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WB3.4: Beam-Steering in 2D via Non-Linear Mapping of 1D Beam-Steering

Pawel Strzebonski*, Raman Kumar, Kent Choquette
*strzebo2@illinois.edu
Photonic Devices Research Group
Electrical and Computer Engineering Department
University of Illinois, Urbana, Illinois 61801 USA

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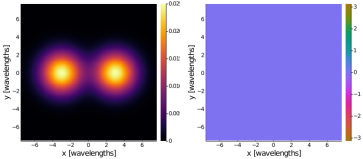
Basic Background

- Beam steering generally refers to the shift in the far-field location of the dominant beam lobe and is powered by near-field phase variation [1][2]
- Generally, a 1D array of emitters can steer the main lobe along a line, and for 2D beam-steering we need a 2D array of emitters [3]
- Optical angular momentum (OAM) modes have spiraling phase
- These can vary in the spiral chirality and total phase variation around the spiral

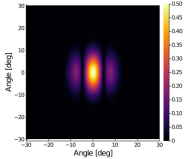
[1] Lehman et al, "Relative phase tuning of coupled defects in photonic crystal vertical-cavity surface-emitting lasers", APL, 2006
[2] Johnson et al, "High-speed beam steering with phased vertical cavity laser arrays", JSTQE, 2013
[3] Lehman et al, "Two-dimensional electronic beam-steering with implant-defined coherent VCSEL arrays", EL, 2007

Far-Field Simulations

- We start with an array of Gaussian intensity emitters in the near-field
- We apply a phase profile, either uniform phase for each emitter for Gaussian modes, or spiral phase for OAM modes
- We use Fraunhoffer propagation to obtain the far-field intensity profile
- Let's start with a 2x1 Gaussian mode array...



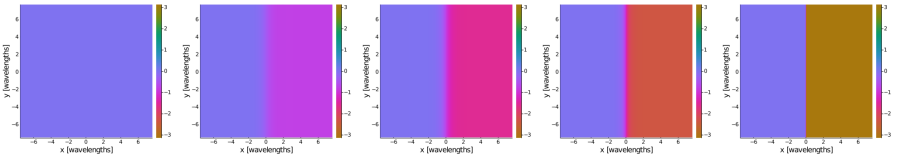
Near-field intensity and phase profiles



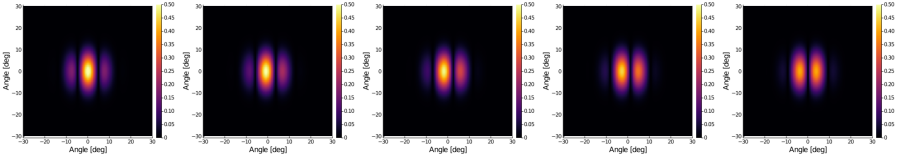
Far-field intensity profile

2x1 Gaussian Mode Array

NF Phase:



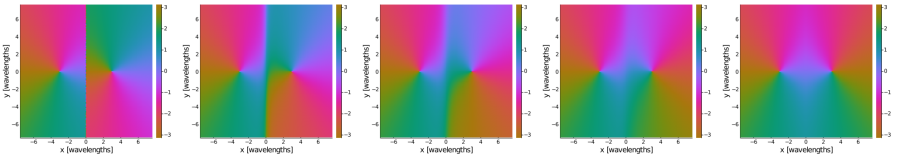
FF Intensity:



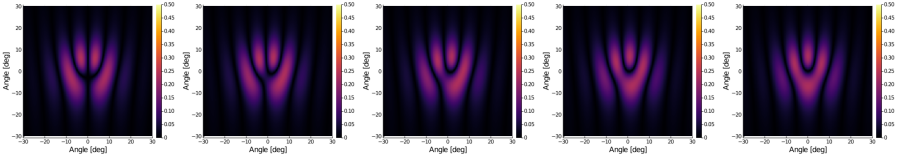
$\Delta\phi_{12}$: 0 $\pi/4$ $\pi/2$ $3\pi/4$ π

2x1 OAM Mode Array

NF Phase:



FF Intensity:



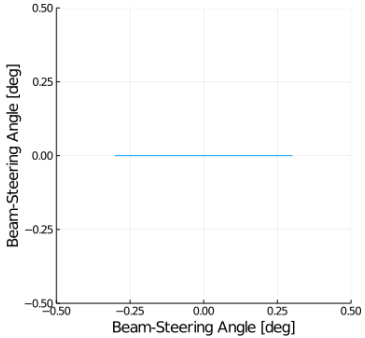
$\Delta\phi_{12}$: 0 $\pi/4$ $\pi/2$ $3\pi/4$ π

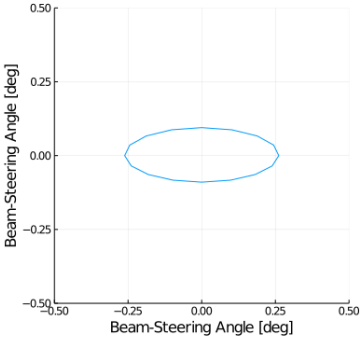
Analyzing the Beam-Steering

- As mentioned earlier, beam-steering is often thought as shifting the "dominant" lobe in the far-field
- However, in the OAM case the lobes mutate as they shift
- This makes it difficult to identify a "dominant" lobe and quantify how it shifts
- So we will define beam-steering in this case as the shift in the center of far-field power
- We calculate and plot the center of far-field power as we tune the inter-element phase for the previously shown 2x1 arrays...

2x1 Array Beam-Steering: Gaussian vs OAM Modes

Trace the center of far-field power as we scan $\Delta\phi_{12}$:

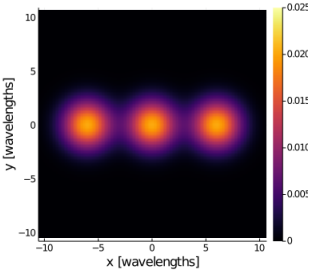




2x1 OAM emitter arrays beam-steer as a non-linear 1D subspace of 2D!

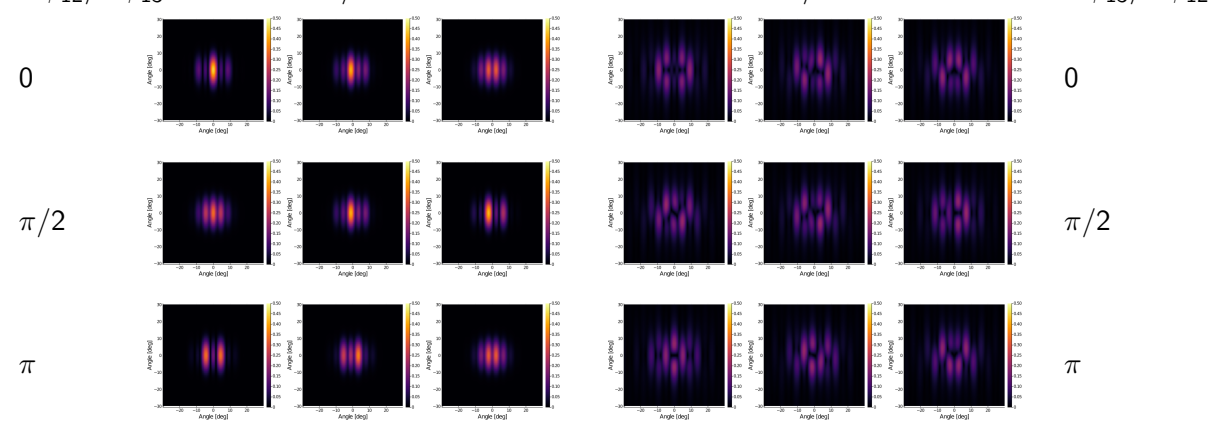
Beyond 2 Elements?

- If we only have 2 elements, then we only have 1 degree of freedom (of inter-element phase) and can only beam-steer within a 1D subspace
- But if we have 3 elements, we have 2 degrees of freedom (of inter-element phase), possibly enabling beam-steering within a 2D subspace
- However, linear 3x1 arrays of Gaussian emitters are still limited to 1D beam-steering
- What about 3x1 arrays of OAM mode emitters? Let's see...



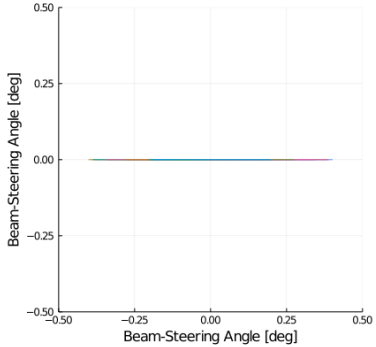
Near-field intensity profile

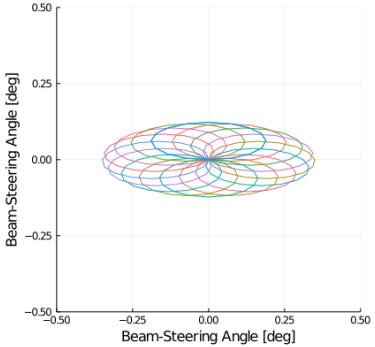
3x1 Array Far-Field: Gaussian vs OAM Emitters



3x1 Array Beam-Steering: Gaussian vs OAM Modes

Each colored curve represents holding $\Delta\phi_{12}$ constant and scanning $\Delta\phi_{13}$:





Linear 3x1 OAM emitter arrays enable 2D beam-steering!

Implications and Conclusions

- Using phased arrays of engineered mode emitters, such as OAM modes, allows us to break some of the usual constraints of phased array beam-steering
- 2 element arrays are no longer limited to scanning a simple line segment but rather can scan a 1D path in 2D space
- Linear arrays of 3 or more elements can scan a 2D space
- Bring the beam-steering capabilities of 2D phased arrays to 1D arrays in systems where moving from 1D to 2D arrays is not easy or possible
- Refer to my colleague Raman's prior presentation (WB3.3) for a discussion of how phased OAM arrays, capable of such beam-steering, can be implemented using VCSELs and integrated phase plates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Backup Slide

- Emitters were assumed to be spaced $6\lambda_0$ center-to-center, with field profiles of $\exp(-\frac{x^2+y^2}{5\lambda_0^2})$
- Our center-of-power definition for beam-steering is by no means equivalent to conventional definition of beam-steering
- The center-of-power beam-steering angle is generally less than the center-of-dominant-lobe beam-steering angle
- The OAM arrays simulated were in the $(+1, -1)$ and $(+1, -1, +1)$ configurations
- Some arrays of OAM modes (such as $(+1, +1)$) do not exhibit these forms of beam-steering