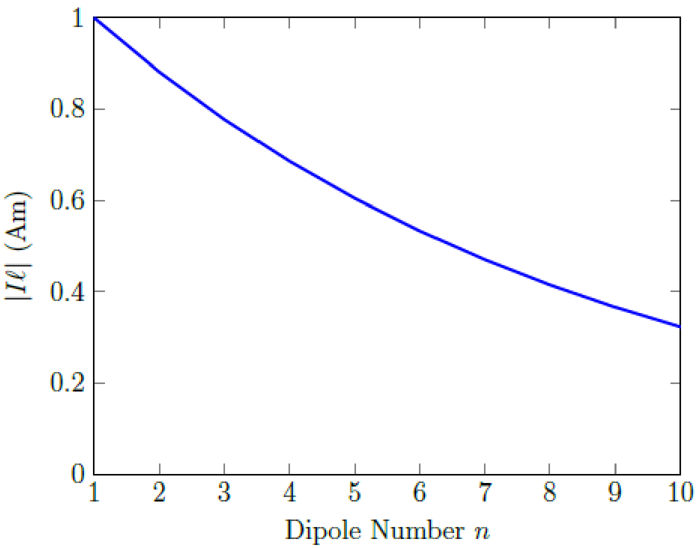
Example: Uniform Current

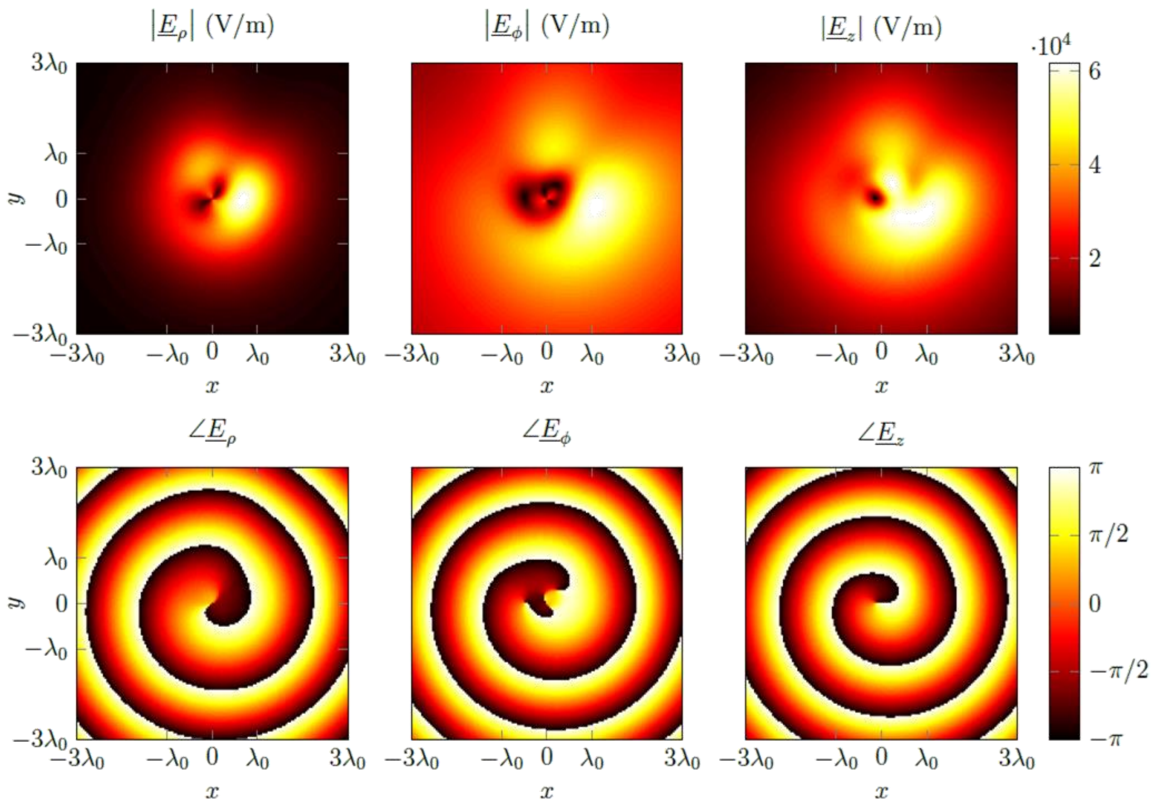




N	m	R	$I_0^\rho \ell/\mathrm{Am}$	$I_0^\phi \ell/\mathrm{Am}$	α (1/rad)	z
10	2	$\lambda_0/2$	1	1	0	λ_0

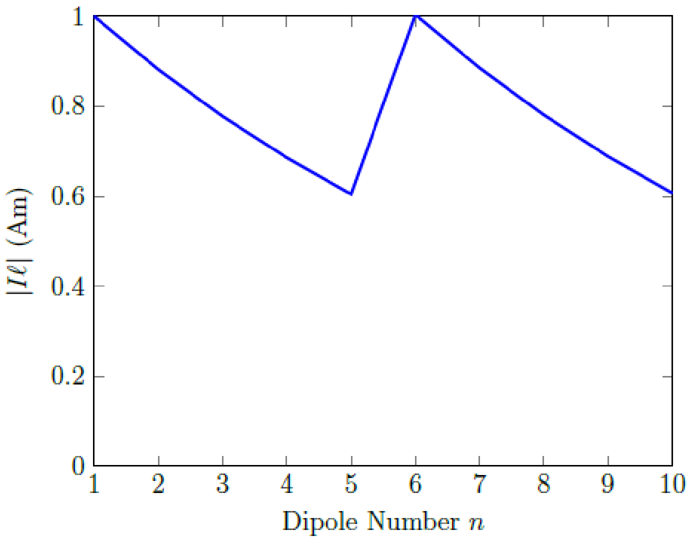
Example: Decaying Current

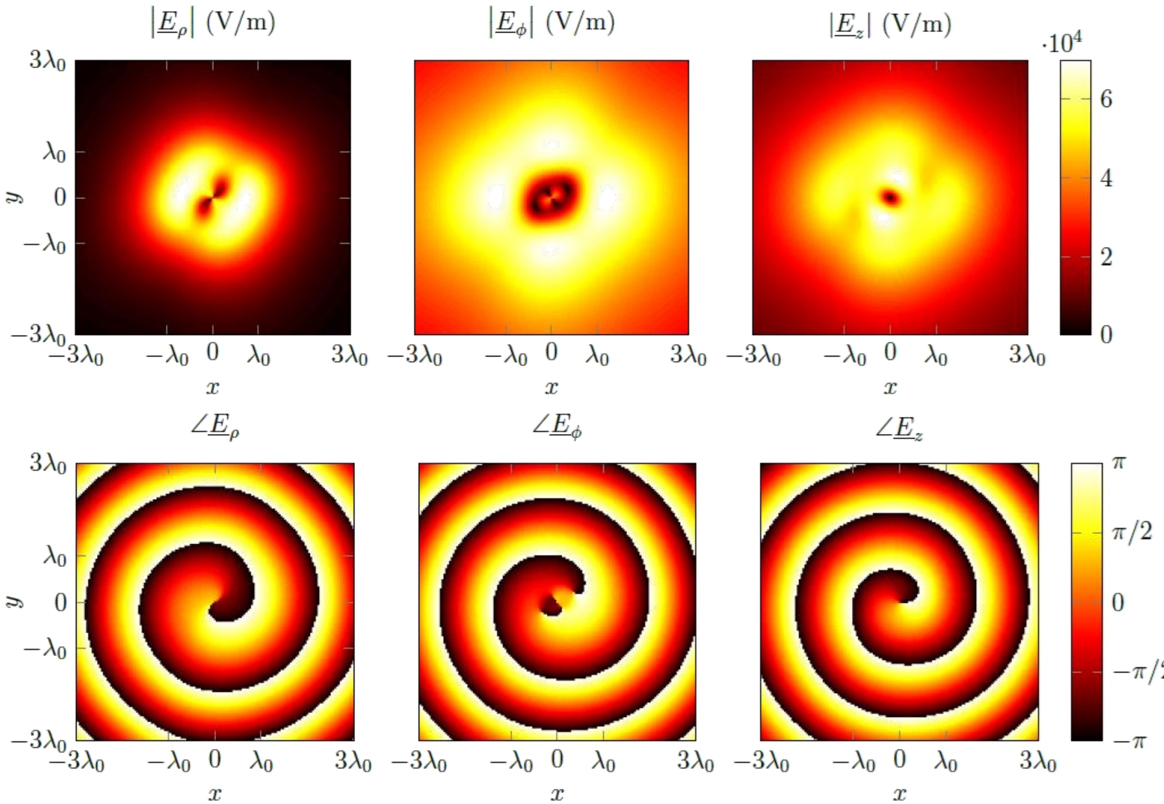




N	m	R	$I_0^{\rho}\ell/\mathrm{Am}$	$I_0^{\phi}\ell/\mathrm{Am}$	α (1/rad)	z
10	2	$\lambda_0/2$	1	1	0.1	λ_0

Example: Decaying Current with Two Points Exciation





N	m	R	$I_0^\rho \ell/\text{Am}$	$I_0^\phi \ell/\text{Am}$	α (1/rad)	z
10	2	$\lambda_0/2$	1	1	0.1	λ_0

I. Introduction

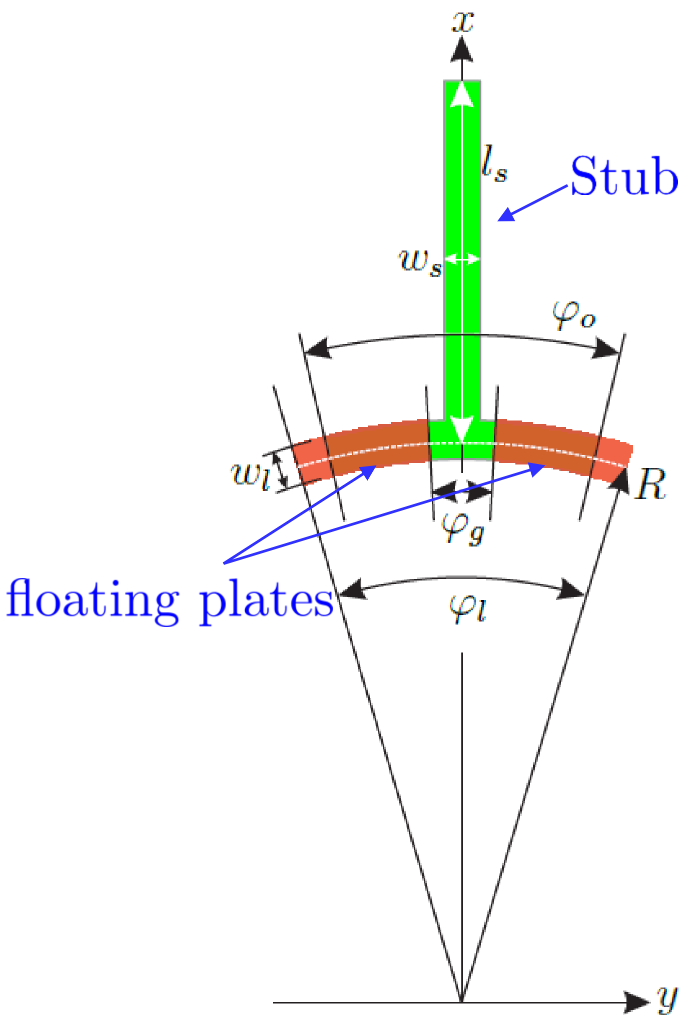
II. Concept Of Generation

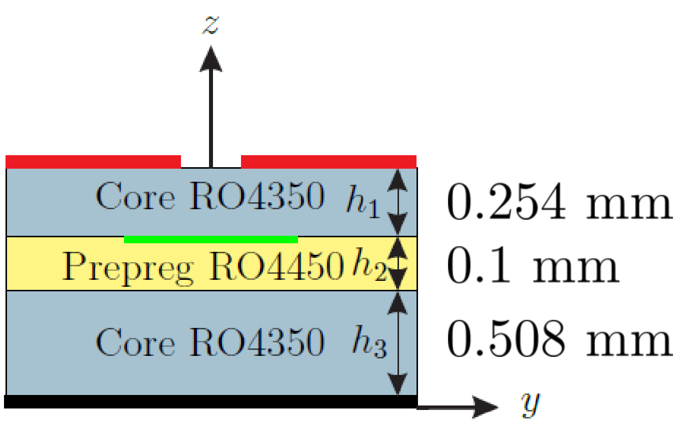
III. Electromagnetic Modeling

IV. Design & Experimental Results

❖ Conclusions & Questions

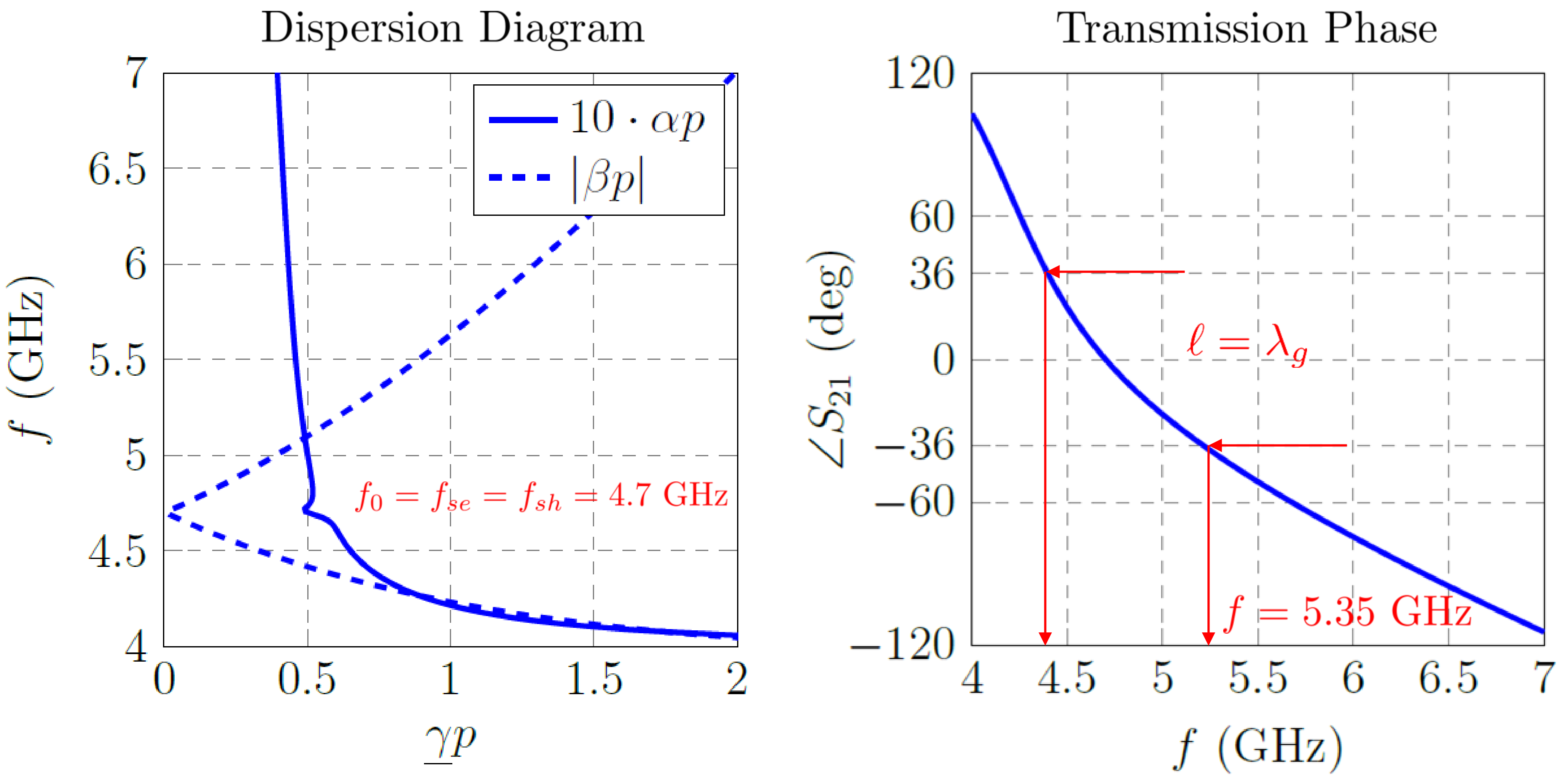
MIM-CRLH Unit Cell Design



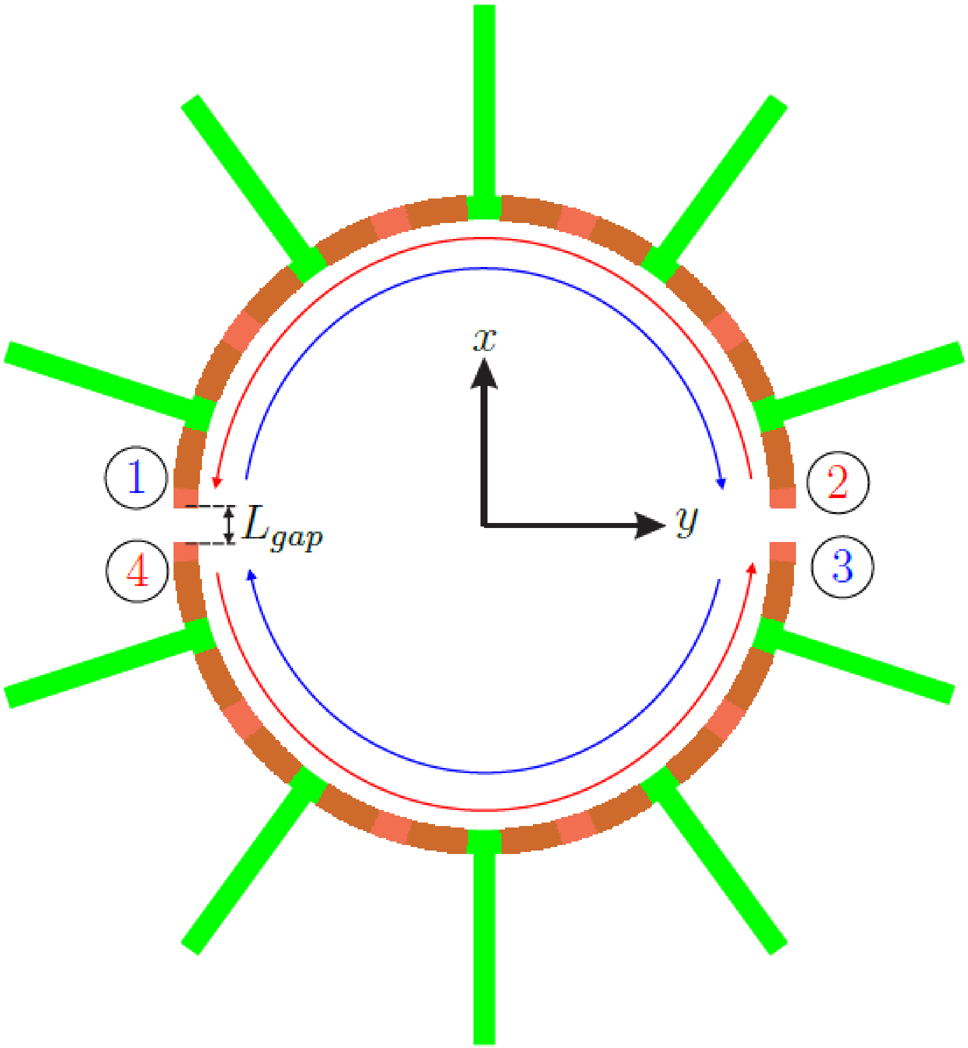


N	R (mm)	w_s (mm)	w_l (mm)	l_s (mm)	φ_l (rad)	φ_g (rad)	φ_o (rad)
10	16.25	1.2	1.1	11.5	$2\pi/N$	0.125	0.505

Simulation Results of One Unit Cell

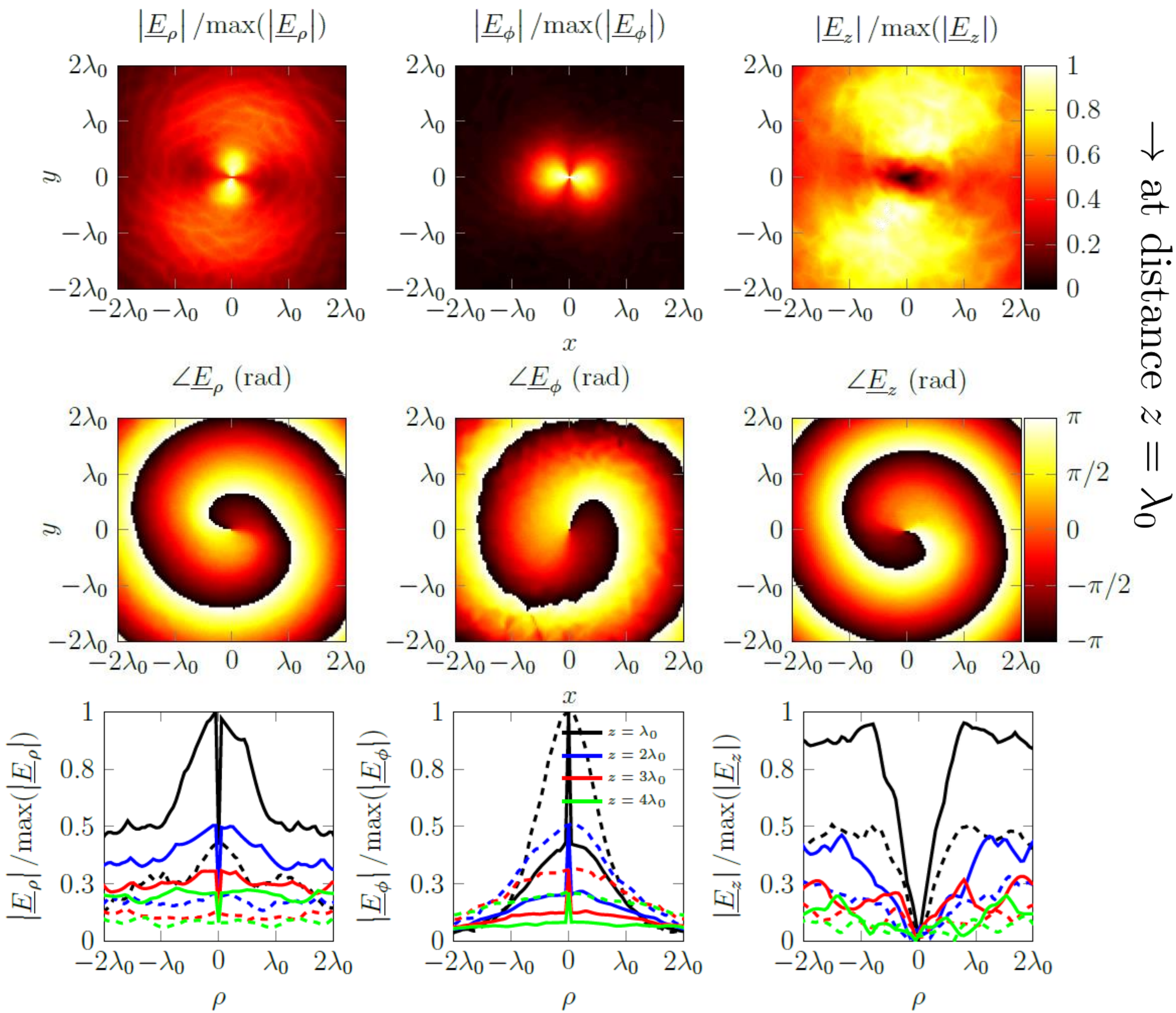


Two Halves CLWA



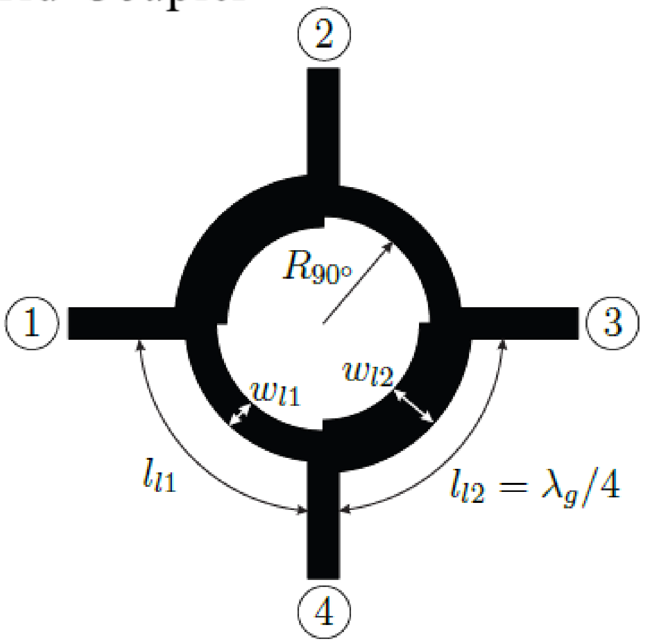
- Separation of $L_{gap} = 2$ mm.
- Two topological charges exciatation is possible.
- Ports excitation $1 - 3$ or $2 - 4$ to generate a topological charge.
- $m = \pm 1,3,5, \ldots$ require differential excitation.
- $m = \pm 0,2,4, \ldots$ require in-phase excitation.

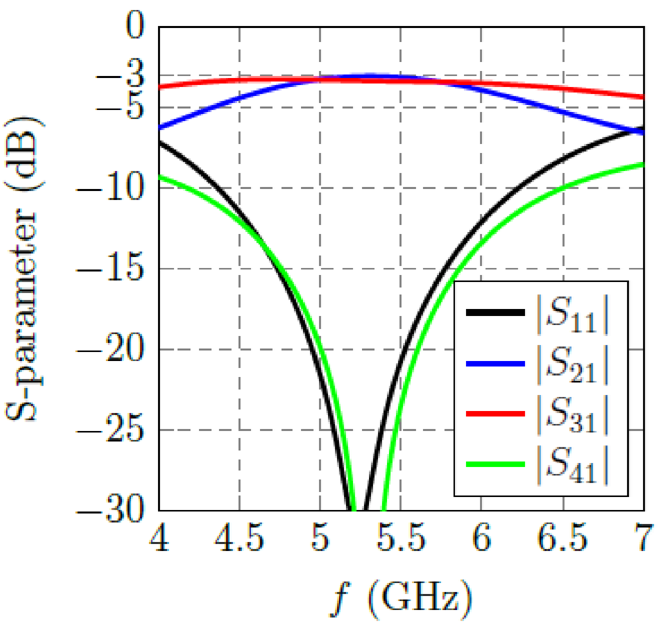
Simulation Results

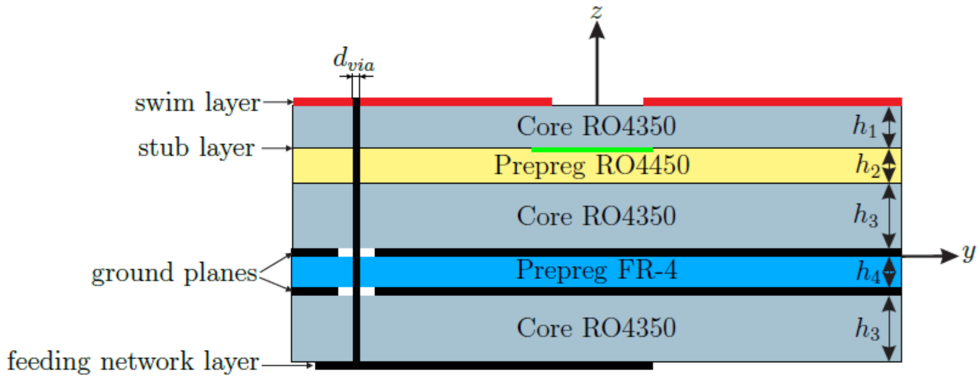


Feeding Network

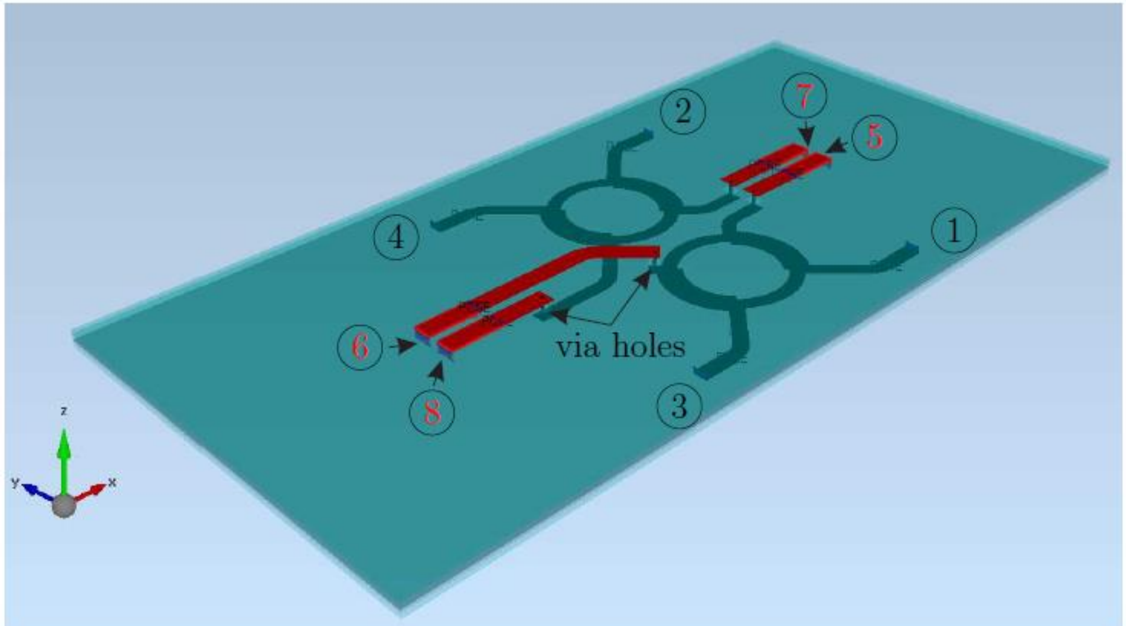
90° Hybrid-Coupler

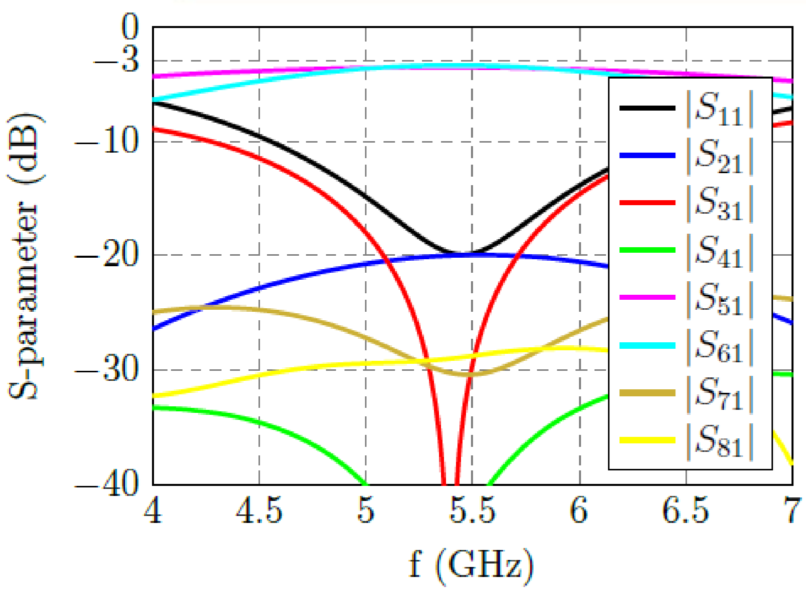


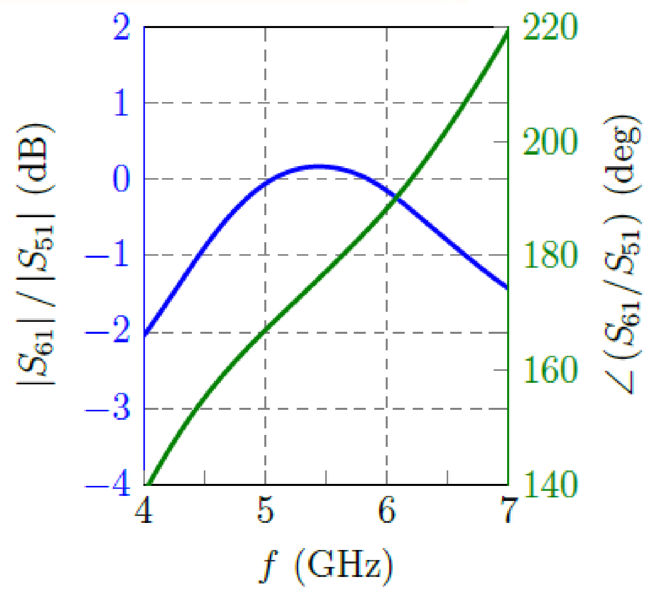




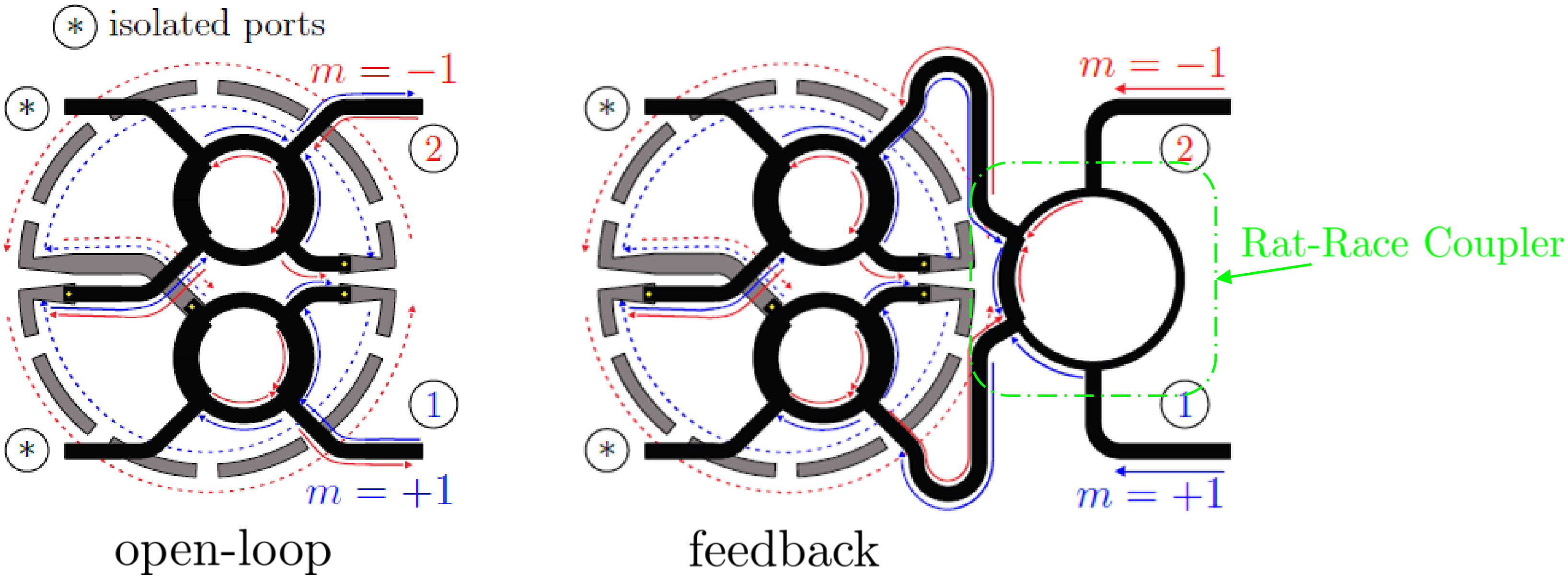
Simulation of the Feeding Network

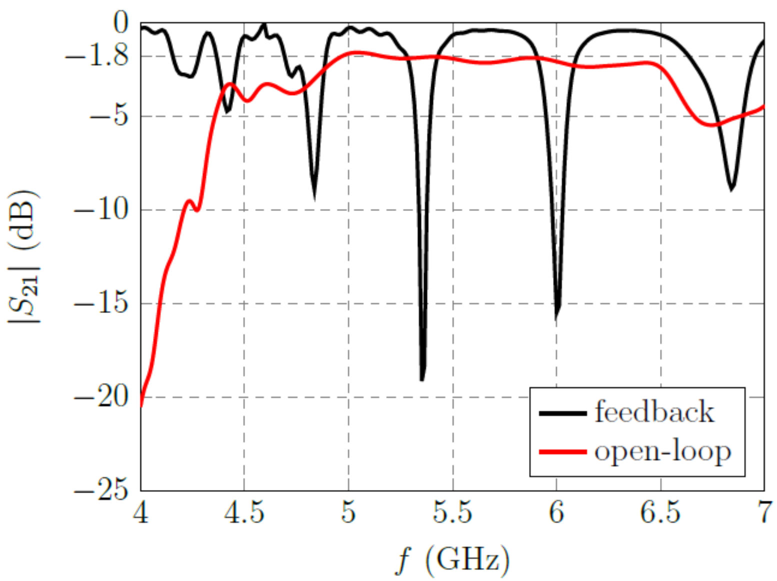






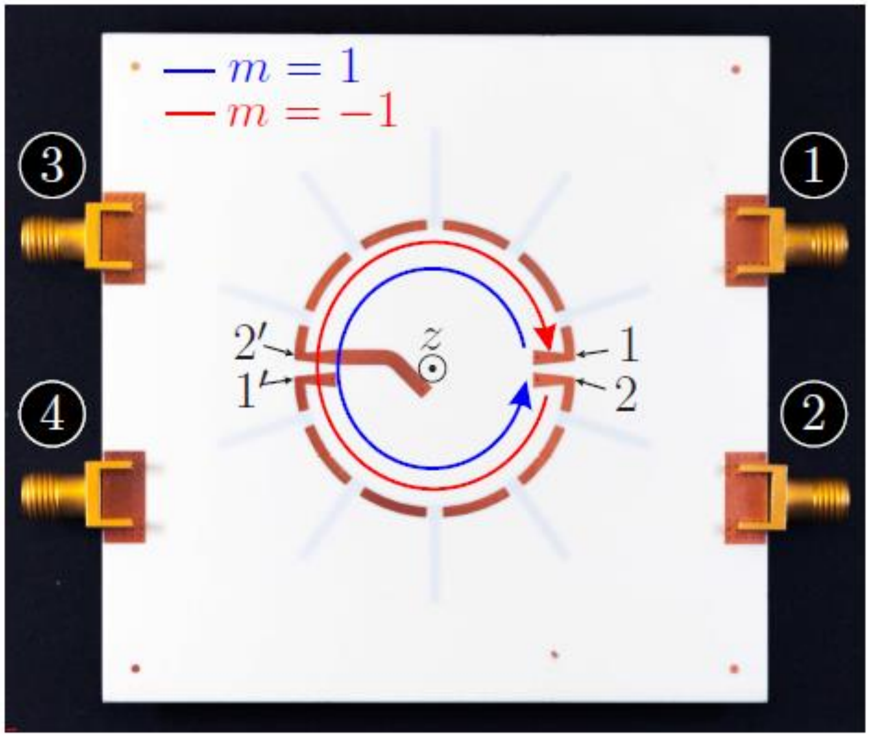
Maximizing Radiation Efficiency



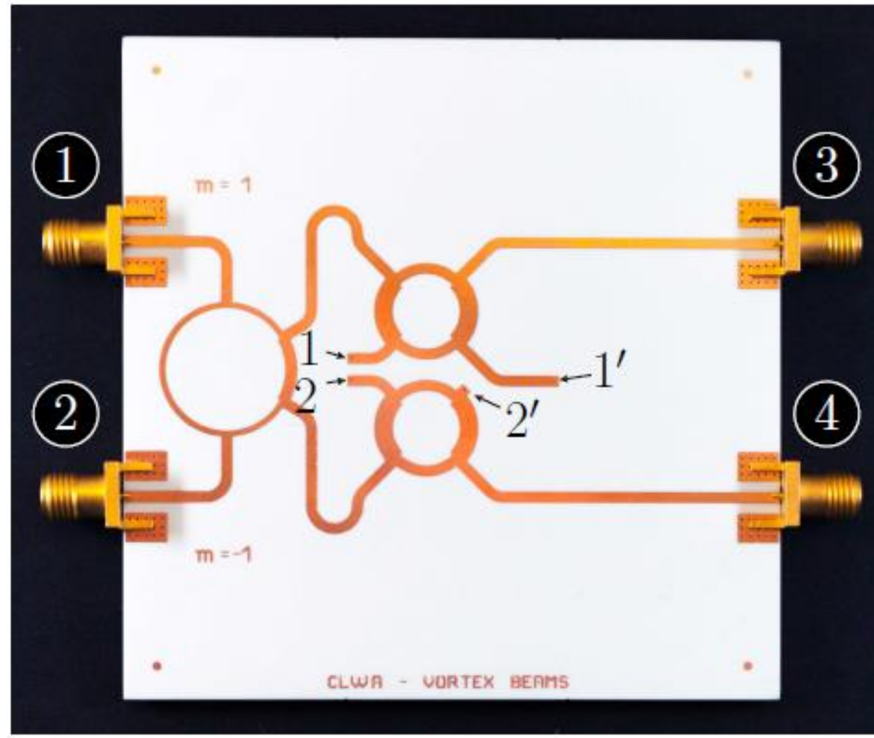


Prototype

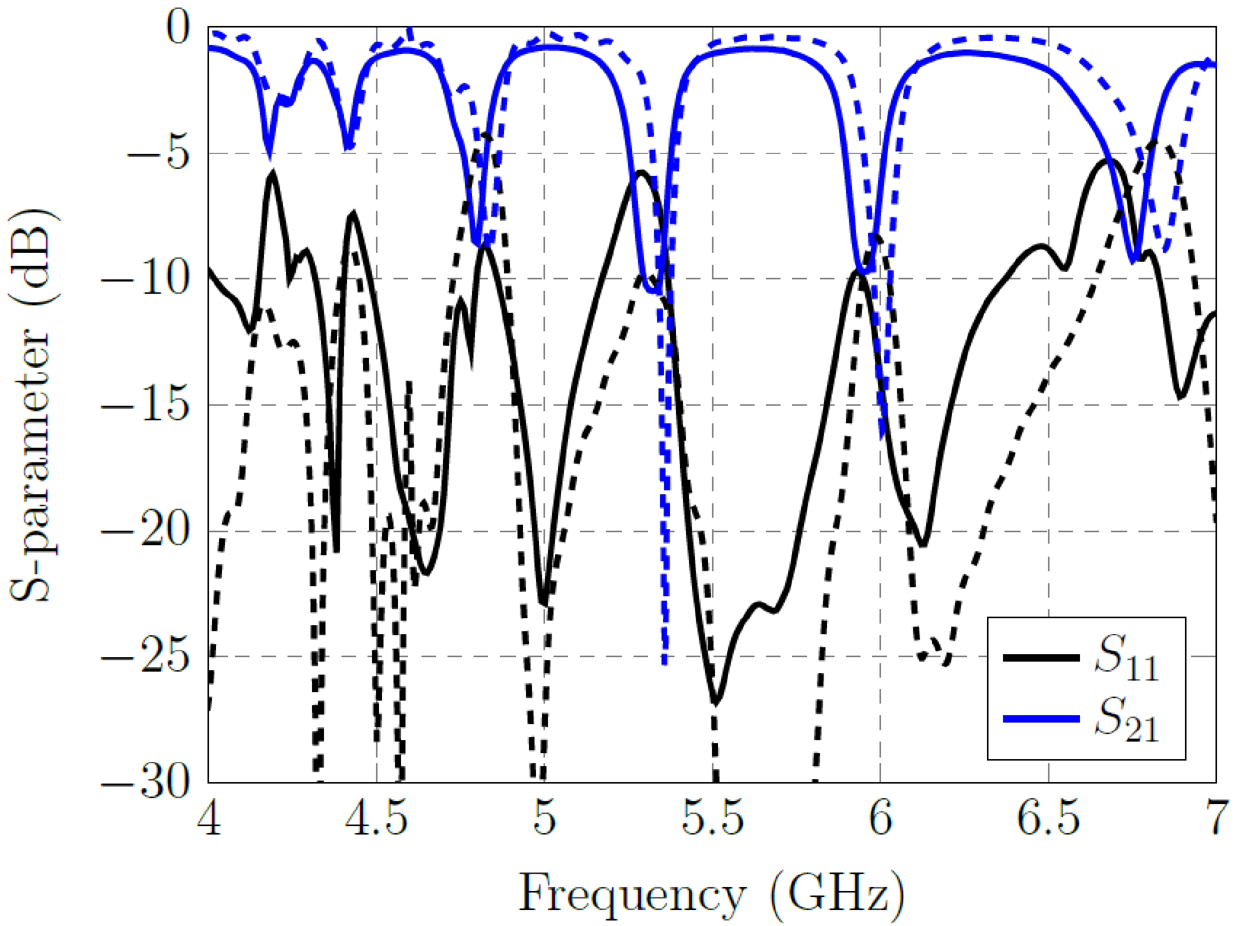
Top View



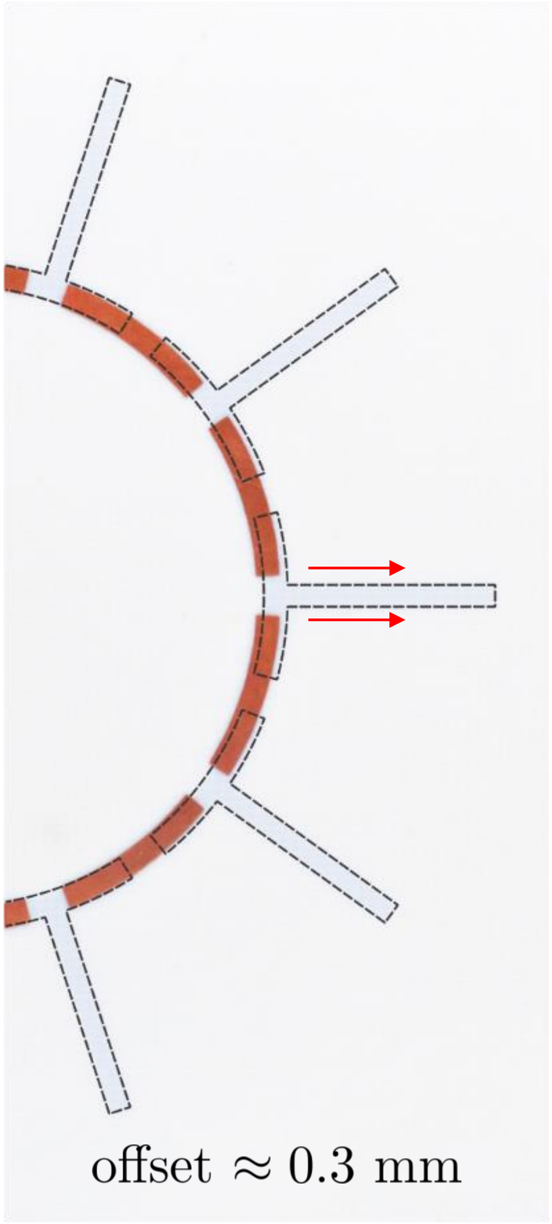
Bottom View



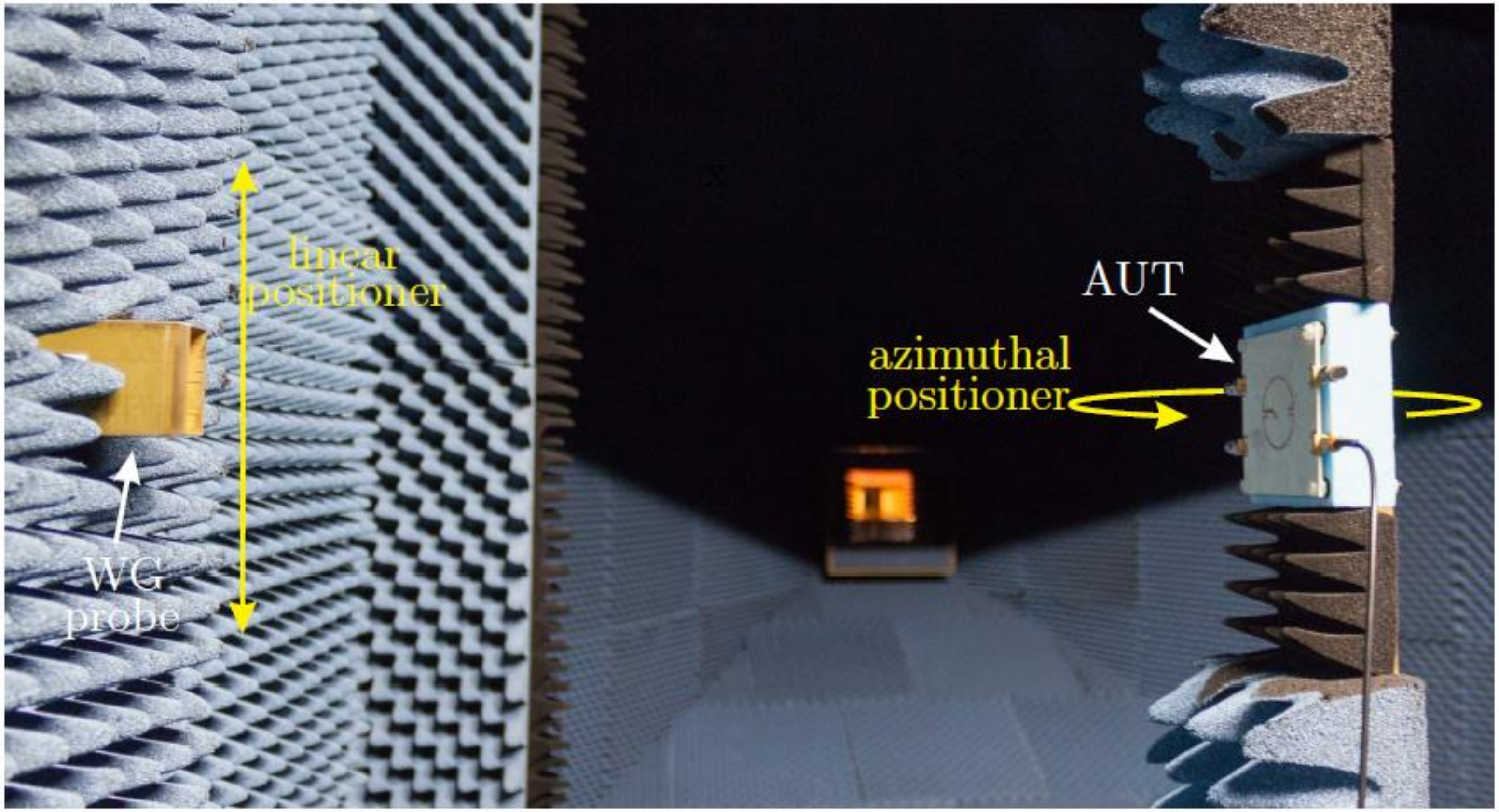
Measurement & Simulation Comparison



(solid)→ measurement
(dashded)→ simulatiuon

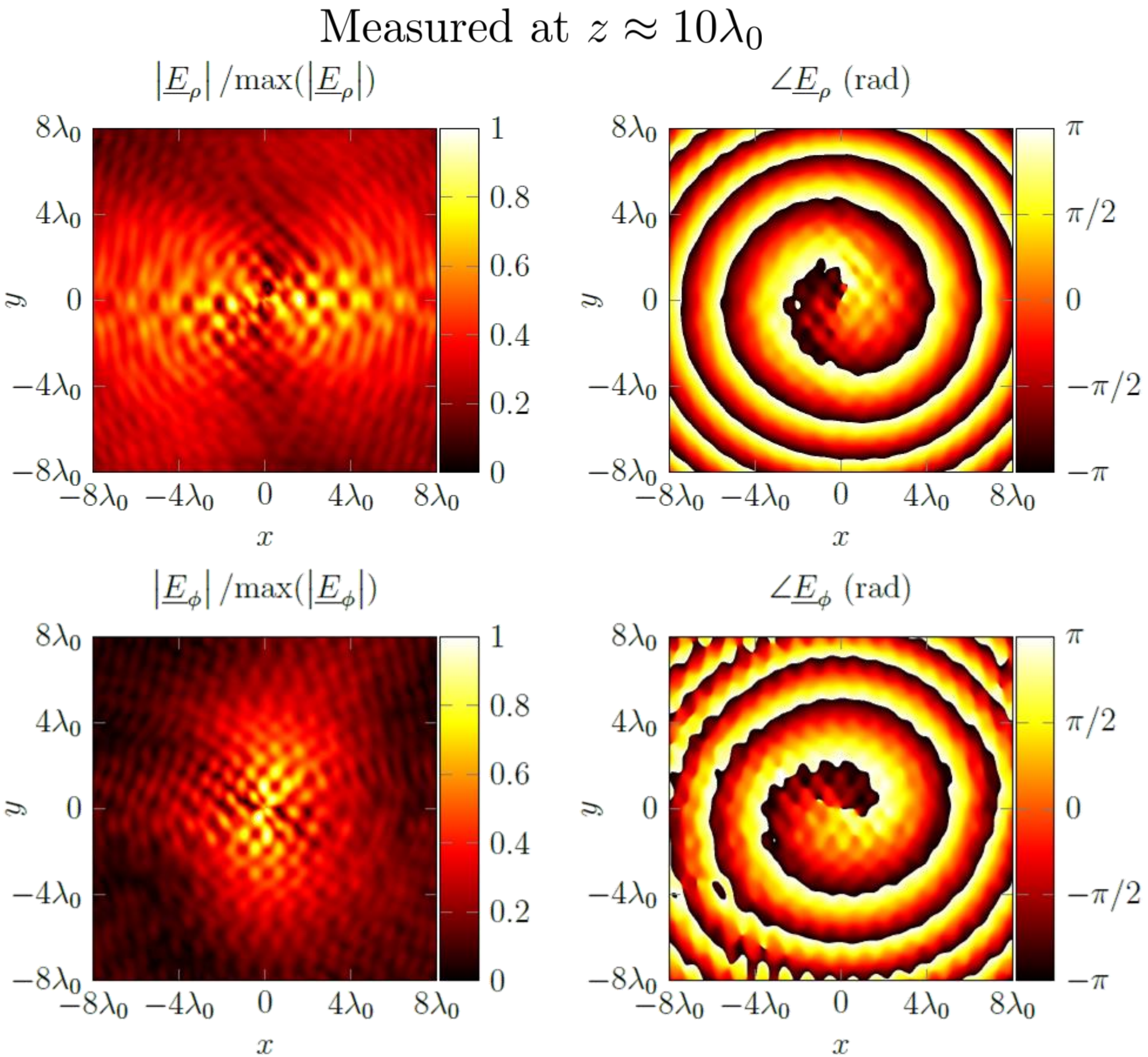


Cylindrical Near-Field Measurement

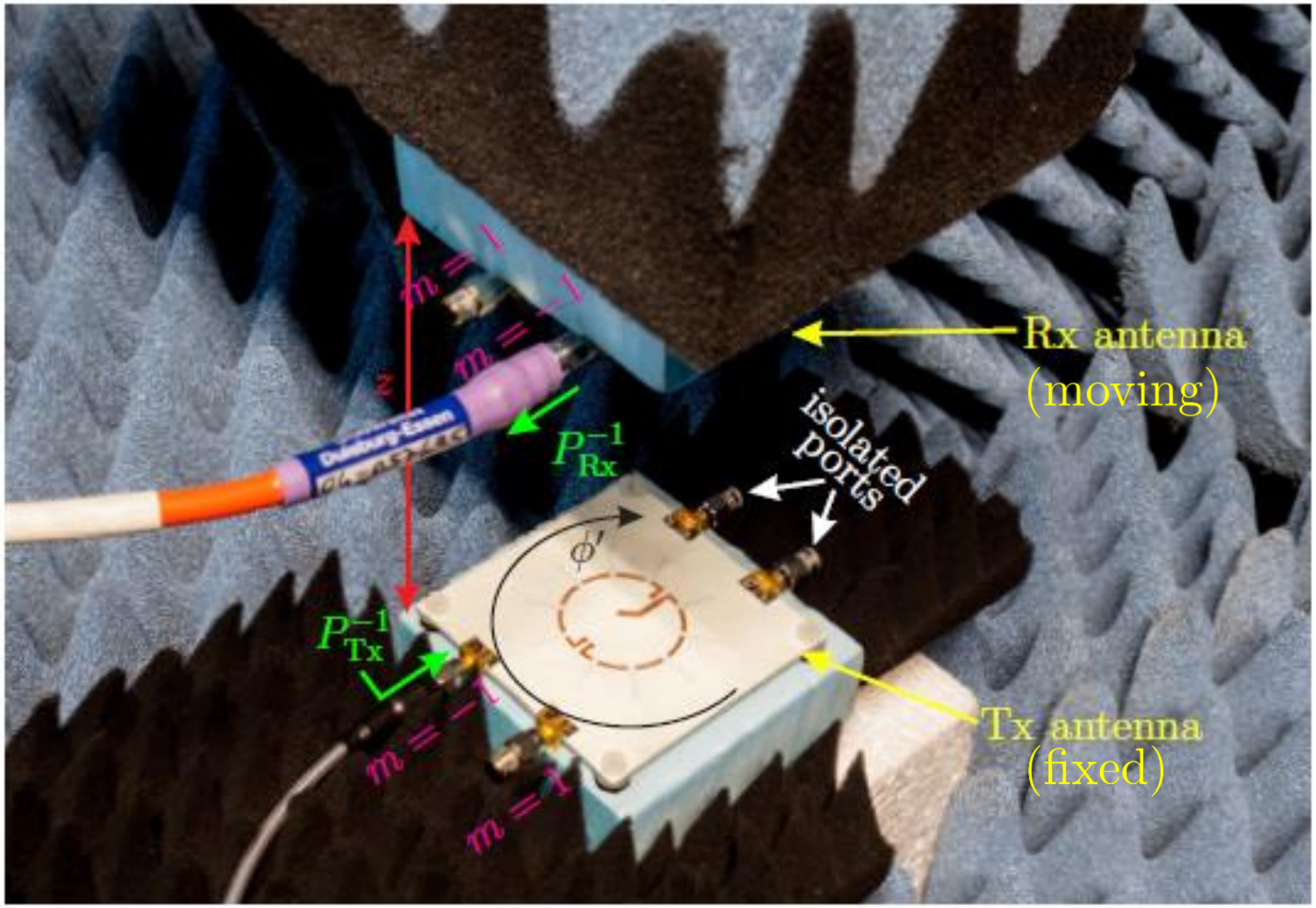


- E-Field sampling on a cylindrical surface
- Near-field to far-field transformation
- Back transformation to planar near-field

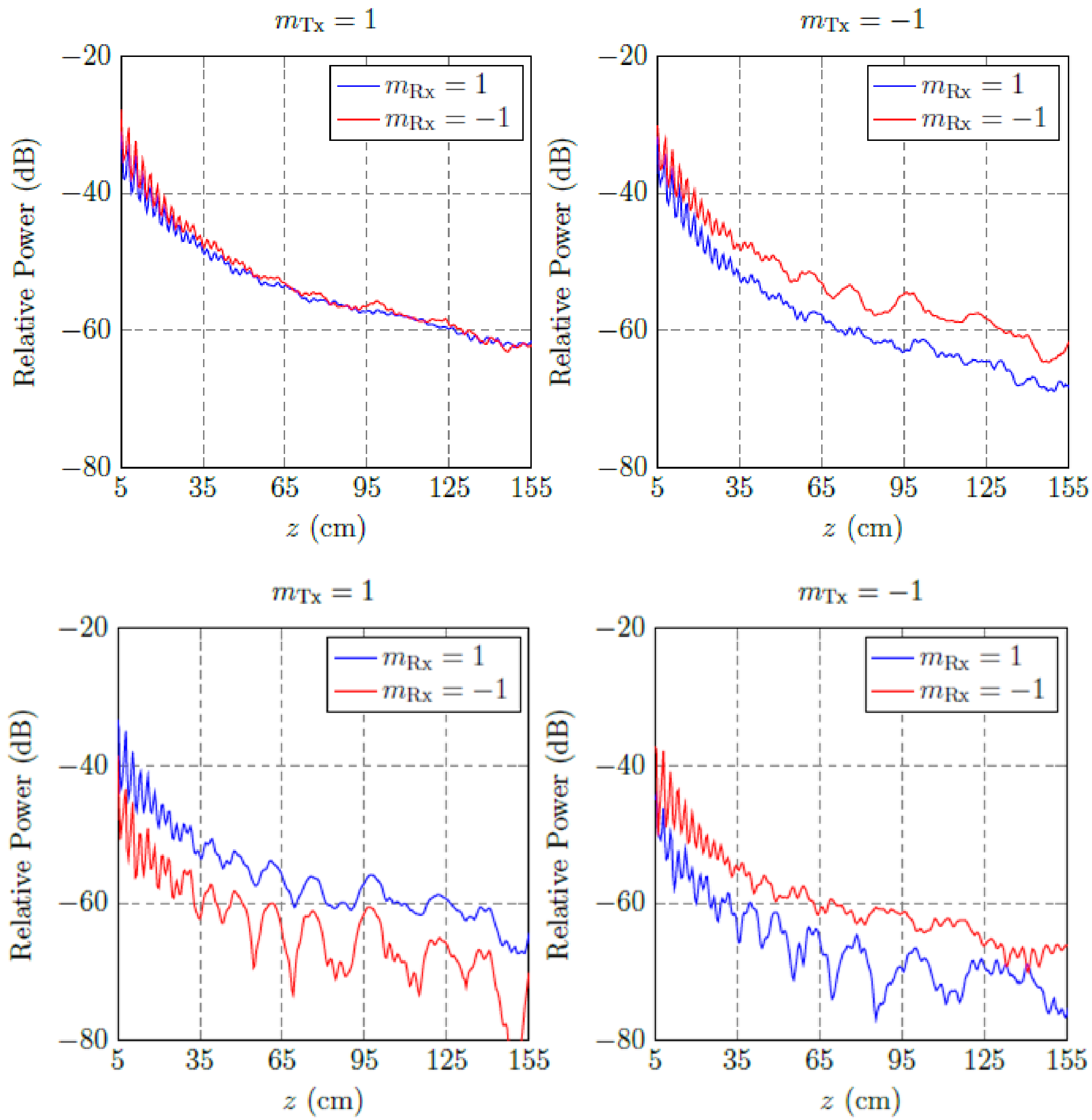
Results of Near-Field Measurement



Transmission Measurement Setup



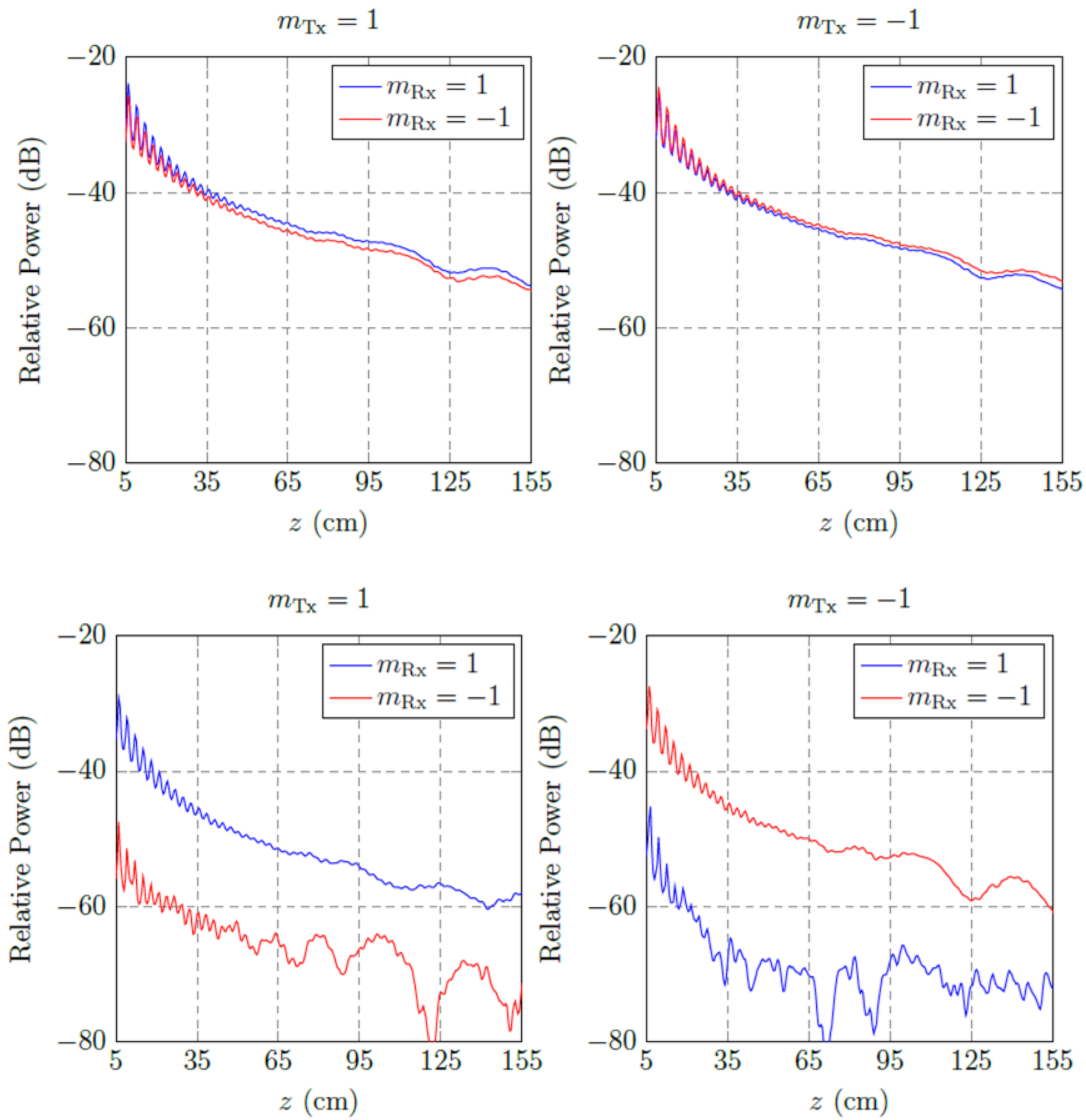
Results of Two Channels Multiplexing @ f = 5.35 GHz



$\phi' = 0°$

$\phi' = 90°$

Results of Two Channels Multiplexing @ $f = 4.8$ GHz

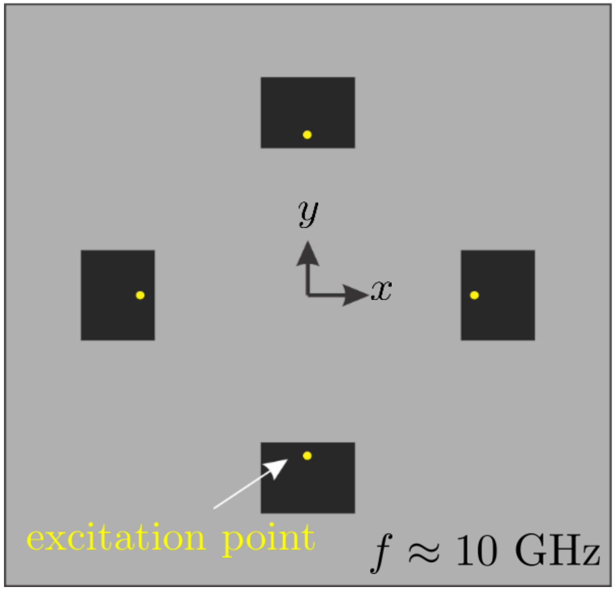


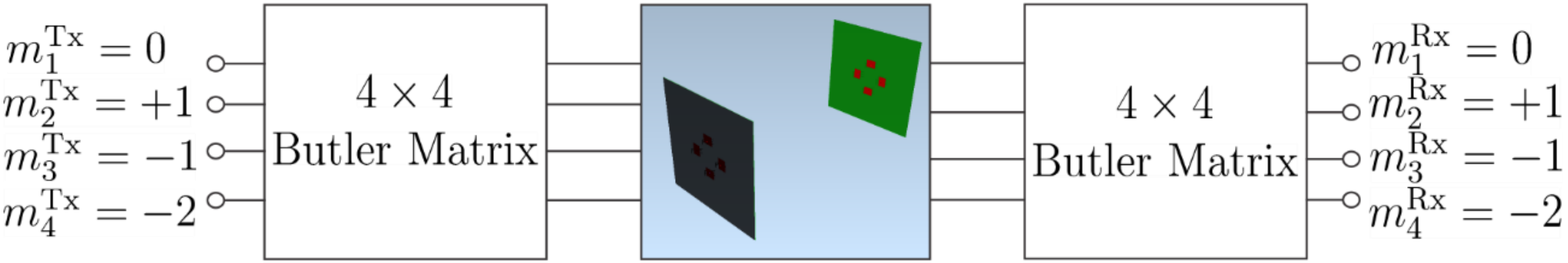
$\phi' = 0°$

$\phi' = 90°$

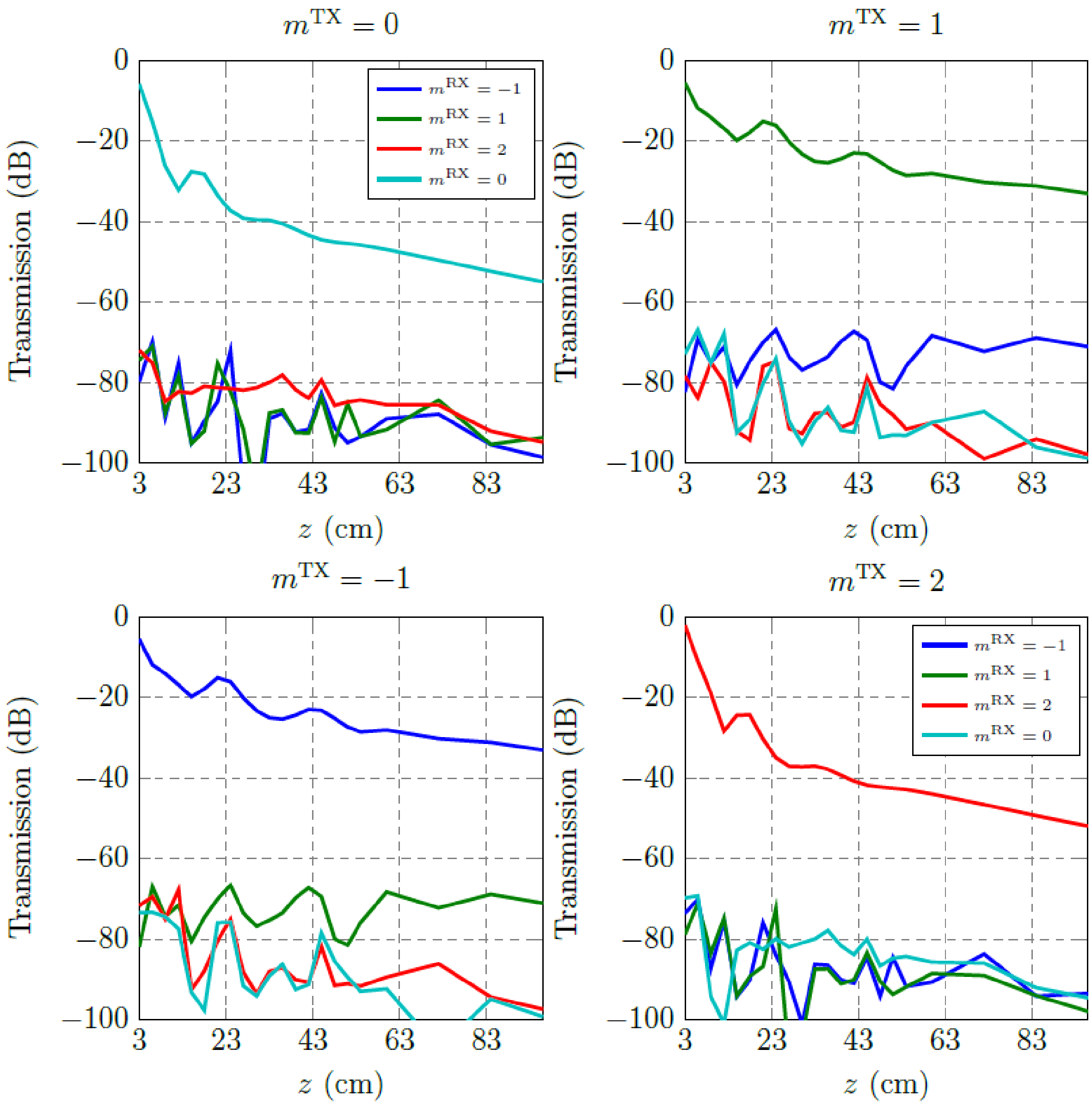
Circular Phased Array: An Alternative to CLWA

Radial patch array





Simulation Results



I. Introduction

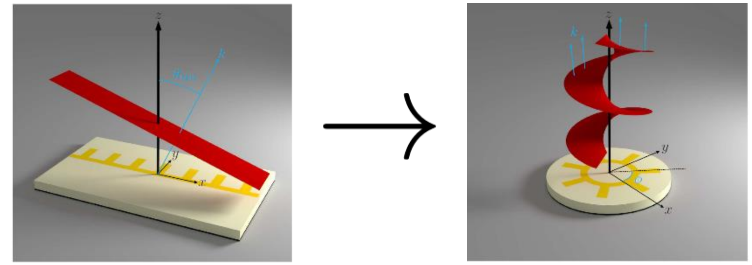
II. Concept Of Generation

III. Electromagnetic Modeling

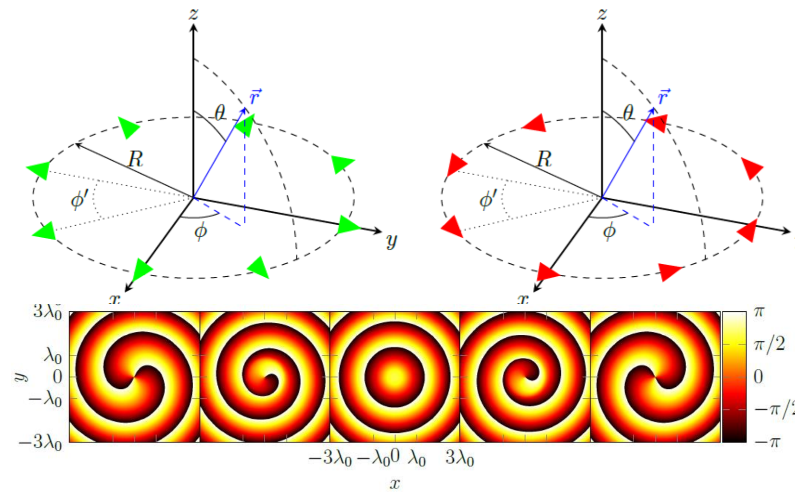
IV. Design & Experimental Results

❖ Conclusions & Questions

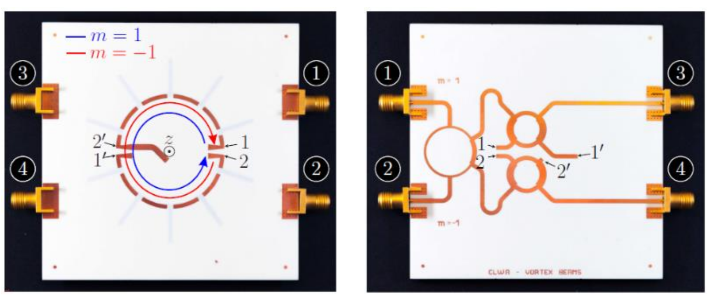
Conclusions



- ❑ Circular leaky-wave antenna to generate orbital angular momentum
  - new technique
  - $\pm m$ simultaneously

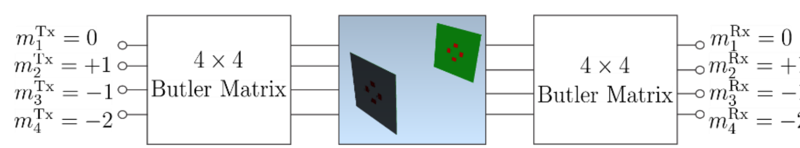


- ❑ EM modeling of CLWA
  - valid in near- and far-field
  - models the series and shunt modes independently
  - pahse & amplitude relations



- ❑ Experimental Validation
  - near-field measurement
  - two channels multiplexing

- ❑ An alternative to CLWA
  - circular phase array
  - N elemets $\rightarrow$ N independent channels



Thank You!

ÉCOLE POLYTECHNIQUE MONTRÉAL

UNIVERSITÄT DUISBURG ESSEN

HFT