Radar Cross Section Characterization of a 222.5 GHz Reconfigurable Reflective Surface

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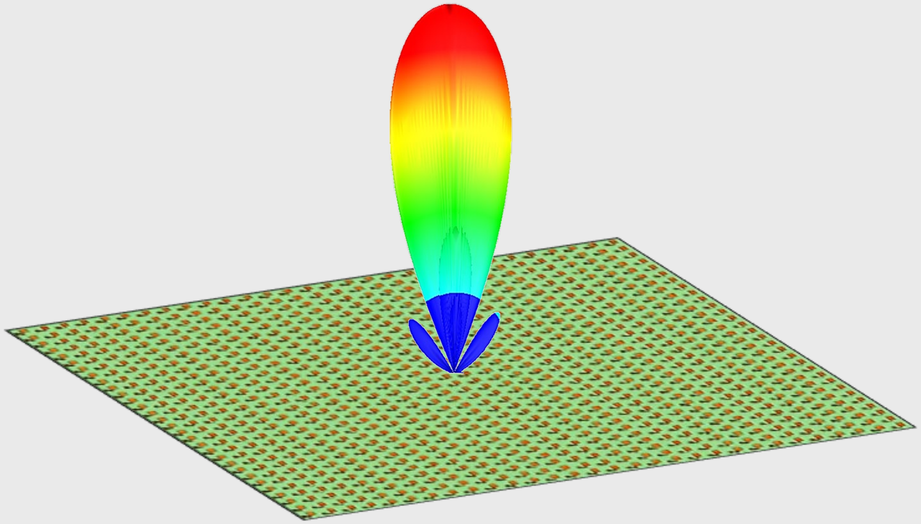
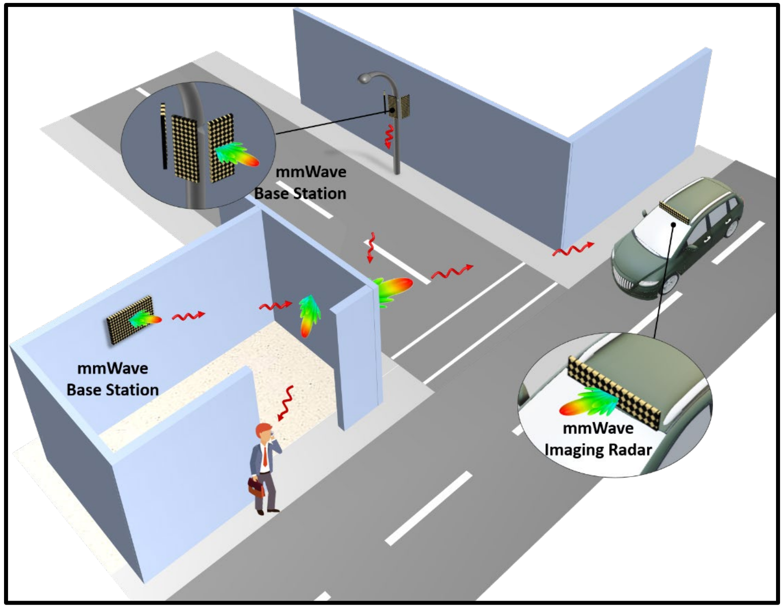


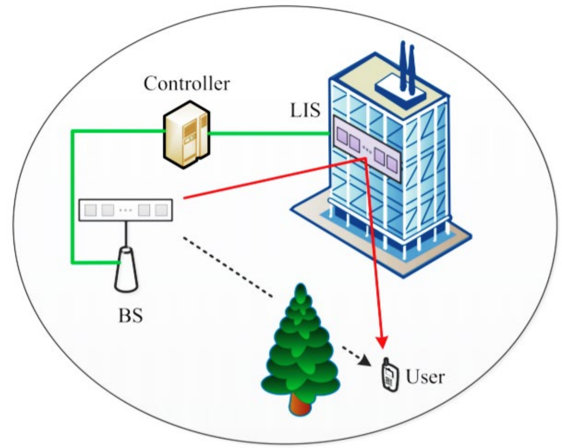
Why mmWave/THz Systems?

Wireless Communications



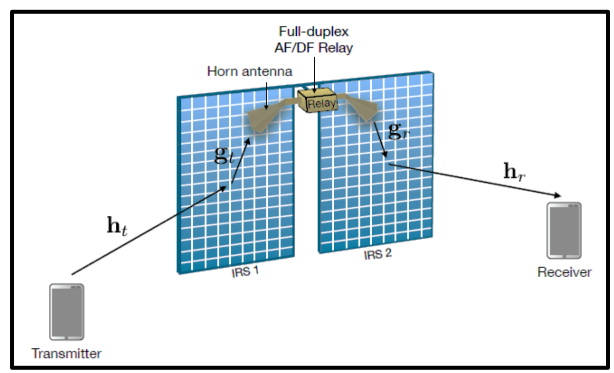
Point-to-point relays

- Improved Coverage.
- Easily embedded systems.
- Reduce the need for more base stations (5G, 6G..) ➔ reduced cost.
- Power efficiency.



Large intelligent Surfaces (LISs)

Y. Han, et.al., "Large Intelligent Surface-Assisted Wireless Communication Exploiting Statistical CSI," in *IEEE Transactions on Vehicular Technology*, 2019.

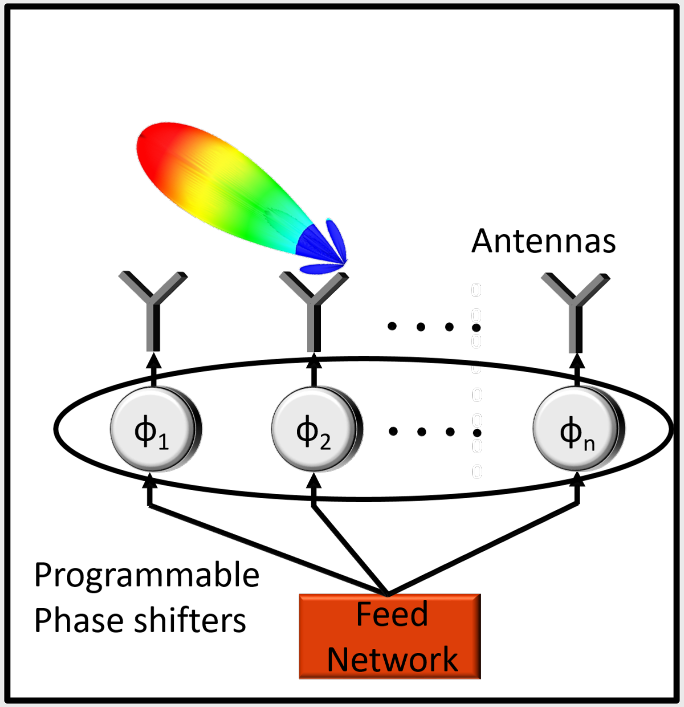


Relay aided intelligent reconfigurable surfaces (IRSs)

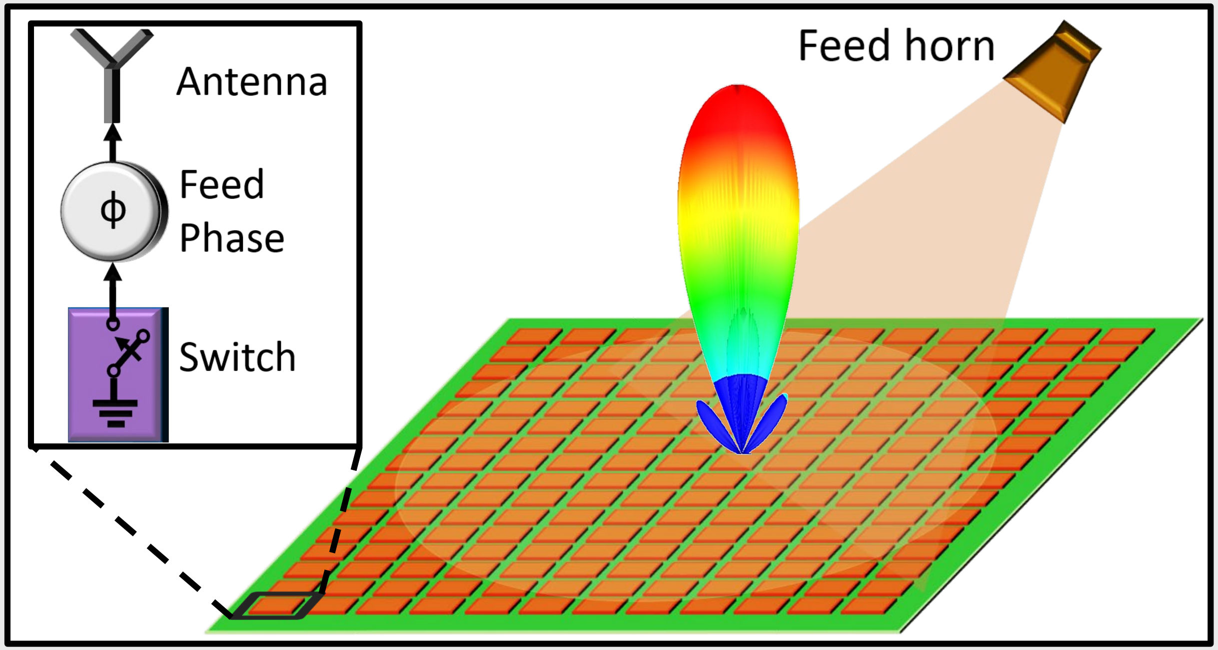
X. Ying, et.al., "Relay Aided Intelligent Reconfigurable Surfaces: Achieving the Potential Without So Many Antennas," arXiv:2006.06644v1.

Why Reflective Surfaces?

Phased Arrays:



Reflective Surfaces:



Challenges

- Large hardware footprint.
- High implementation cost.
- Lossy transmission lines at mmWave/THz frequencies
  ➔ Low efficiency.

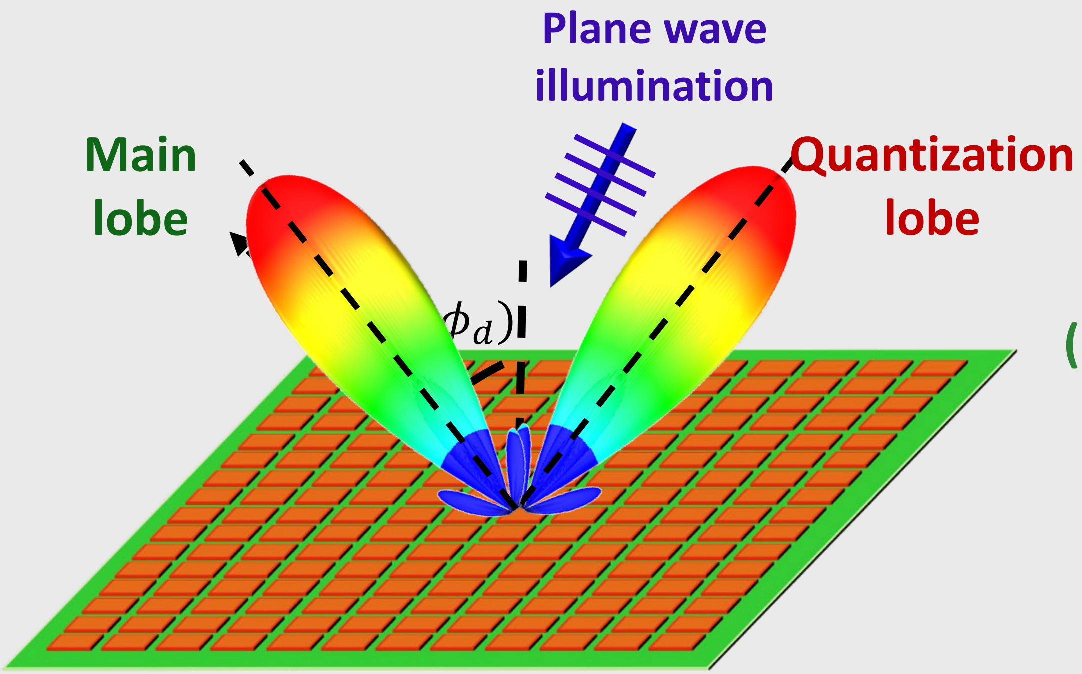
Advantages

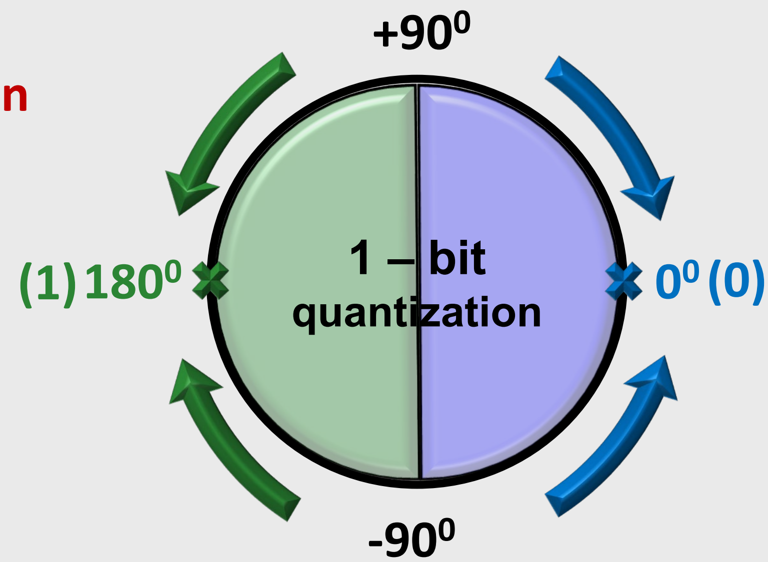
- Low profile and low weight.
- Relative ease of fabrication.
- Low implementation cost.
- Non-scalable losses.
- Compatible for high frequency designs.

Existing Switching Techniques:

- Graphene
- Vanadium-di-oxide
- HEMT

Quantization Lobe in 1-bit Reflective Surface Designs





$$\varphi_{mn}^{0} = -k_0(x_m sin\theta_d cos\phi_d + y_m sin\theta_d sin\phi_d)$$

$$\varphi_{mn}^{illum} = k_0(x_m sin\theta_i cos\phi_i + y_m sin\theta_i sin\phi_i)$$

$$\varphi_{mn} = \varphi_{mn}^{0} - \varphi_{mn}^{illum}$$

Quantization lobe results from:

- **Periodicity of the phase rounding quantization error.**
- **Lower # of bits → higher error.**

Mitigating Quantization Lobes

<u>Straight forward solution</u>:

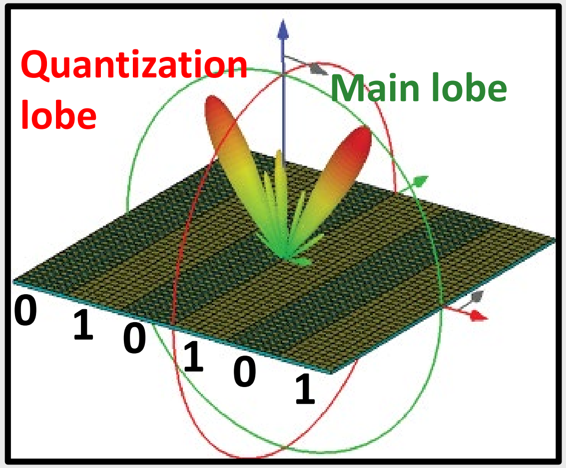
Use more bits!

E.g. 2 –bit design ➔ Quantization lobe level greatly reduced.

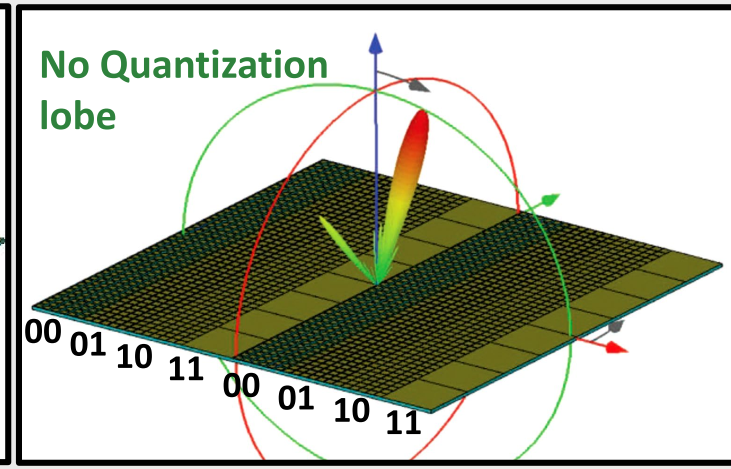
<u>Challenges</u>

- **Bulky feed and biasing circuit.**
- **More RF devices/switches.**

1 –bit design



2 –bit design



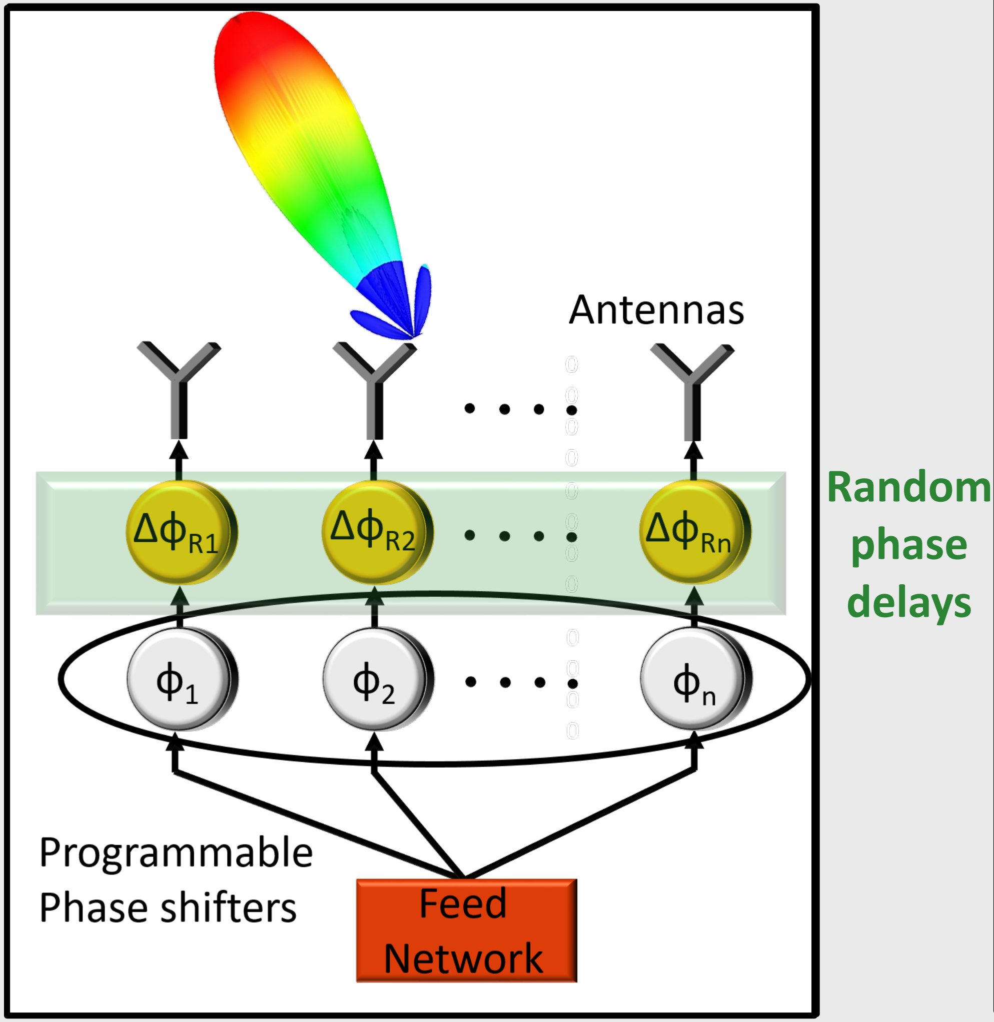
T. J. Cui, et.al., "Coding Metamaterials, Digital Metamaterials, and Programmable Metamaterials." in *Light: Science and Applications, 2014.*

So what do we need?

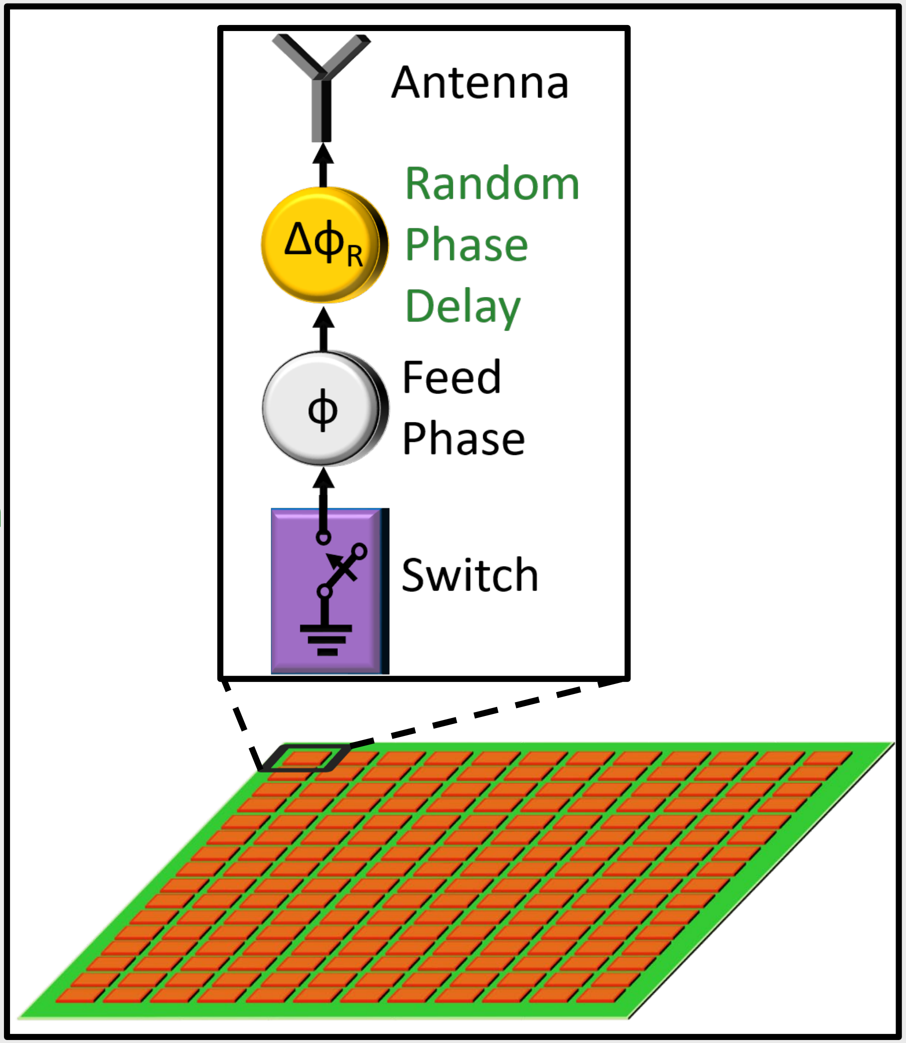
A technique to suppress quantization lobes using 1-bit coding

Random Phasing Technique to Suppress Quantization Lobes

Technique first introduced in phased arrays



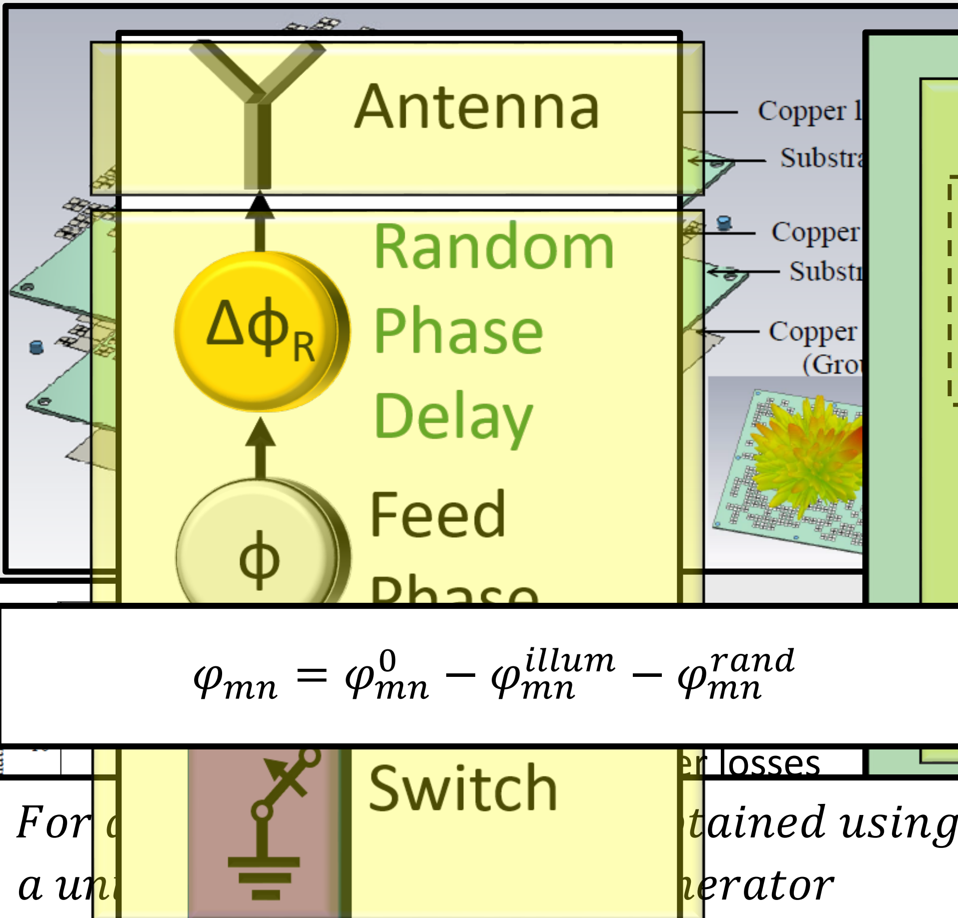
Implementation in Reflective Surfaces



Existing Designs vs Proposed Design

Recent Developments / Implementation of Proposed Design

Unit cell @ 226 GHz

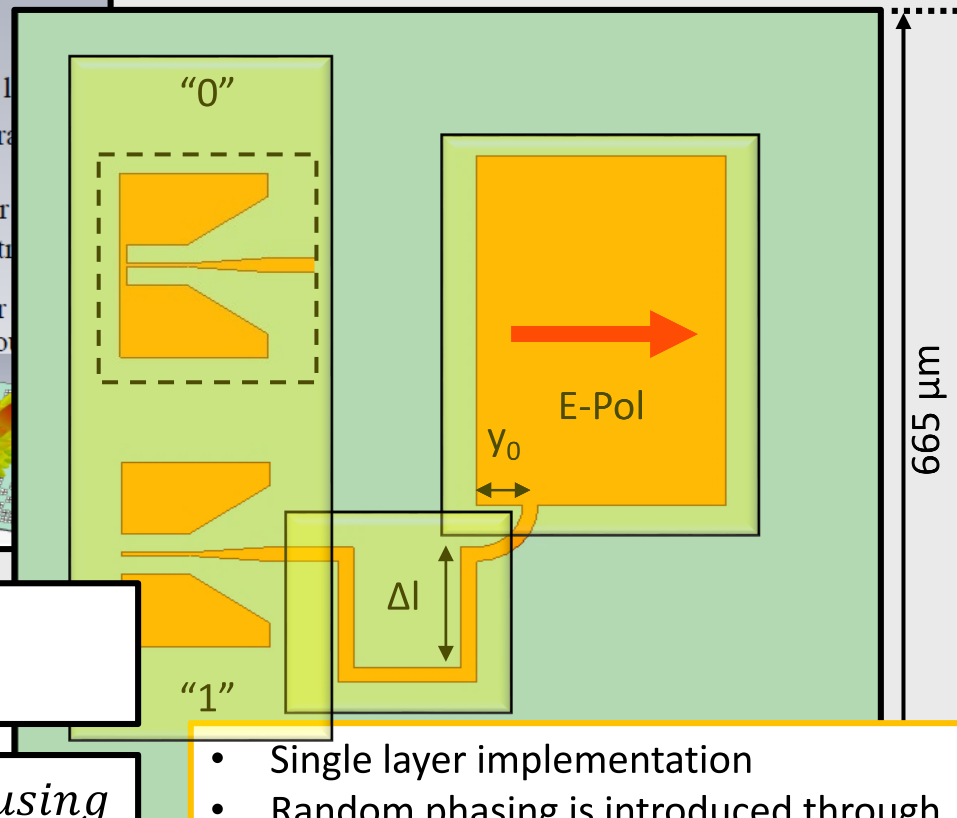


$$\varphi_{mn} = \varphi_{mn}^{0} - \varphi_{mn}^{illum} - \varphi_{mn}^{rand}$$

...er losses

For ... tained using a uni... nerator

$$\phi_{rand} = rand(1, N) \cdot \pi$$

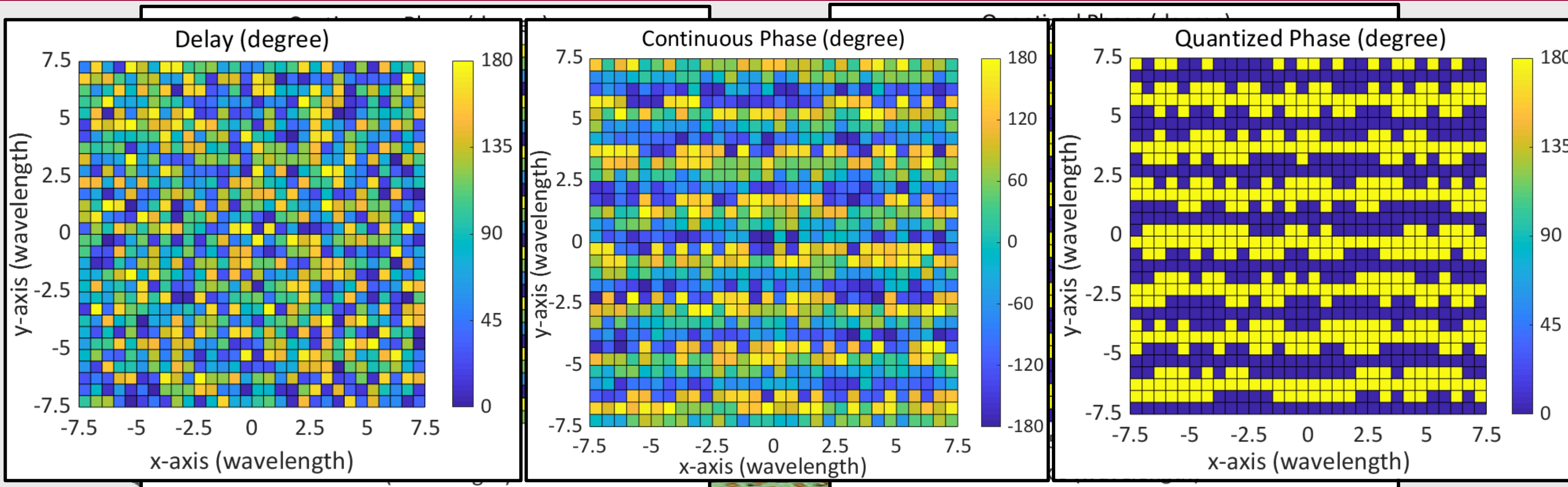


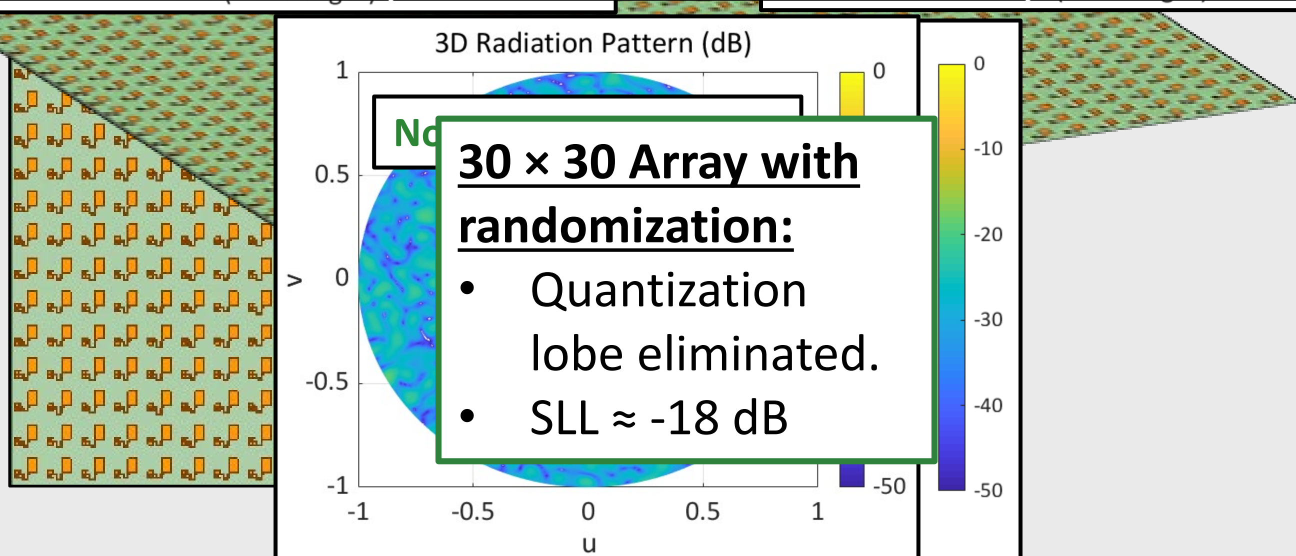
- Single layer implementation
- Random phasing is introduced through varying lengths of delay lines (Δl).
- $180^0 \pm 10^0$ phase shift achieved between the states '0' and '1'.

J. Yin, et.al., "Single-Beam 1-Bit Reflective Metasurface Using Pre-Phased Unit Cells for Normally Incident Plane Waves," in *IEEE Transactions on Antennas and Propagation*, 2020

Effect of Introducing Random Phasing

$$\varphi_{mn} = \varphi^0_{mn} - \varphi^{illum}_{mn} - \varphi^{rand}_{mn}$$ ➔0

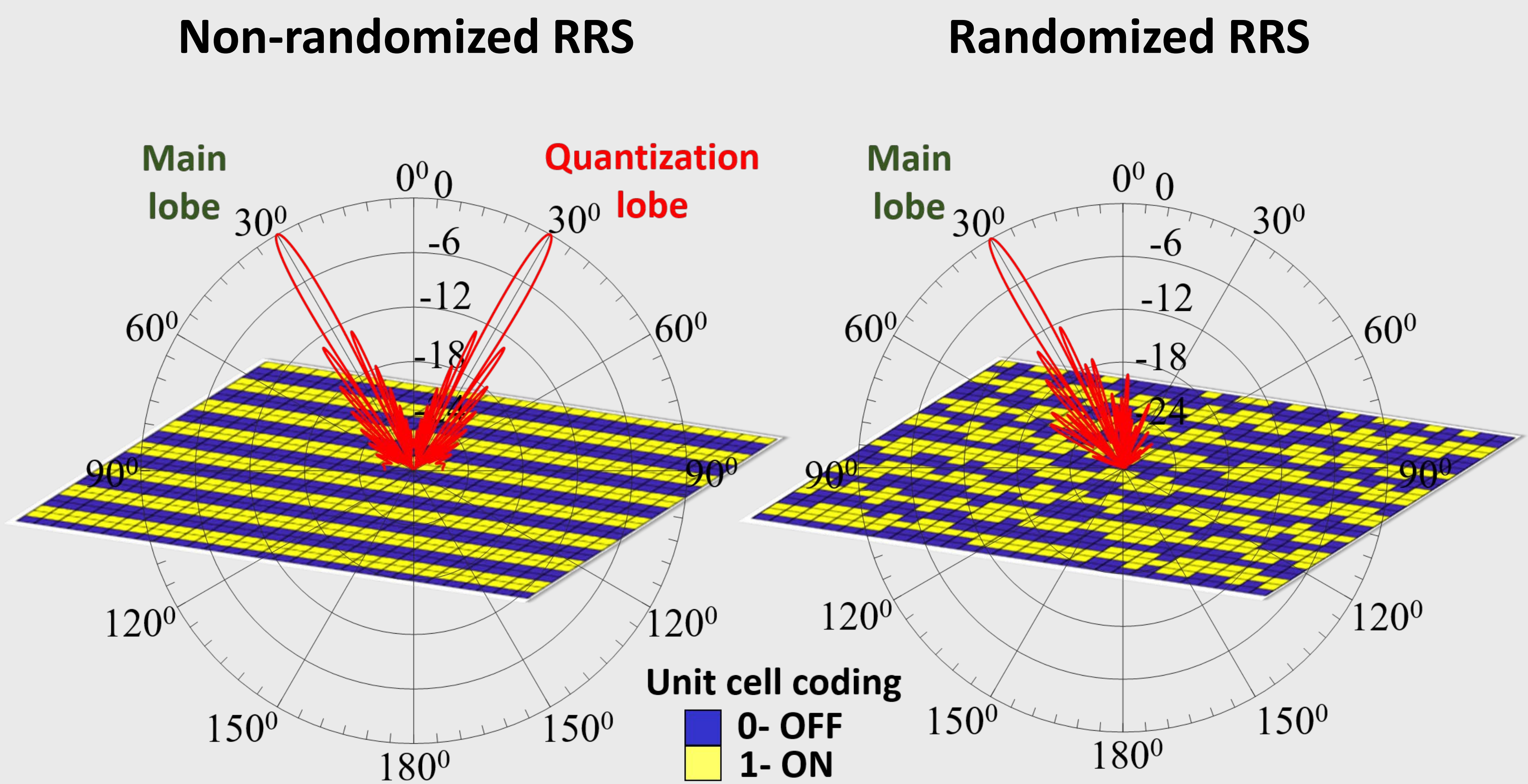




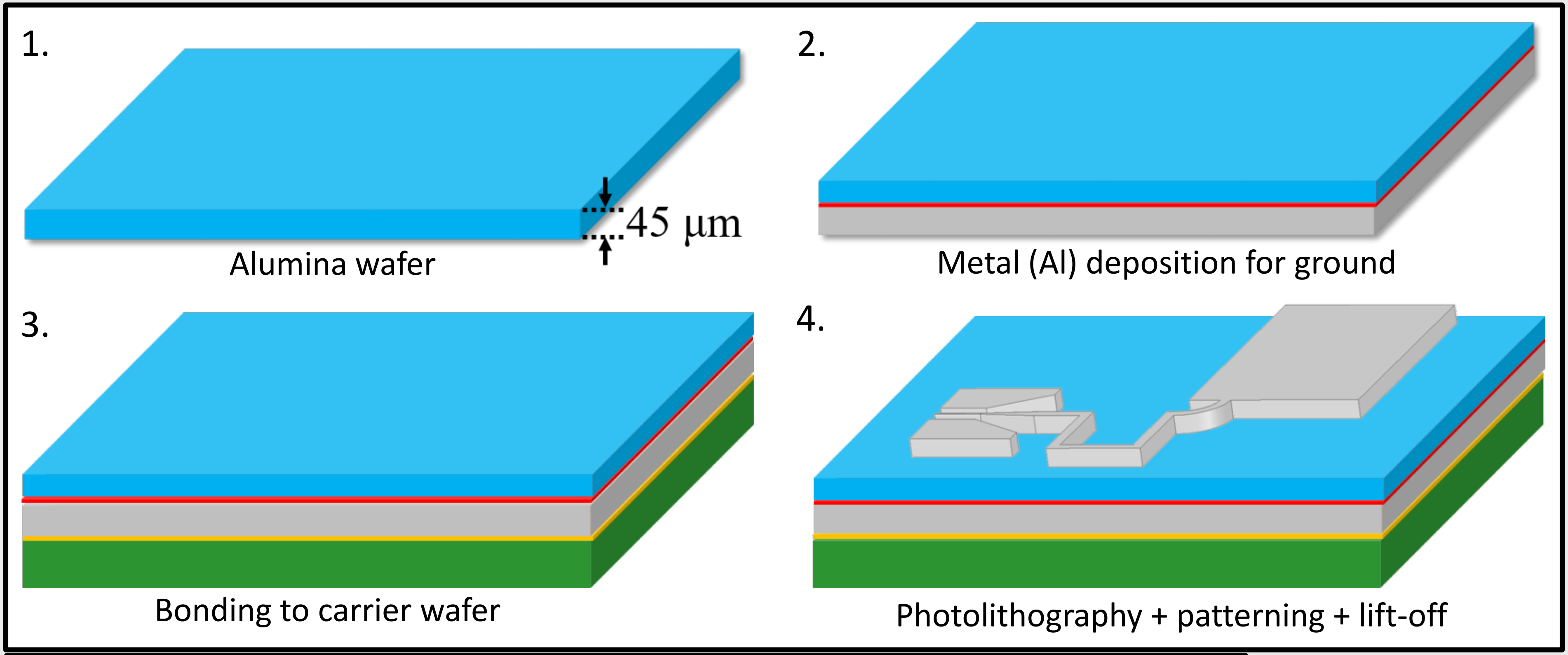
30 × 30 Array with randomization:

- Quantization lobe eliminated.
- SLL ≈ -18 dB

Non-Randomized vs. Randomized RRS

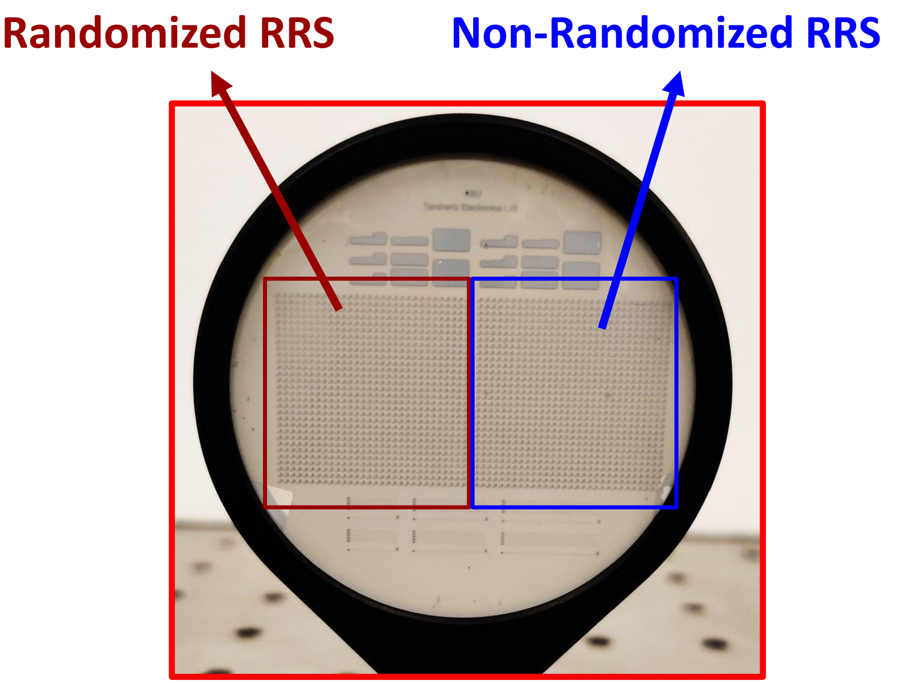


Fabrication Technique



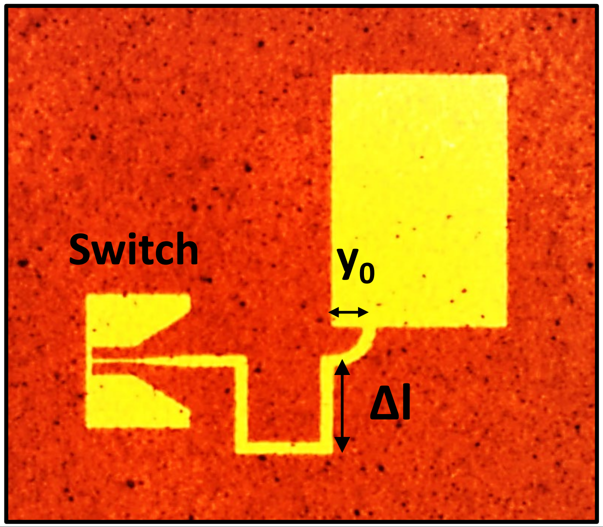
- Alumina ribbon ceramic substrate from Corning Inc. ($\epsilon_r = 10$, $tan\delta = 10^{-3}$)
- Aluminum (ground + patch)
- Bonding glue
- Titanium
- Carrier wafer (500 µm quartz)

Fabricated Reflective Surfaces



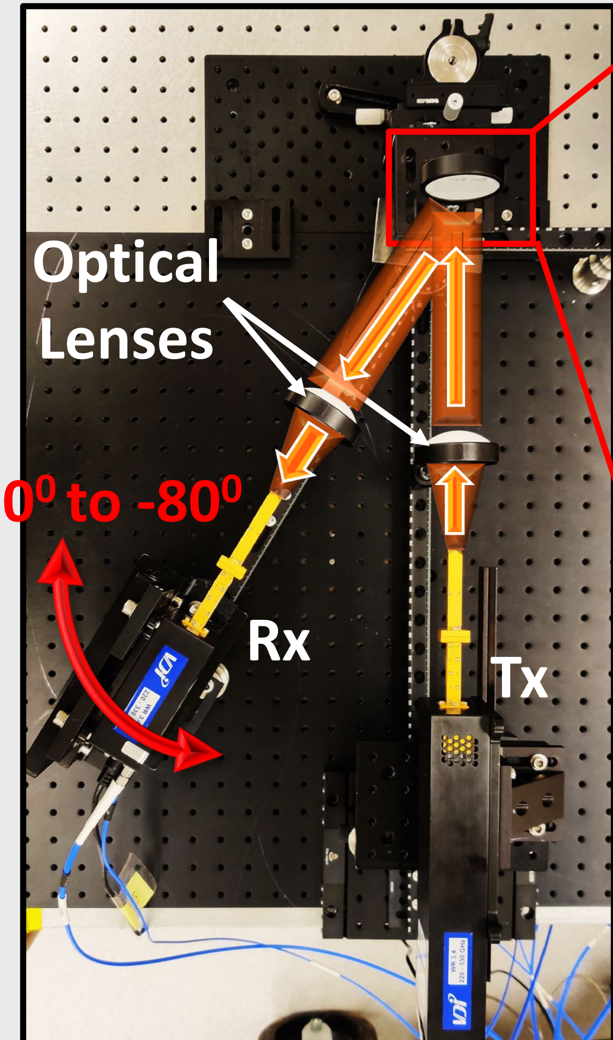
Fabricated prototype of 30 × 30 - 2D reflective surfaces on an alumina wafer

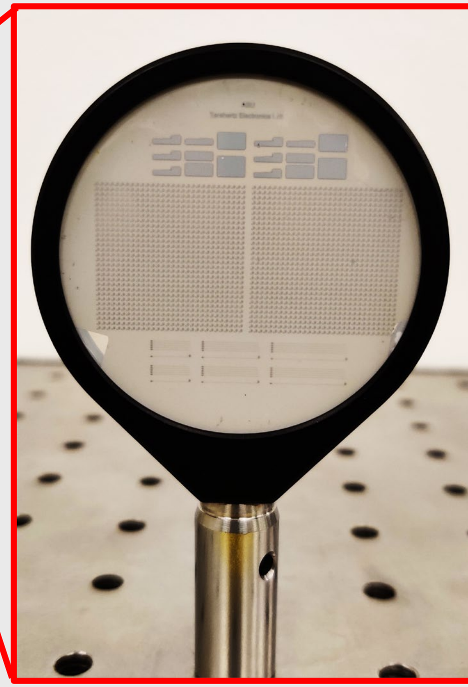
High-mag image of individual unit cell

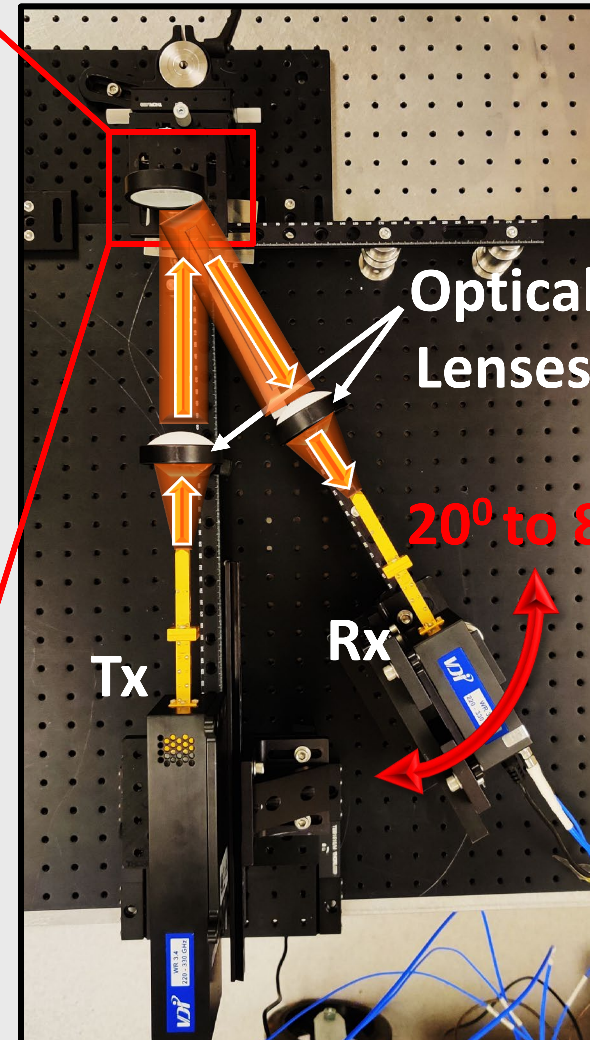


B. G. Kashyap, P. C. Theofanopoulos, Y. Cui and G. C. Trichopoulos, "Mitigating Quantization Lobes in mmWave Low-Bit Reconfigurable Reflective Surfaces," in IEEE Open Journal of Antennas and Propagation, 2020.

Quasi-Optical Measurement Setup for RCS Characterization



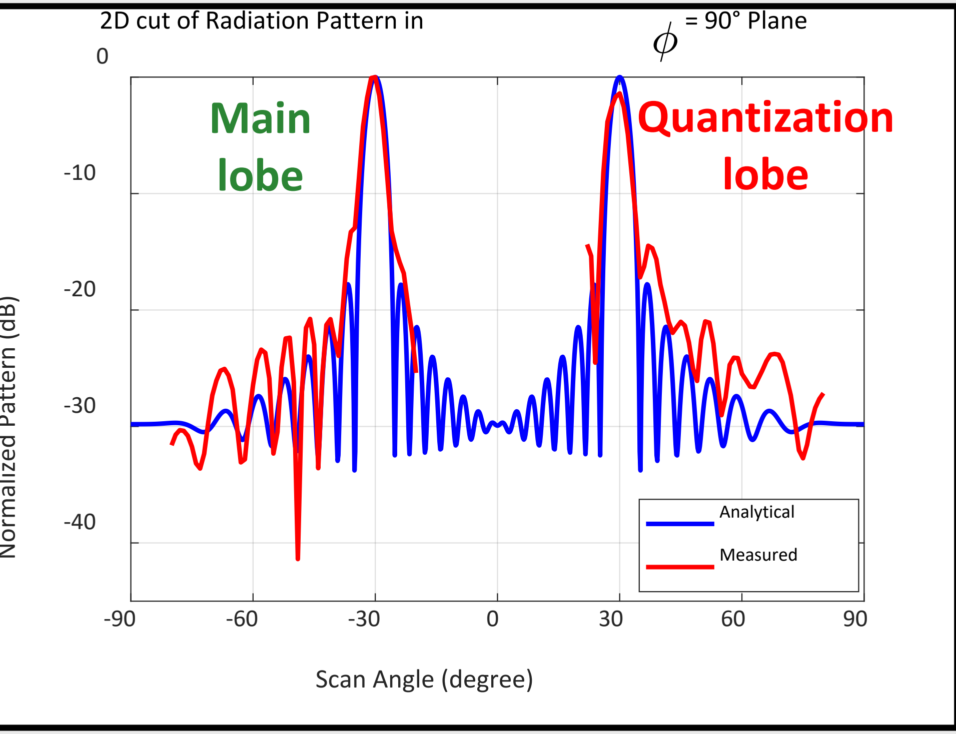




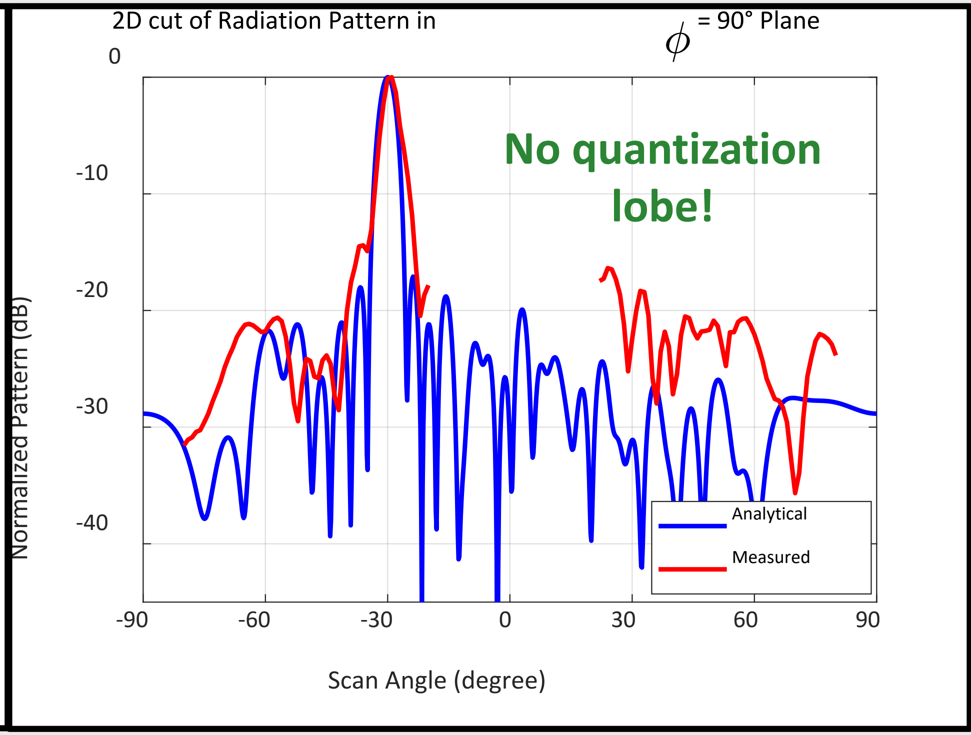
Prototype of the designed reflective surfaces

Measurement Results

Non-Randomized Array

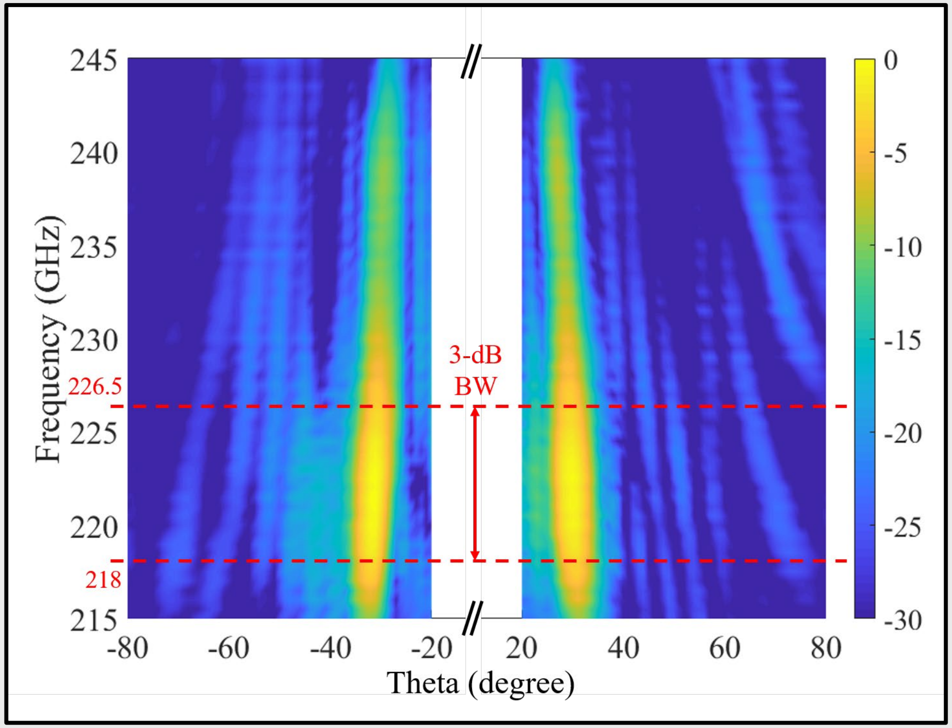


Randomized Array

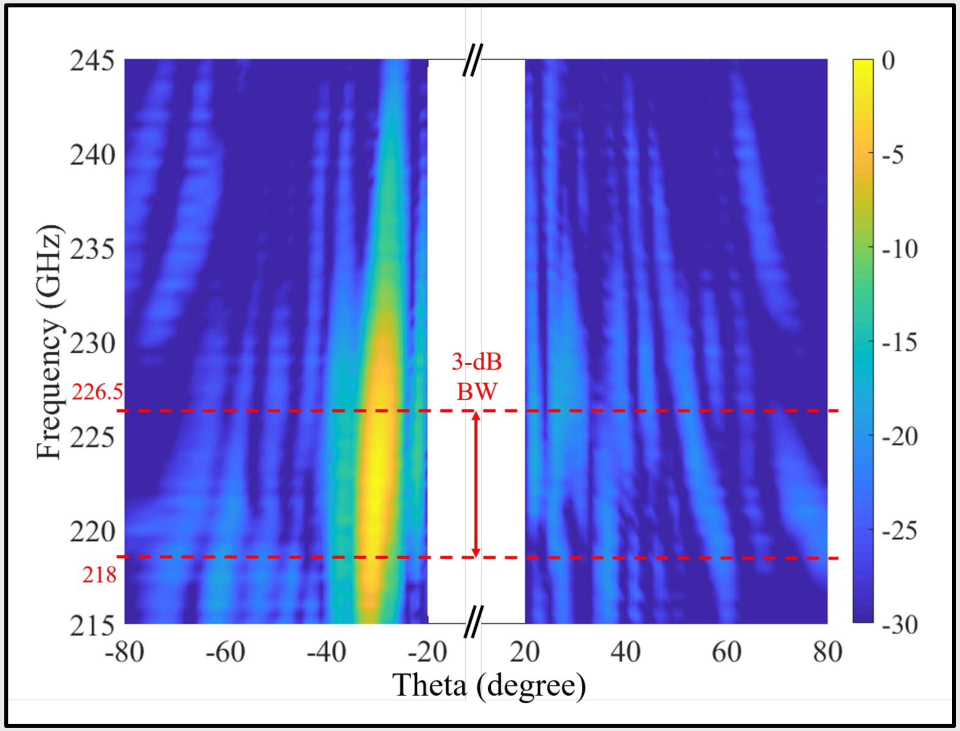


Measurement Results

Non-Randomized Array

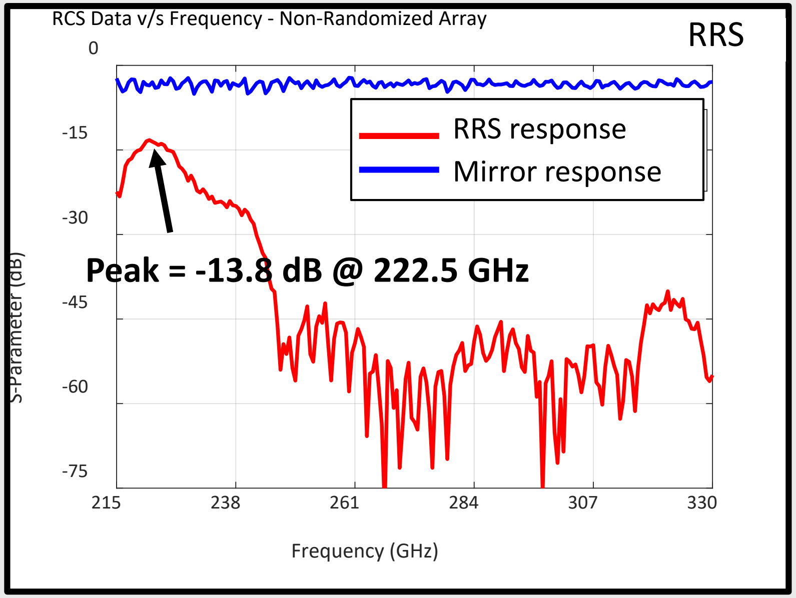


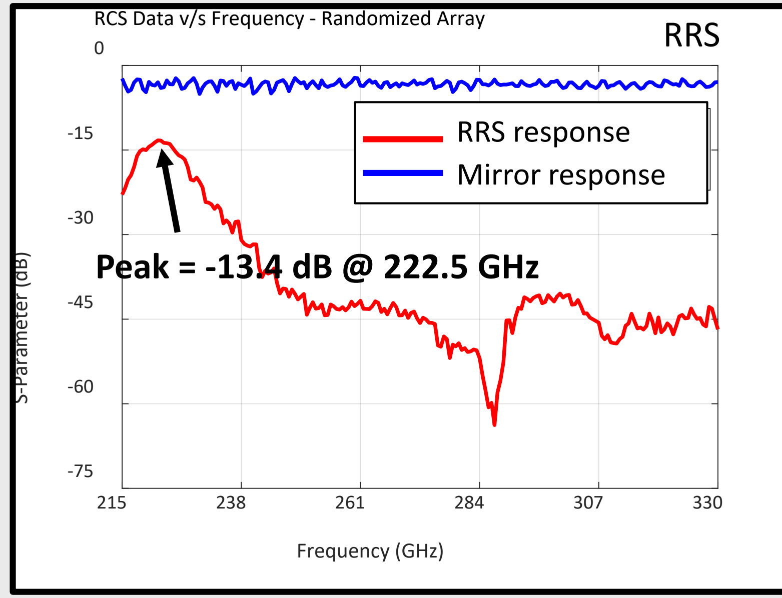
Randomized Array



3dB BW = 8.5 GHz ➔ Fractional BW of 3.8%

Efficiency of the RRS





Reflective surface efficiency (η) ≈ 30 %

Inherent System Losse

Source of Loss	Magnitude of Loss
Alignment + system imperfections	-3.90 dB
Quantization Loss	-3.01 dB
Aperture Loss	-1.25 dB
Total loss ≈	**-8.16 dB**

designed RRS

Source of Loss	Magnitude of Loss
Surface wave Loss	-1.80 dB
Dielectric Loss	-0.17 dB
Conductor Loss	-3.37 dB
Total loss ≈	**-5.34 dB**

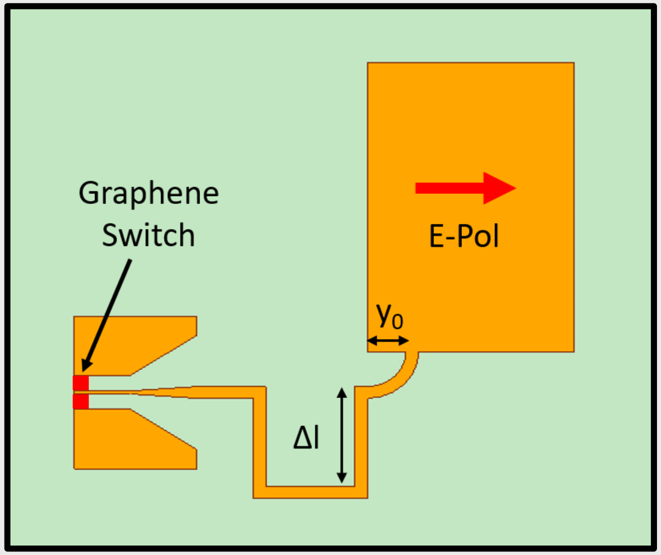
Conclusions and Future Work

Conclusions

- A robust technique for mitigating quantization lobes in single bit reconfigurable reflective surfaces with plane wave excitation is proposed.
  - Quantization lobe suppressed by randomizing the phase quantization error.
- Proposed a fabrication technique suitable for large scale production of mmWave /THz reflective surfaces.
- Characterized the RCS of mmWave reflective surfaces using a quasi-optical measurement setup.

Future Work

- Incorporate actual switches to realize reconfigurability.



Thank you!

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