A Low-Power OAM Metasurface for Rank-Deficient Wireless Environments

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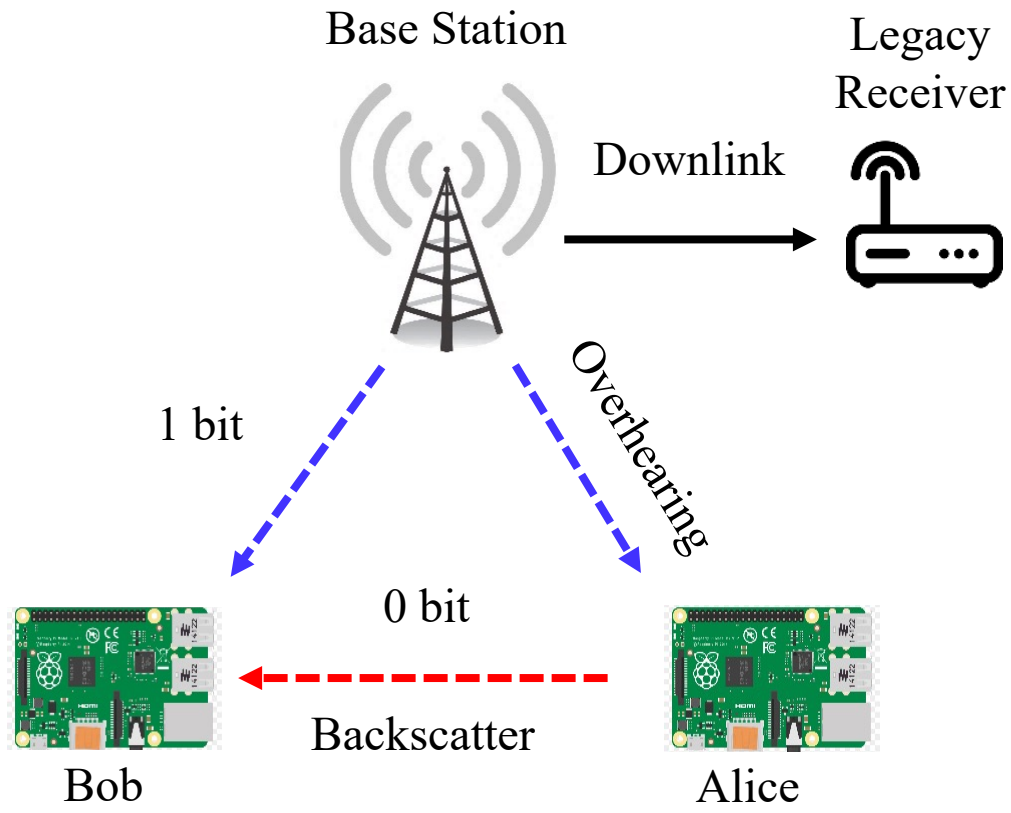
Common uses of backscattering systems

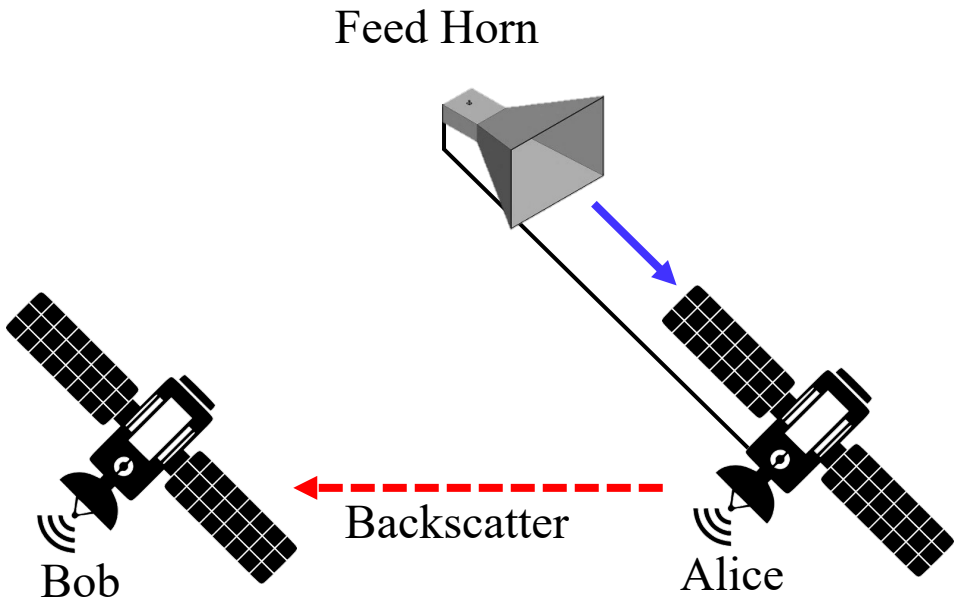
Low Power Devices in Smart Agriculture



‘0’ bit – reflect BA signals

‘1’ bit – absorb BA signals

Satellite Channels in Space Communication



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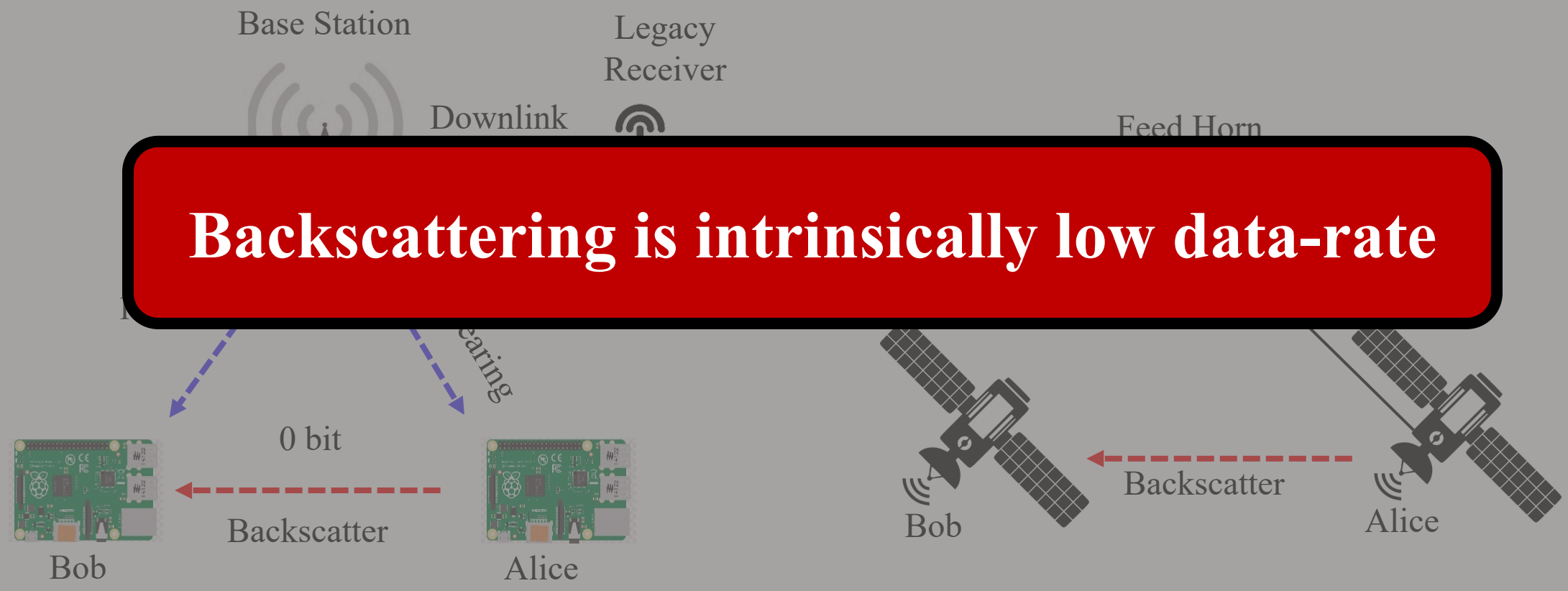


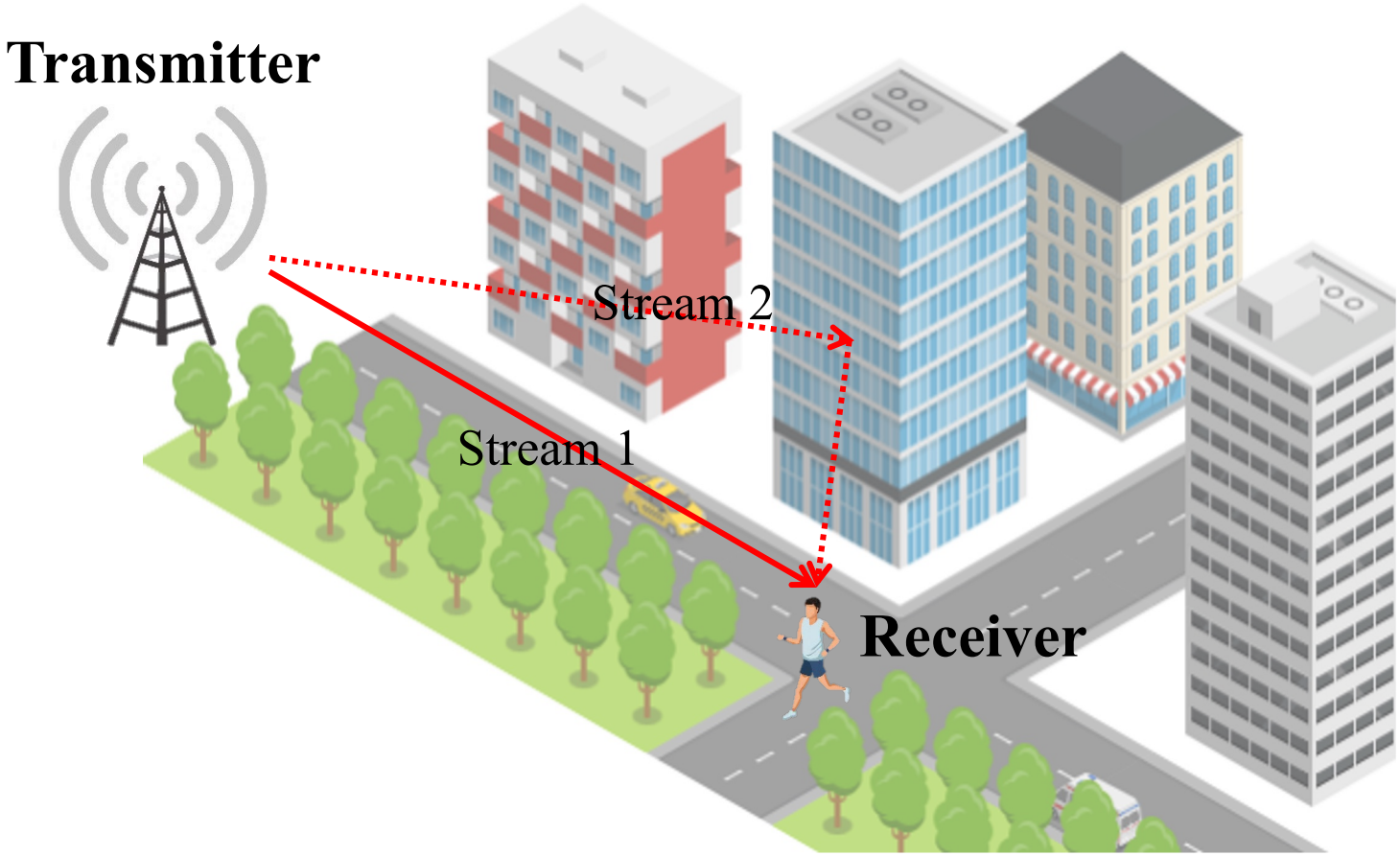
Backscattering is intrinsically low data-rate

‘0’ bit – reflect BA signals

‘1’ bit – absorb BA signals

Can we leverage a spatial multiplexing for backscattering systems?

Multiple-Input Multiple-Output (MIMO) exploits ***multipath*** propagation to ***multiply*** link capacity.



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In such cases, wireless channel is rank-deficient!

Our solution: spatial multiplexing with a smart surface!

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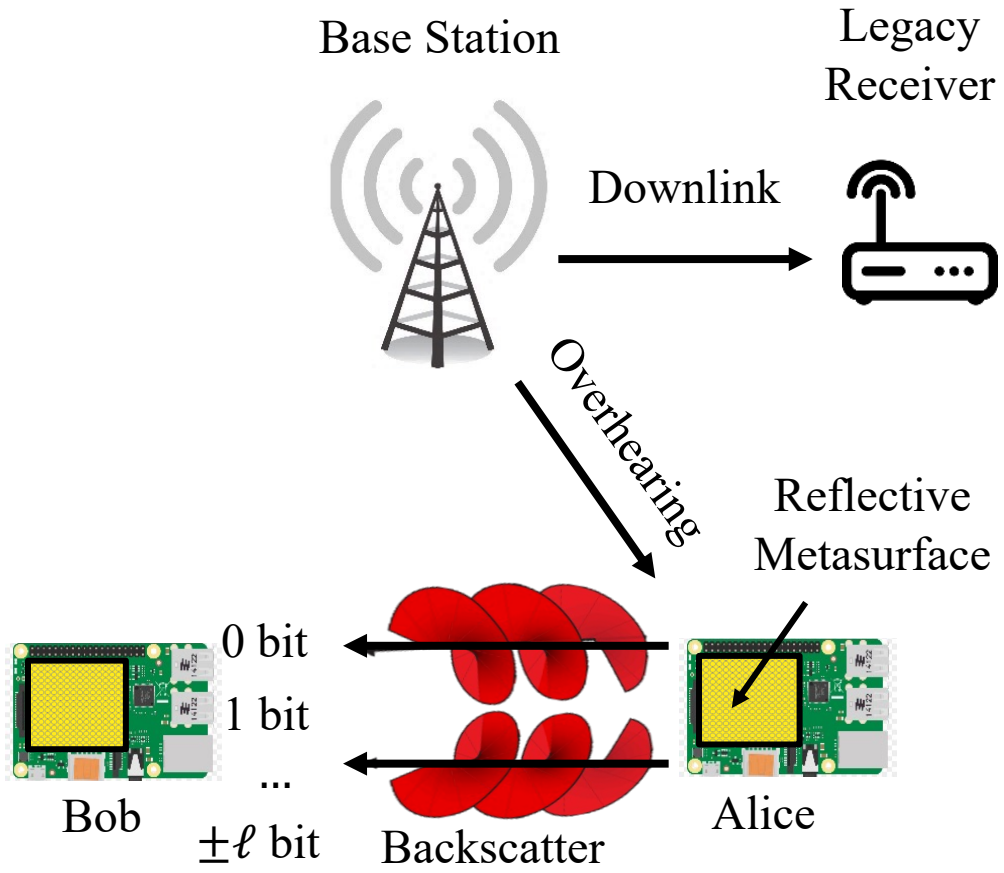

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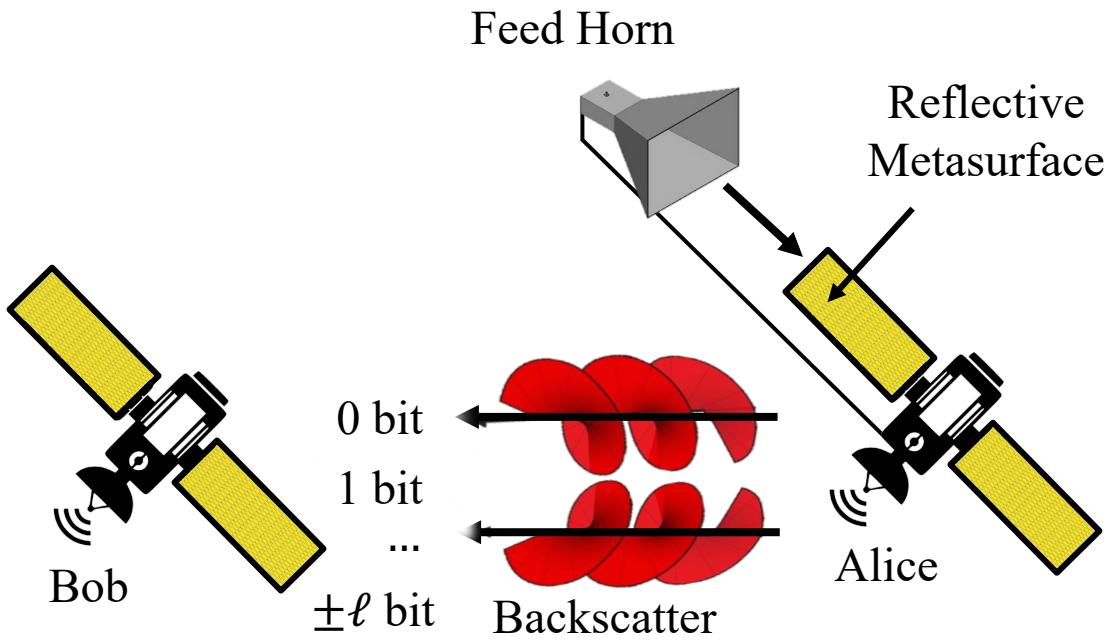

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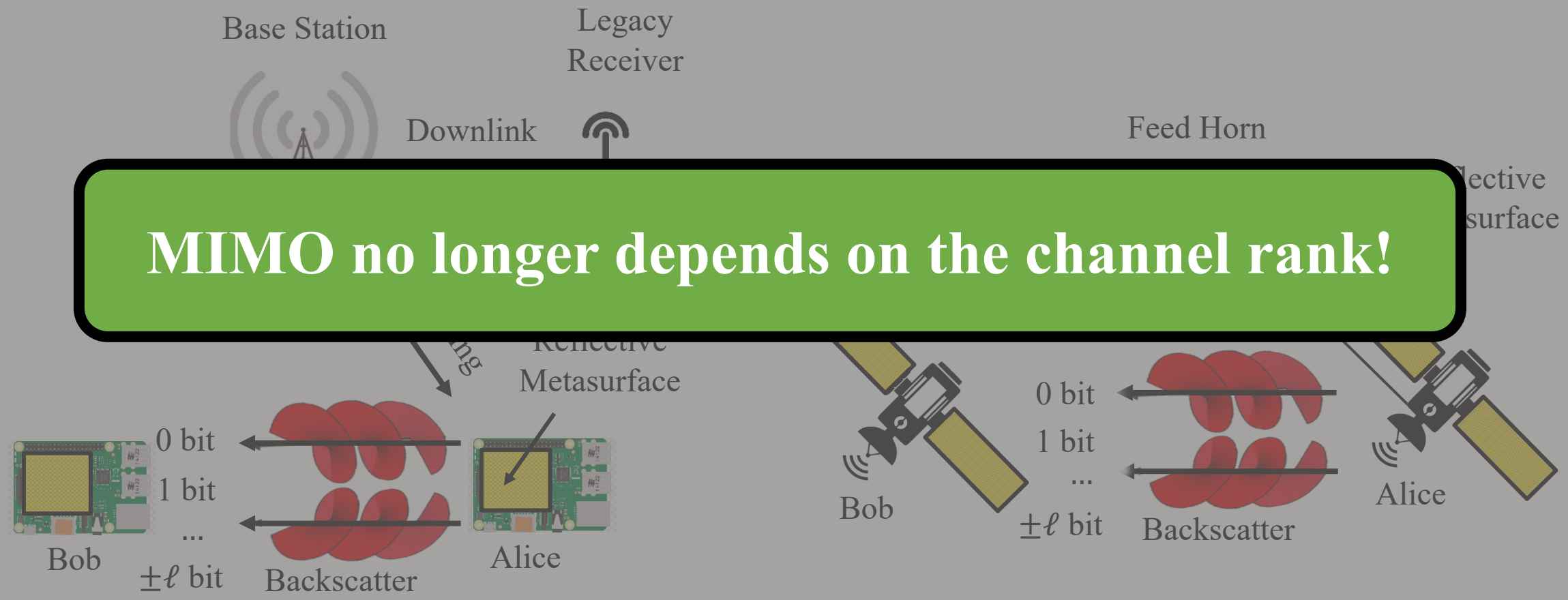


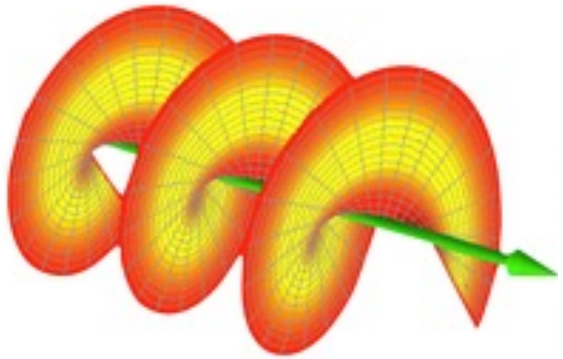
Orbital Angular Momentum (OAM)

Spin angular momentum (SAM): Polarization

SAM has three states:

S = −1 (right-hand circular pol.)
S = 0 (linear pol.)
S = 1 (left-hand circular pol.)

Orbital angular momentum (OAM): Spatial Distribution

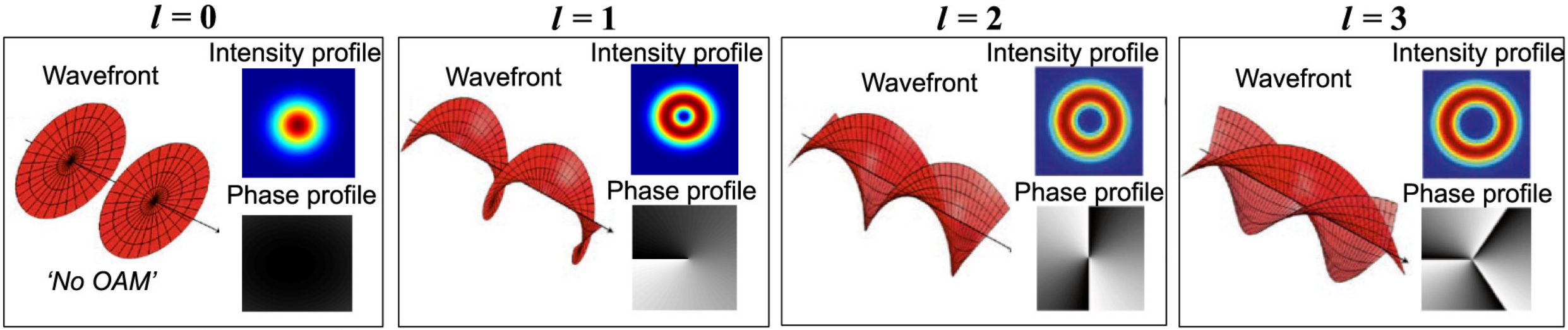


OAM has theoretically ***infinite*** states:

S determined by the topological charge of ℓ.

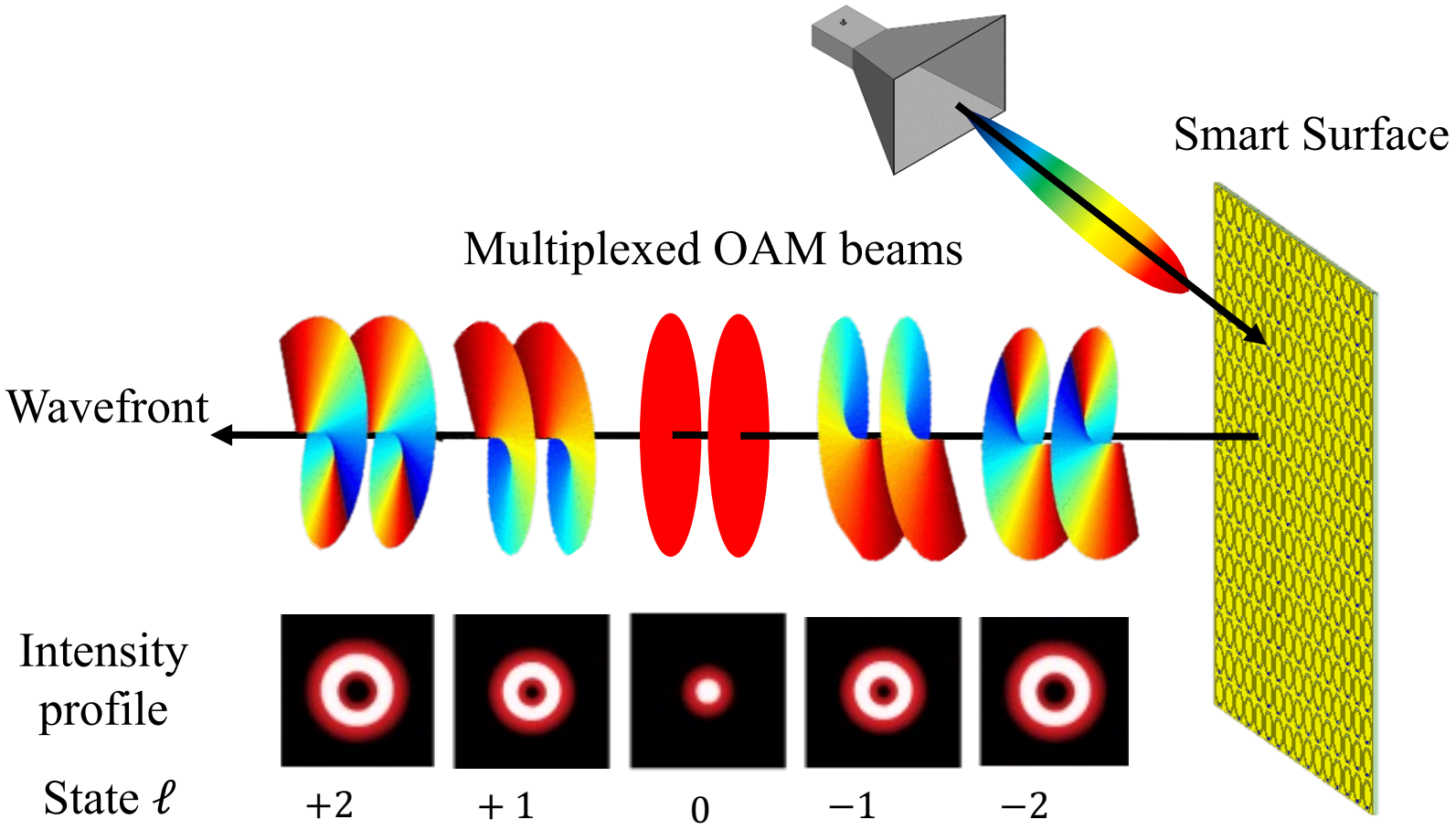
Orbital Angular Momentum (OAM)

OAM beam has state ℓ where the phase ***twists*** ℓ times over distance of one wavelength:



$$\varphi(r,\varphi) = \exp(i\ell\varphi) \text{ where } (\ell = \ldots -3, -2, -1, 0, +1, +2, +3 \ldots)$$

Orbital Angular Momentum (OAM)



Creating beams with different OAM states that are ***orthogonal*** to each other

→ Enabling MIMO spatial multiplexing

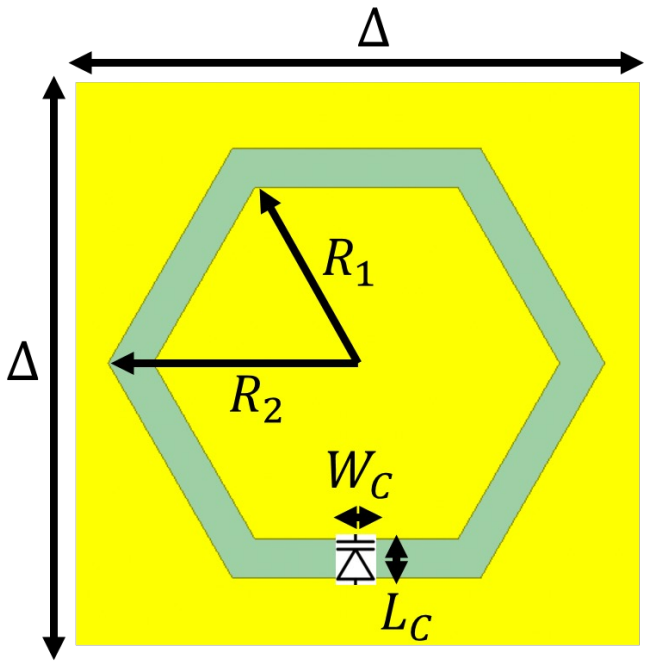
Metasurface Offers Unprecedented OAM Capabilities

	Antenna Type	Electronically reconfigurable	Low Loss	Beamforming Capability	Low power consumption	High steering resolution
Lee [1]	UCA	Fixed	✓	✗	✗	✗
Shi [2]	UCA	Discrete	✗	✗	✗	✗
Liu [3]	Metasurface	Discrete	✓	✓	✓	✗
Monolith	Metasurface	Continuous	✓	✓	✓	✓

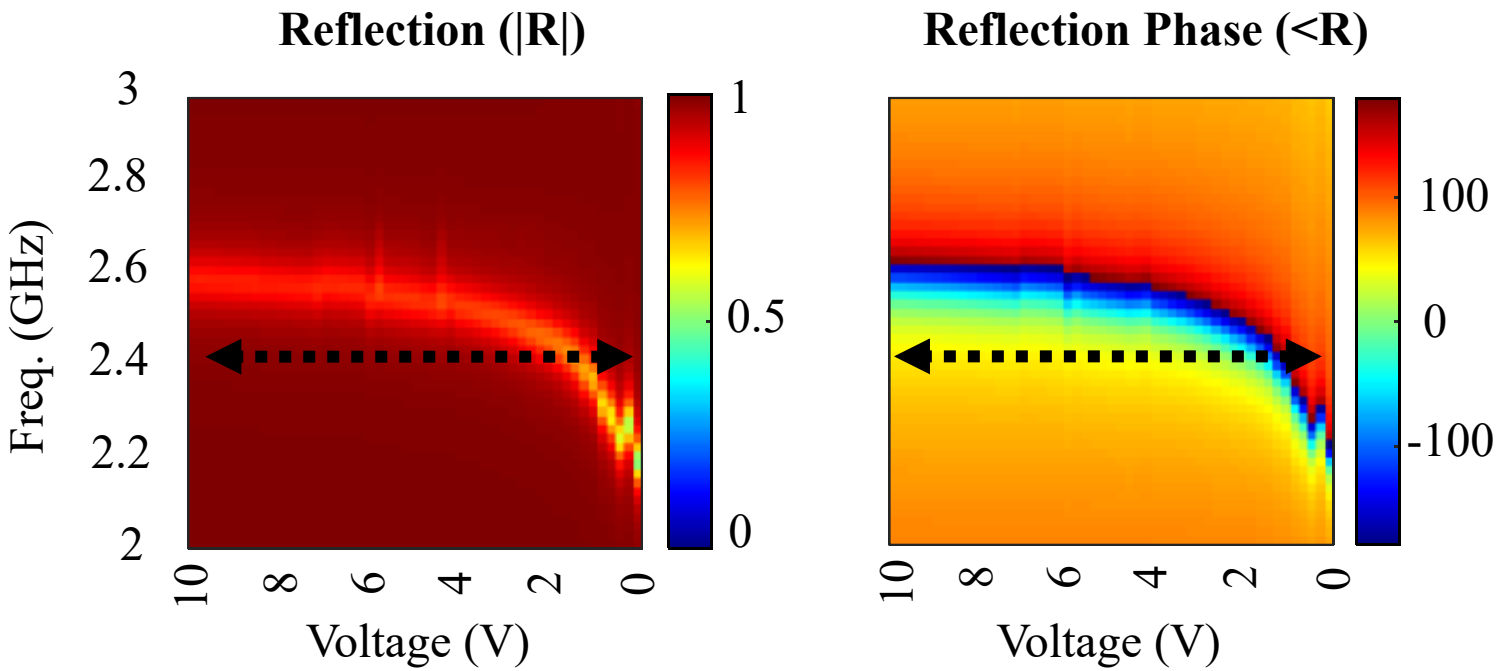
[1] Lee, Doohwan, et al. "An experimental demonstration of 28 GHz band wireless OAM-MIMO (orbital angular momentum multi-input and multi-output) multiplexing." *2018 IEEE 87th Vehicular Technology Conference*, 2018.
[2] Shi, Chengzhi, et al. "High-speed acoustic communication by multiplexing orbital angular momentum." *Proceedings of the National Academy of Sciences* 114.28 (2017): 7250-7253
[3] Liu, Baiyang, et al. "Generation of an orbital-angular-momentum-mode-reconfigurable beam by a broadband 1-bit electronically reconfigurable transmittarry." *Physical Review Applied* (2021).

How to generate OAM beams?

Reflective Meta-atom

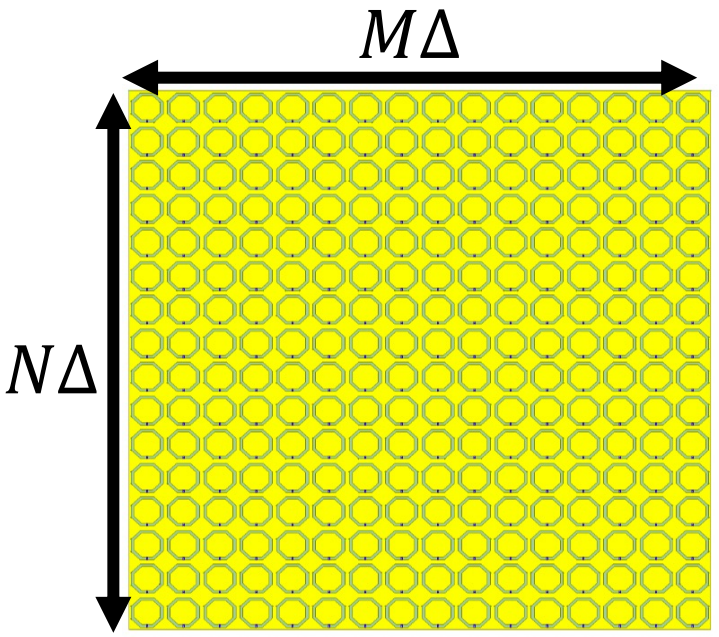


Reflection coefficient across voltage levels



How to generate OAM beams?

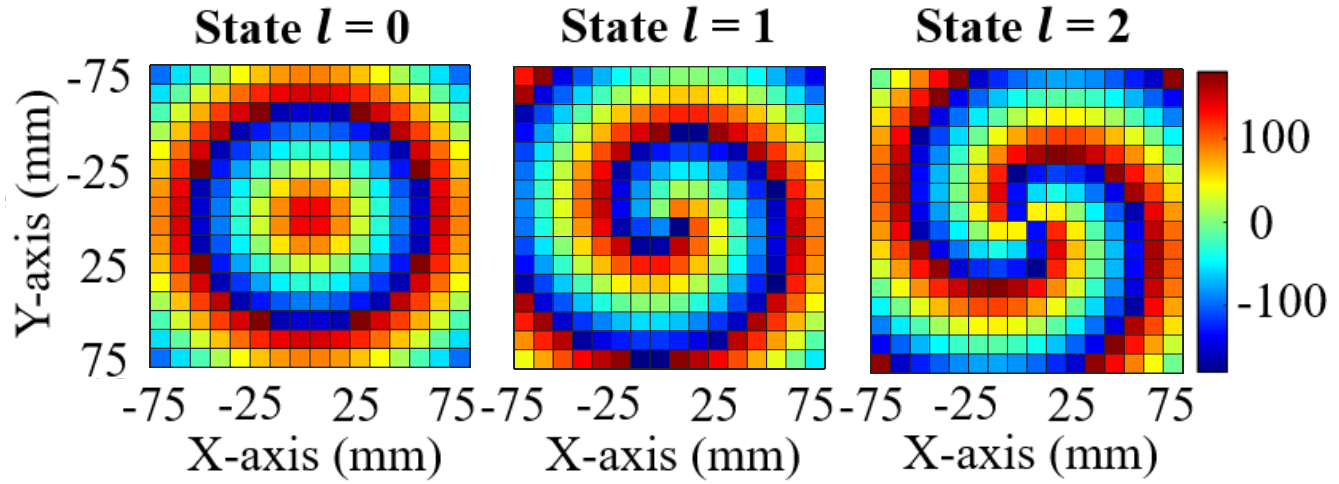
Reflective Metasurface



(1) Compute required phase shifts for an OAM state l

$$\varphi(x,y) = l \cdot \tan^{-1}\left(\frac{y}{x}\right) - 2\pi/\lambda \cdot r_{xy} \text{ where } r_{xy} = \sqrt{x^2 + y^2 + d^2}$$

Required Phase Distribution



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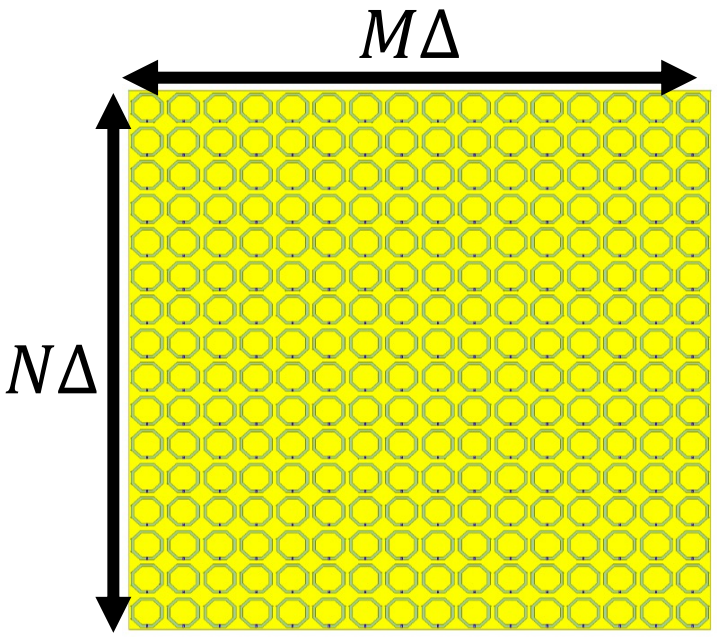
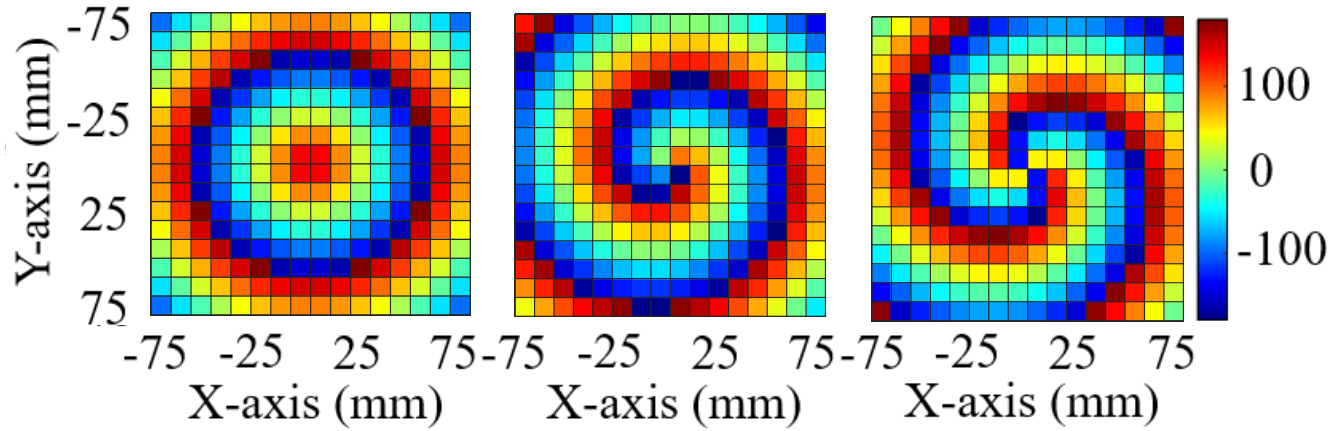


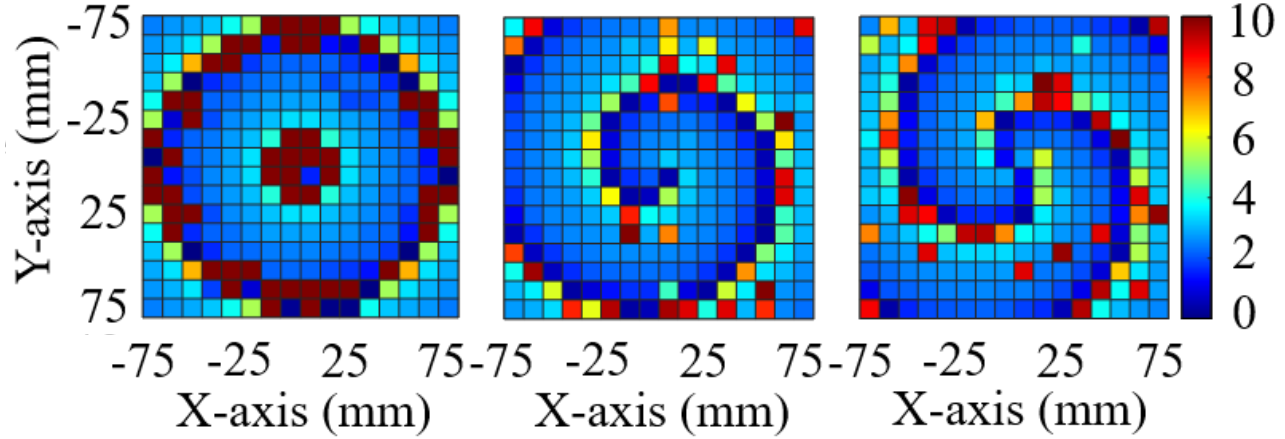
Required Phase Distribution



(2)

$$\Theta^* = argmin \sum_{x,y} (|F(V(x,y)) - \varphi(x,y)|)$$

Voltage Distribution



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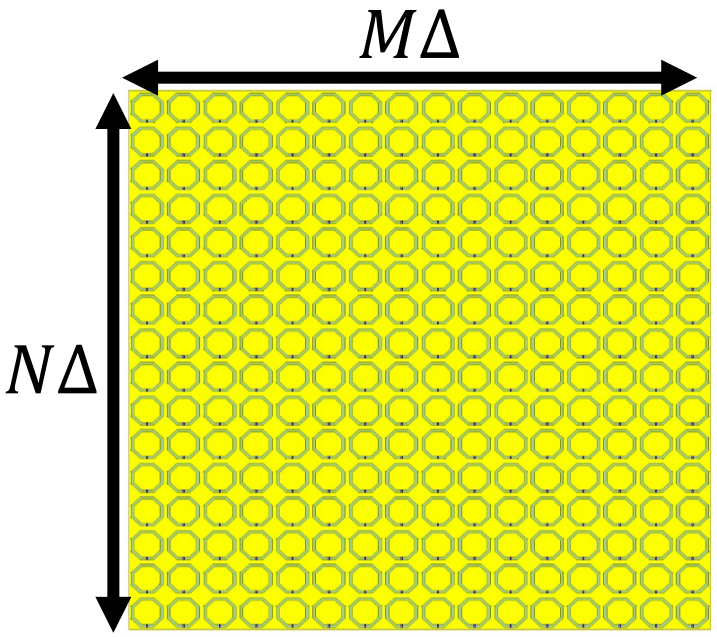

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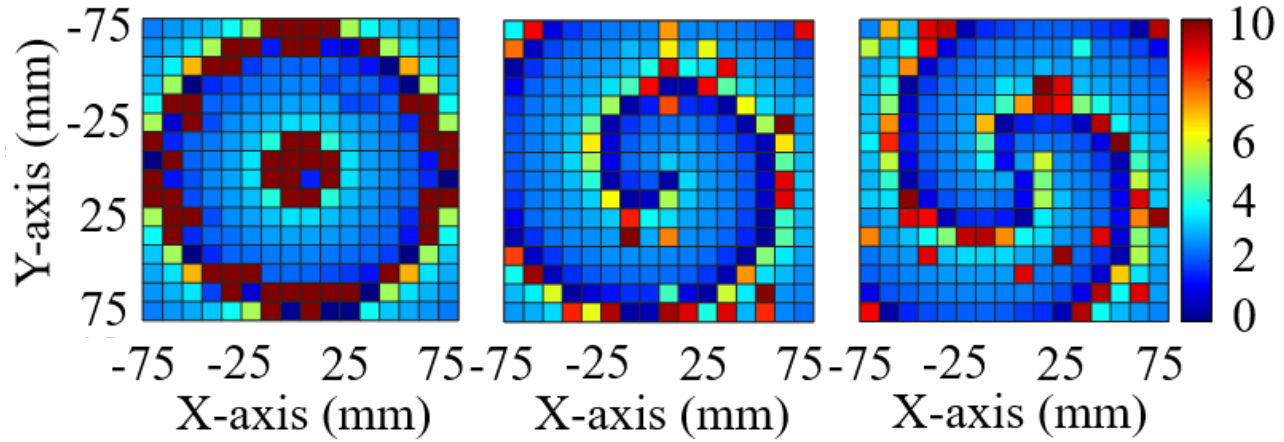
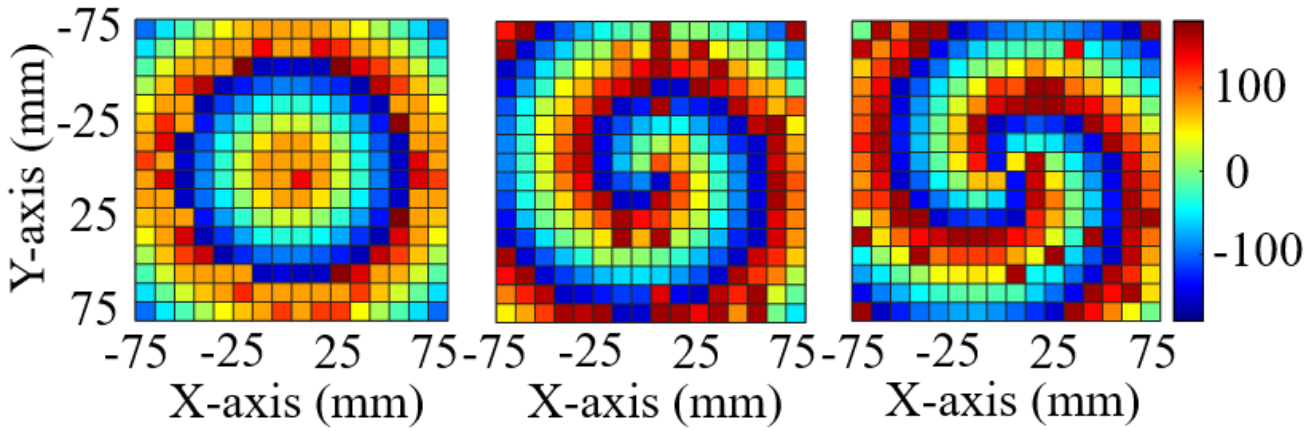
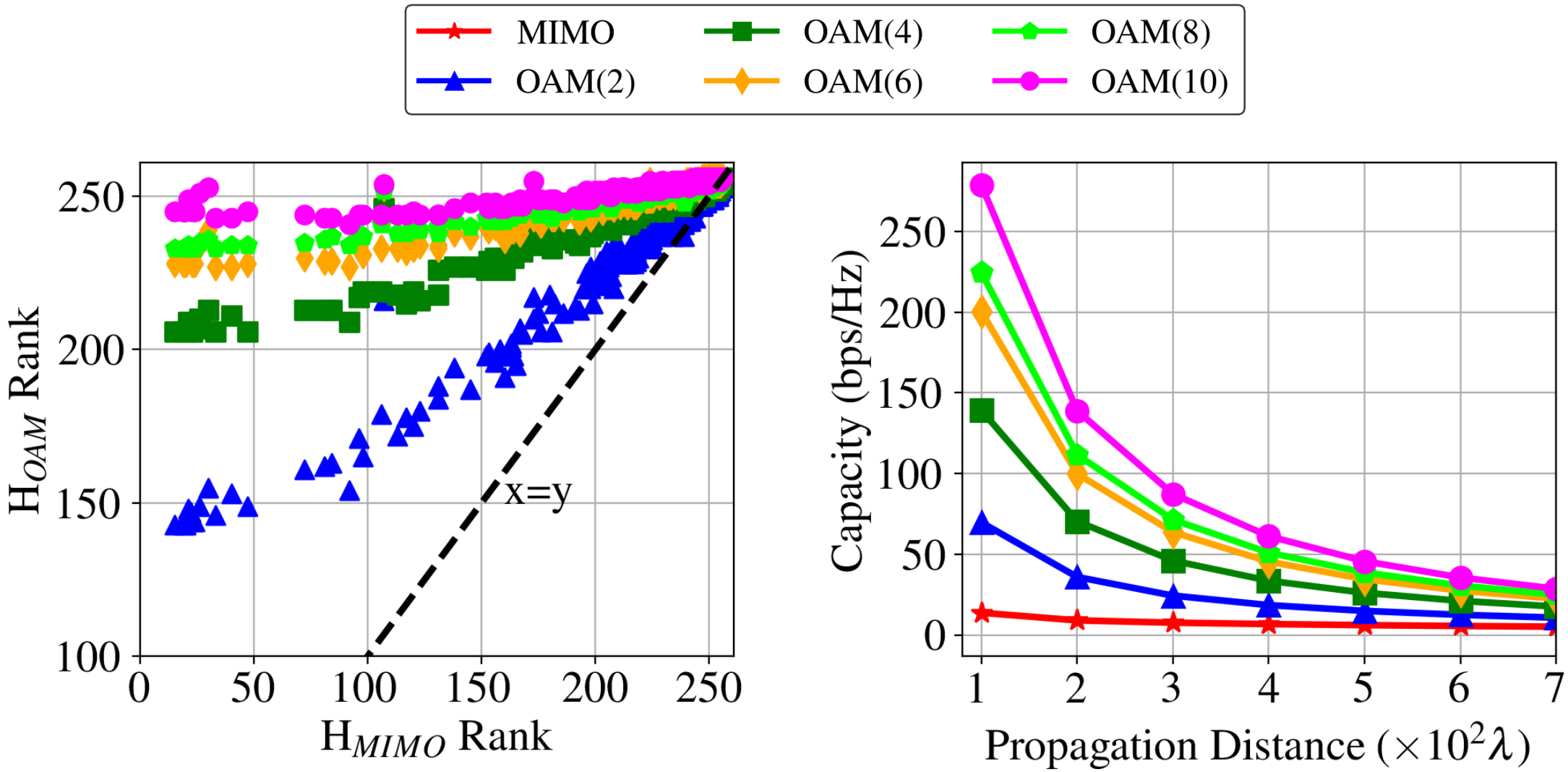


(3) Apply voltage distr. to generate beams

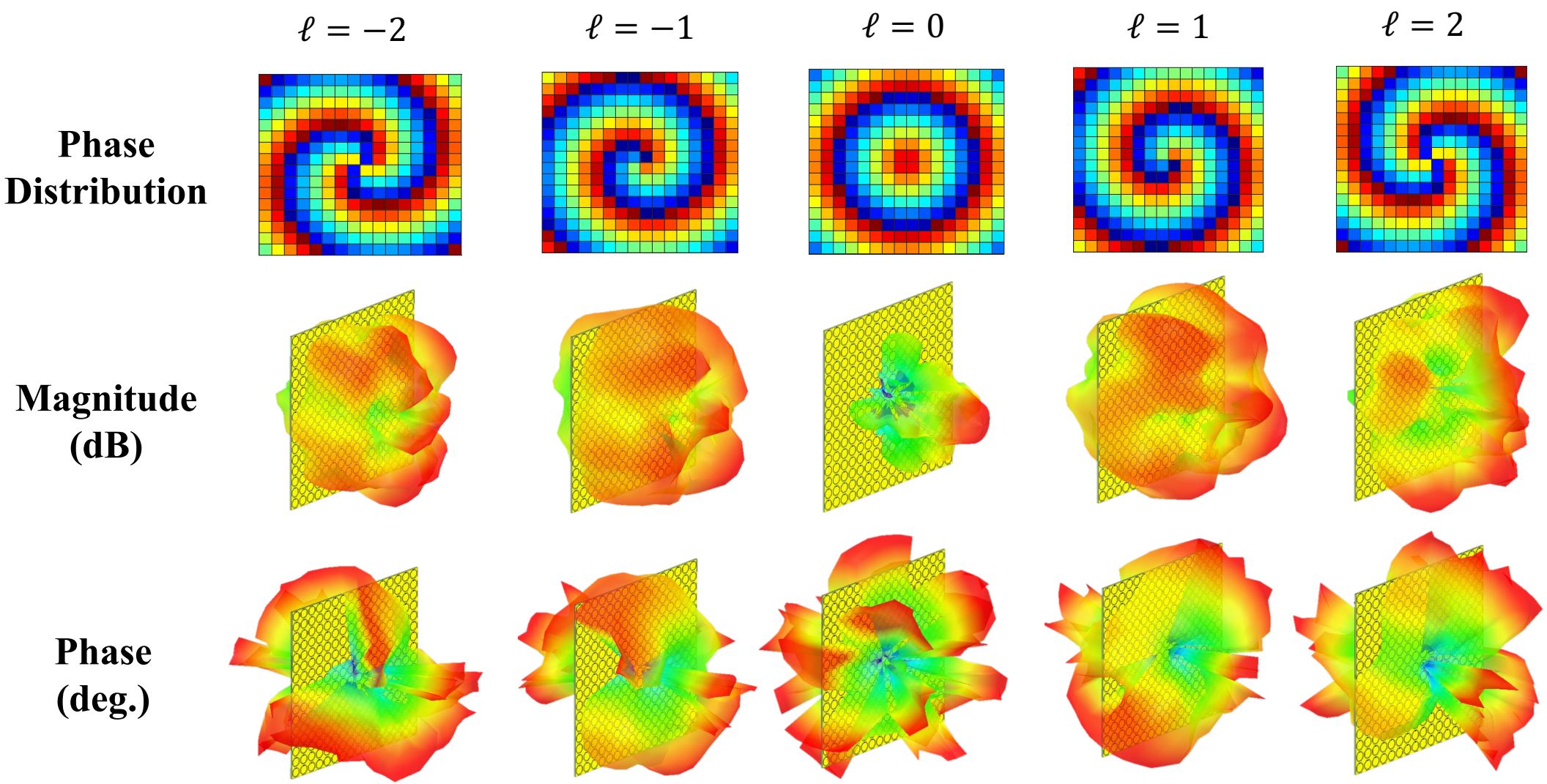
Acquired Phase Distribution



Channel capacity gain in free-space systems



Generated OAM Beams



Conclusions and Future Work

- **Monolith** for rank-deficient wireless environments
  - Expanding the applicability of MIMO in rank-deficient wireless environments.
  - Advantages of low power, high gain, and flexible capability of modulating EM waves
- Future Works
  - Beam divergence, beam distortion, beam steering.
  - Free-space optical communication (FSO) at extremely high frequency.

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