



WE4B-4

A 3D Printed Terahertz Metamaterial Lens for Beam-Steering Applications

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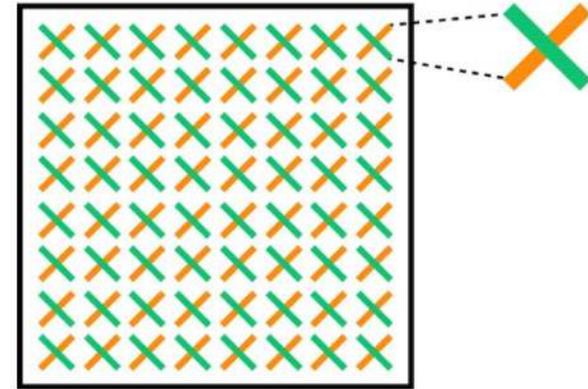
- Introduction
- Details of the work
- Results
- Conclusion
- Q&A

- **5G Antenna**

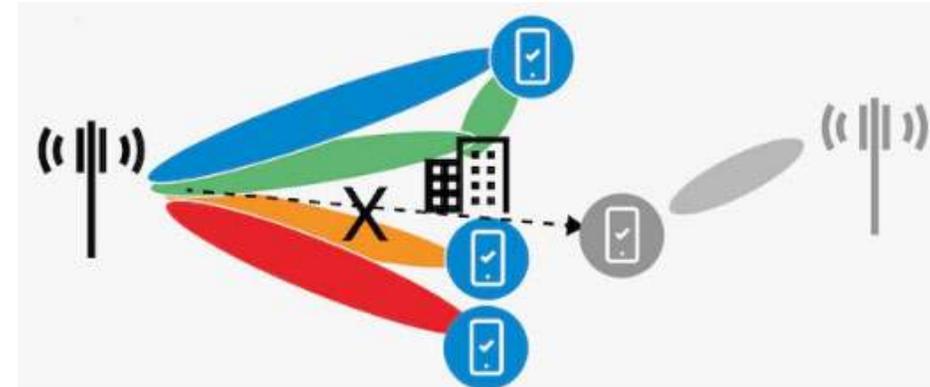
- Sub-6GHz & millimeter wave
- Dual-polarized antenna
- Massive MIMO antenna
- Beamforming / beamscanning

- **Potential Technologies in 6G**

- THz
- Beamscanning



Massive MIMO antenna

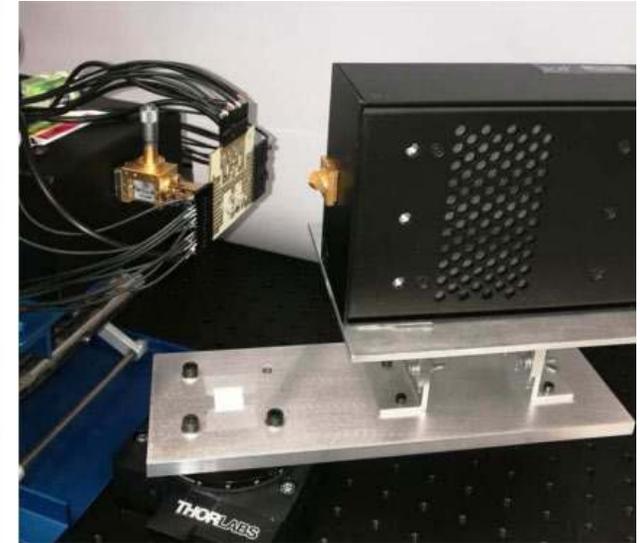
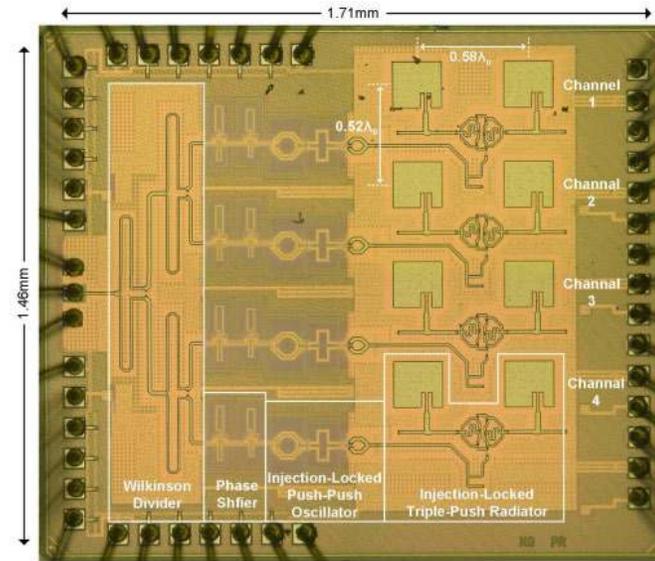


Beamforming / Beamscanning

- **Beamsteering Technology**

- Phase Array Antenna^[1]

- Gain (11.7 dBi)
 - Bandwidth (529-534 GHz)
 - Beamsteering angle ($\pm 30^\circ$)
 - Dimension (1.71 mm)
 - Fabrication (40 nm Bulk CMOS)



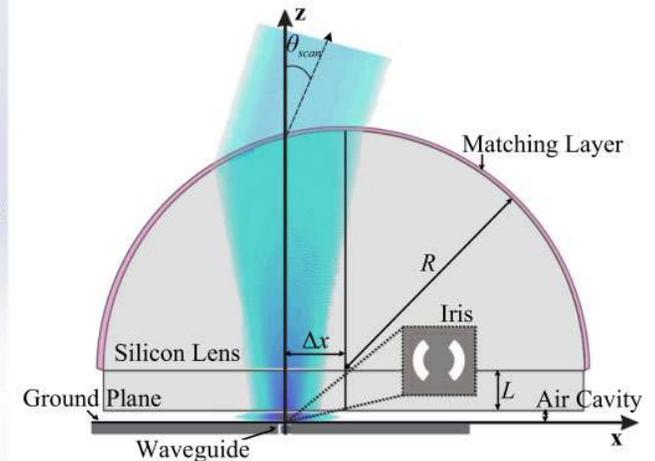
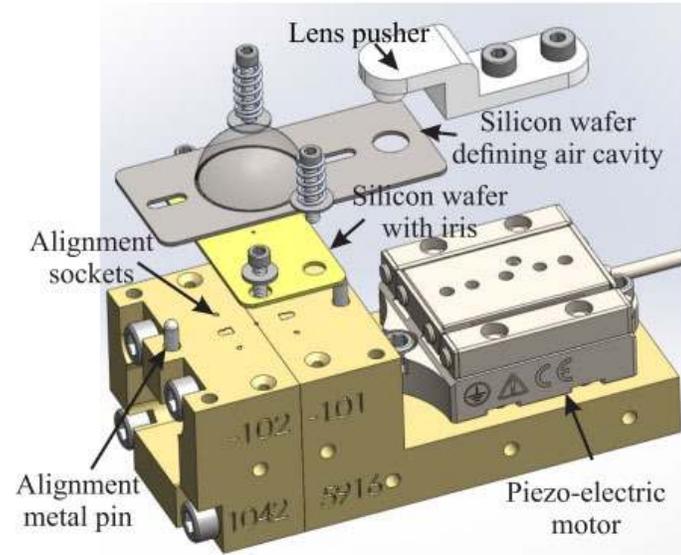
0.53-THz phased array and measurement setup

[1]. K. Guo, et. al, "A 0.53-THz Subharmonic Injection-Locked Phased Array With 63- μ W Radiated Power in 40-nm CMOS," in IEEE JSSC, vol. 54, no. 2, pp. 380-391, Feb. 2019

- **Beamsteering Technology**

- Dielectric Lens Antenna^[2]

- Gain (27 dBi)
 - Bandwidth (520-550 GHz)
 - Beamsteering angle (-11°~13.5°)
 - Dimension (12 mm)
 - Fabrication (Silicon micro-fabrication)



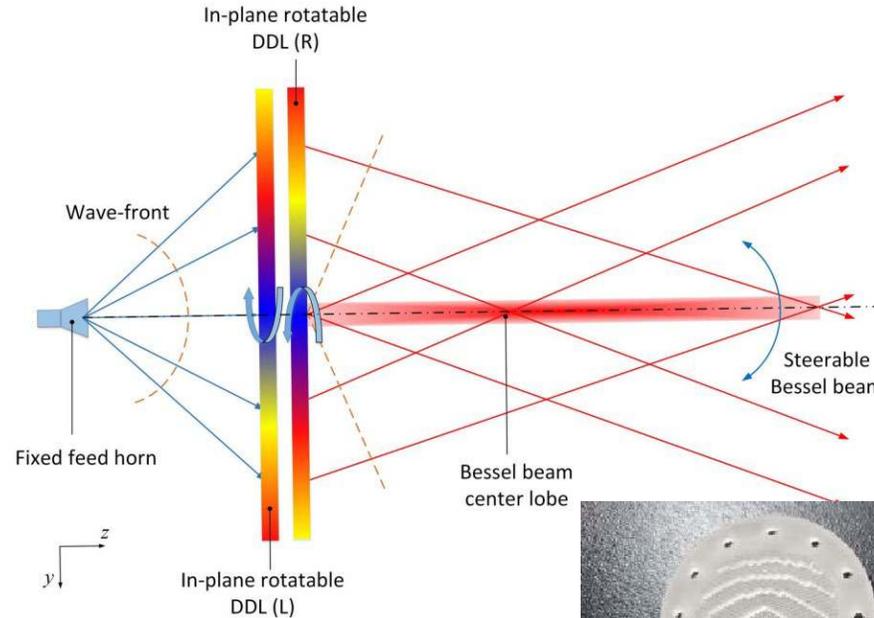
0.55-THz silicon lens antenna and the schematic

[2]. M. Alonso-delPino, et. al, "Beam Scanning of Silicon Lens Antennas Using Integrated Piezomotors at Submillimeter Wavelengths," in IEEE TTST, vol. 9, no. 1, pp. 47-54, Jan. 2019

- **Beamsteering Technology**

- Planar Lens Antenna^[3]

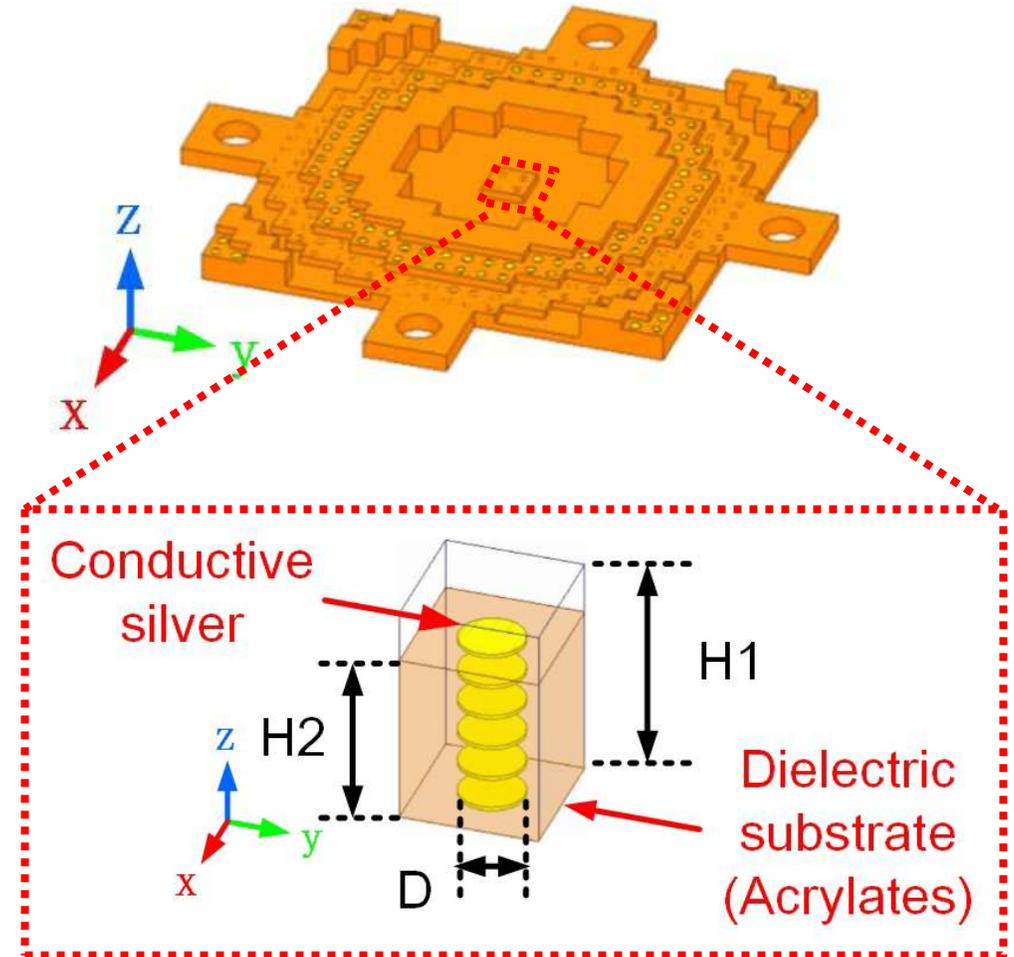
- Bandwidth (300 GHz)
- Beamsteering angle ($\pm 43.1^\circ$)
- Dimension (15 mm)
- Fabrication (Dielectric 3D printing)



Schematic of beamsteering and Photograph

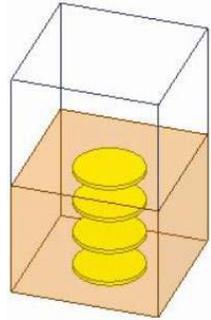
[3]. G. -B. Wu, et. al, "A 2-D Beam-Scanning Bessel Launcher for Terahertz Applications," in IEEE TAP, vol. 68, no. 8, pp. 5893-5903, Aug. 2020

- **Lens unit cell**
 - Gradient refractive index (GRIN) metamaterial lens (Metalens)
 - Metal-dielectric structure
 - Sub-wavelength capacitive patches

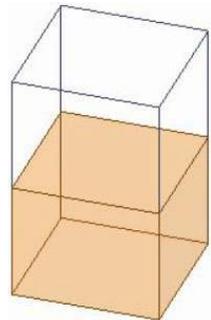


Planar lens and unit cell

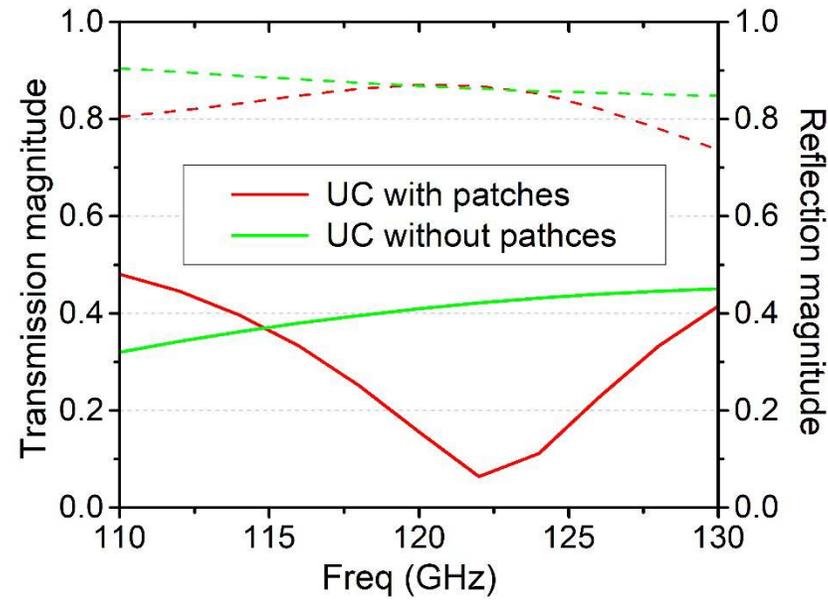
- Lens unit cell



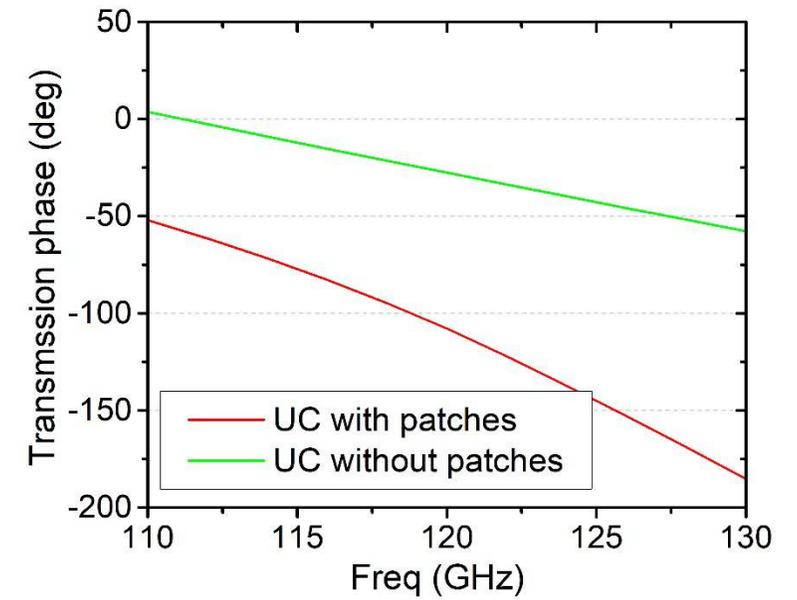
UC with patches



UC without patches

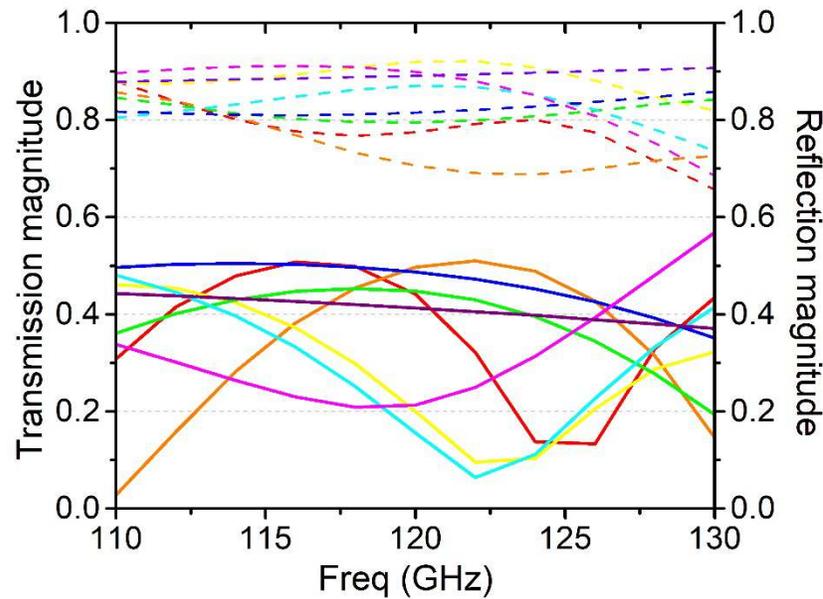
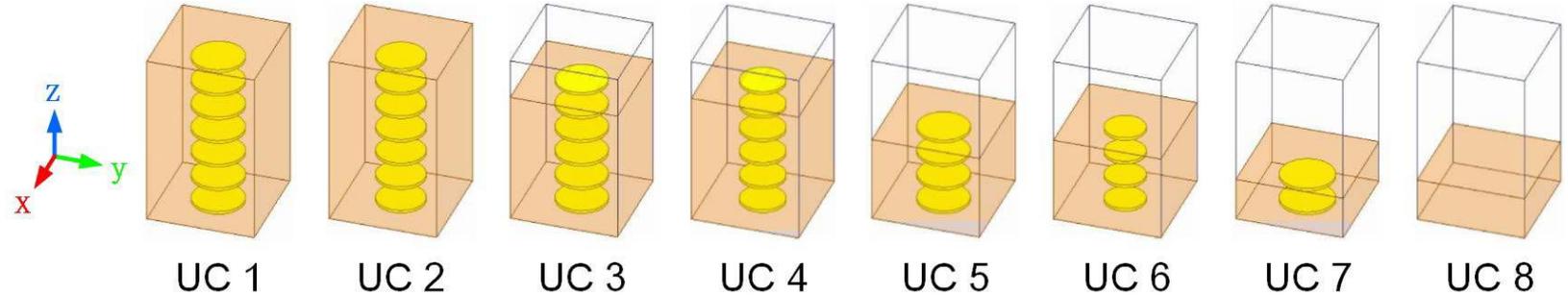


Transmission and reflection magnitude

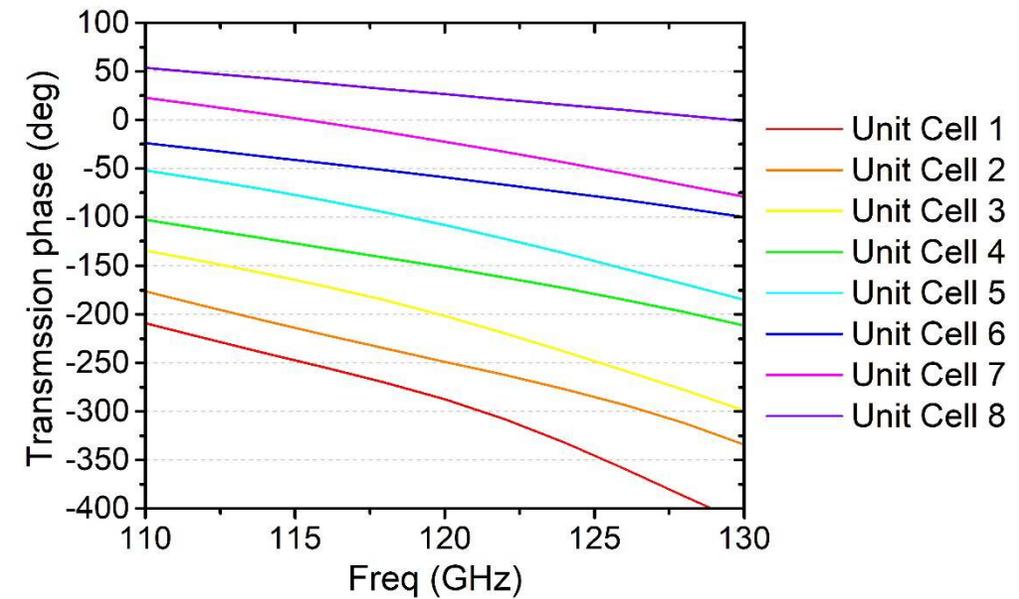


Transmission phase

- Lens unit cell
 - Patches layer
 - Diameter
 - Proportion



Transmission and reflection magnitude



Transmission phase

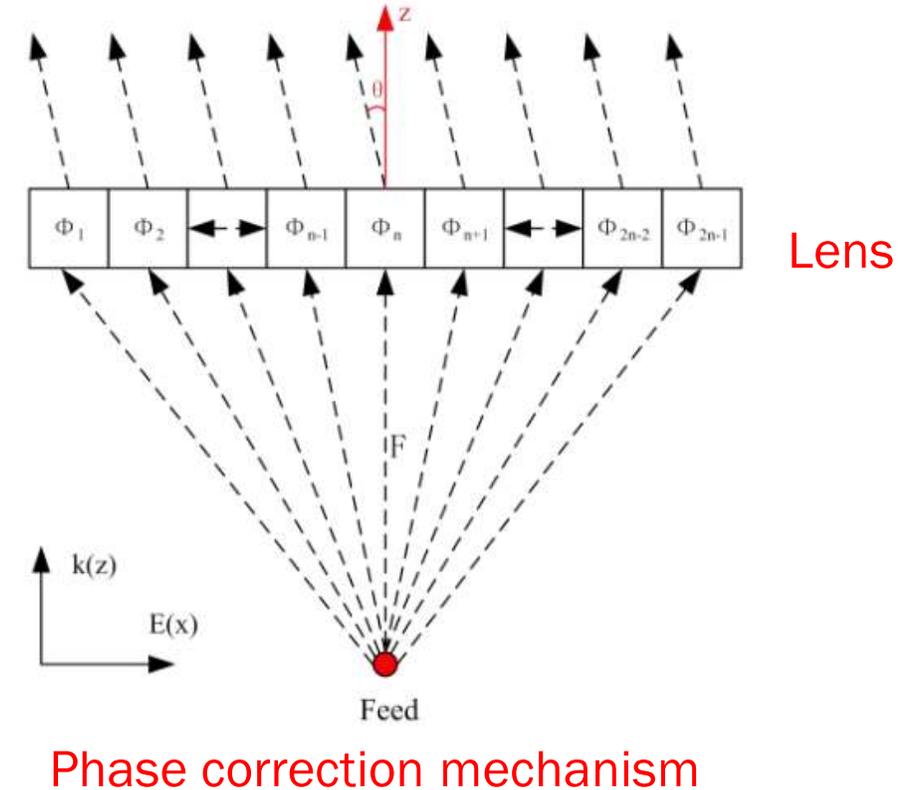
- Phase distribution

- Fermat's principle^[4]

$$\phi_n = \frac{2\pi f}{c} \left\{ \sqrt{F^2 + (x_n - x_0)^2} - F - x_n \sin \theta \right\} + \phi_0$$

- Wavefront transformation :

- Spherical wave to Plane wave



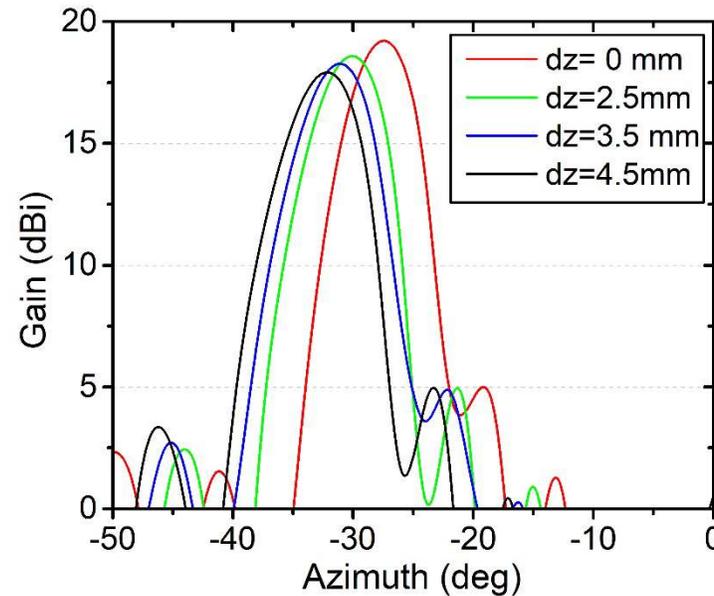
[4]. H. Yi, et. al, "3-D Printed Millimeter-Wave and Terahertz Lenses with Fixed and Frequency Scanned Beam," in IEEE TAP, vol. 64, no. 2, pp. 442-449, Feb. 2016

- Phase distribution

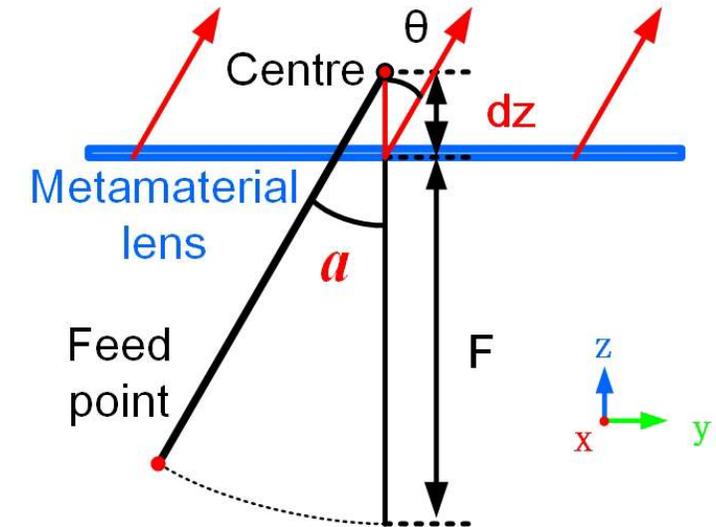
- Optimization
- Beam deviation factor (BDF)

$$BDF = \theta / \alpha$$

- $dz = 2.5 \text{ mm}$



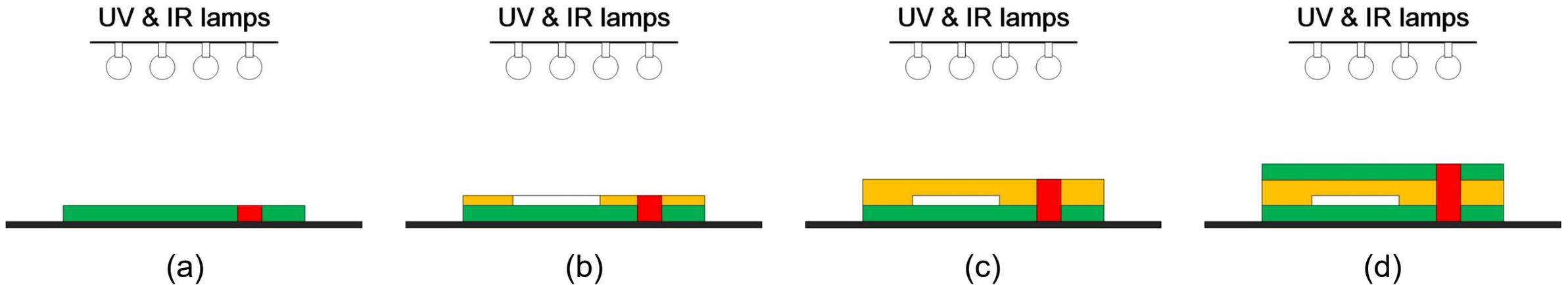
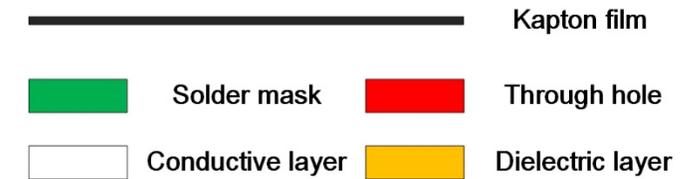
Radiation pattern when $\alpha=30^\circ$



Schematic of beamsteering

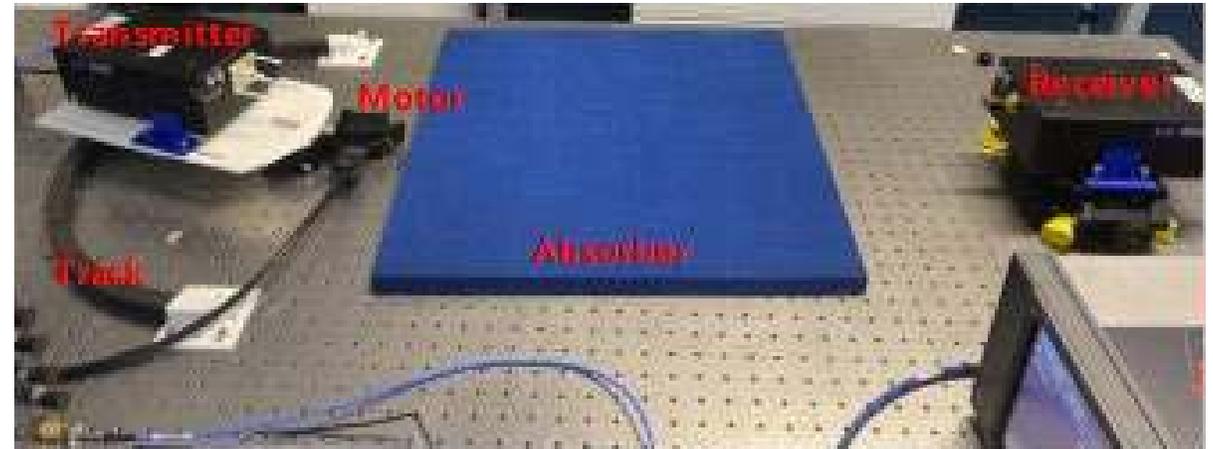
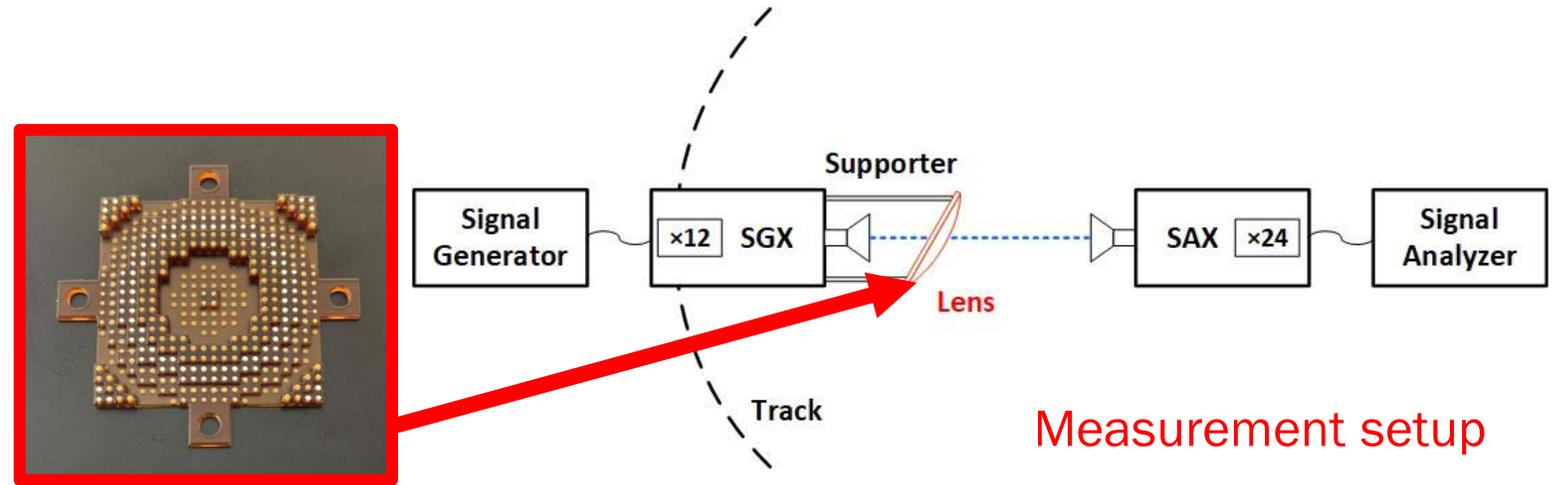
- **Fabrication**

- DragonFly LDM printer
- Conductive and dielectric dultimaterial 3D printing



Fabrication process

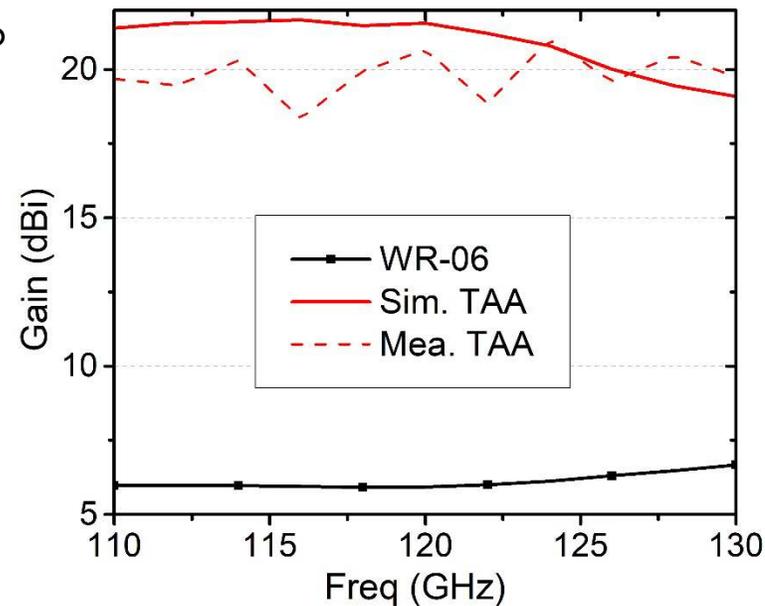
- **Measurement**
- Keysight signal generator and analyzer
- VDI frequency extender SGX and SAX



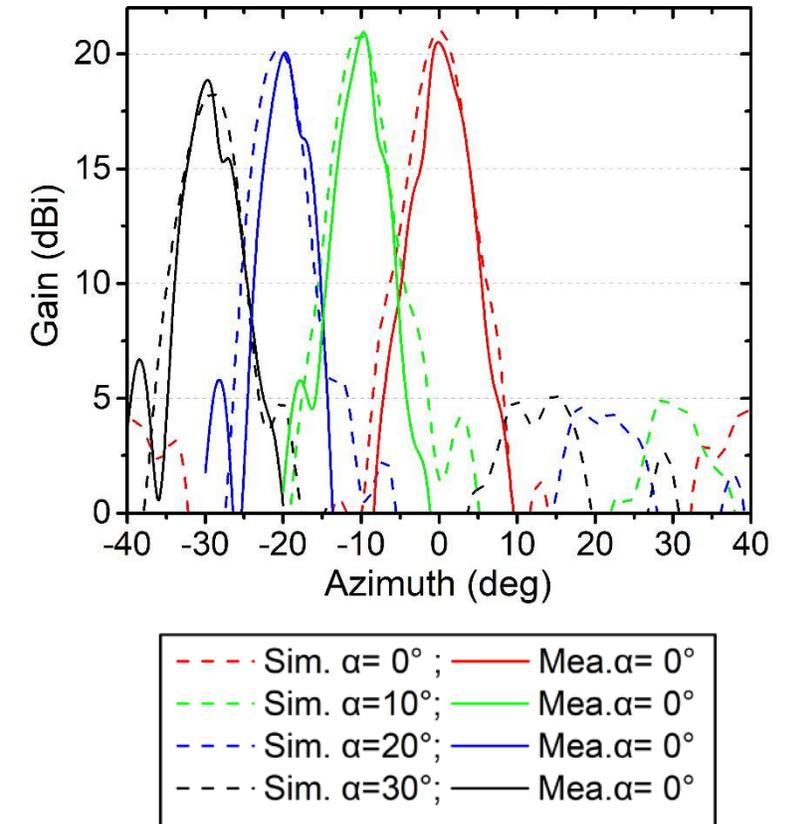
Photograph of the Far-field measurement

- Comparison between simulated and measured results

- Gain: 21.5 dBi when $\alpha=0^\circ$
- Sim. Gain: 19 ~ 21.6 dBi
- Mea. Gain: 18.8 ~ 21 dBi
- Scan loss: 3 dB
- BDF : 1



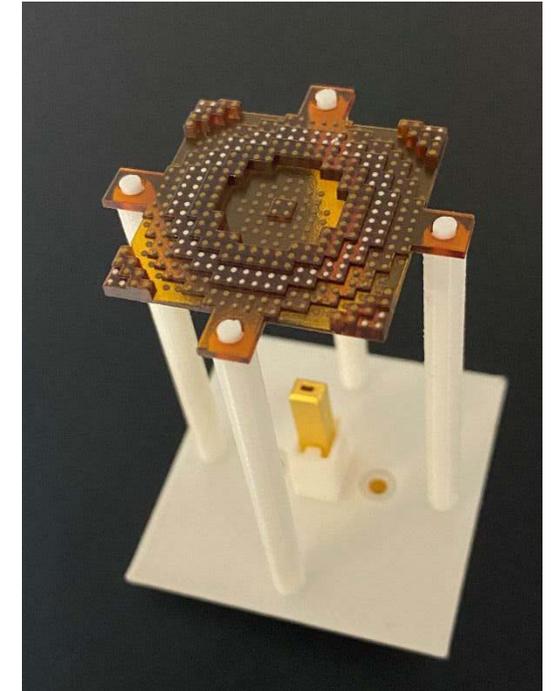
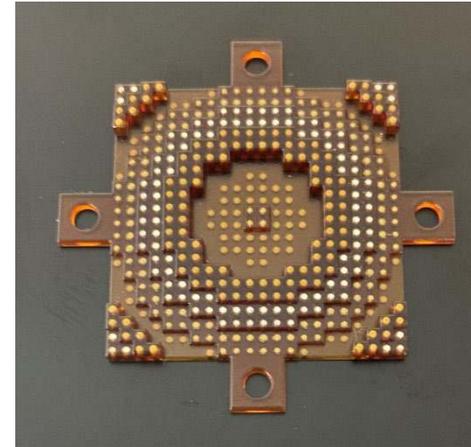
Gain versus frequency



Beamsteering radiation pattern at 120 GHz

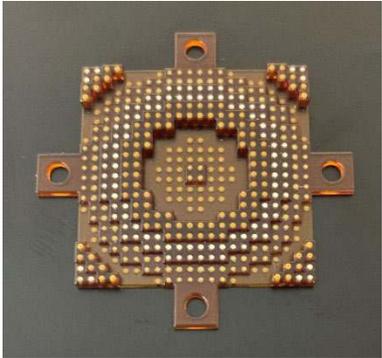
- **GRIN metamaterial lens antenna**
- Sub-wavelength capacitive patches
- Phase distribution optimization for DBF
- Conductive and dielectric multimaterial 3D printing

Gain (21.5 dBi)
Bandwidth (110-130 GHz, 16.7%)
Beamsteering angle ($\pm 30^\circ$)
Dimension (26.4 mm, 10.5λ)
Fabrication (DragonFly LDM printing)



Photograph of the GRIN metamaterial lens antenna

- Comparison



	Gain (dBi)	Freq (GHz)	Bandwidth (%)	Dimension (λ)	Beam. Angle ($^\circ$)	Fabrication
This work	21.5	110-130	16.7	10.5	± 30	DragonFly LDM Printing
[1]	11.7	529-534	0.9	3.0	± 30	40nm Bulk CMOS
[2]	27	520-550	5.6	21.4	-11 ~ +13.5	Silicon micro Fabrication
[3]	/	300	300	15	± 43.1	3D Printing

Q&A

