Aalto University
School of Electrical
Engineering

Millimeter-wave antenna arrays

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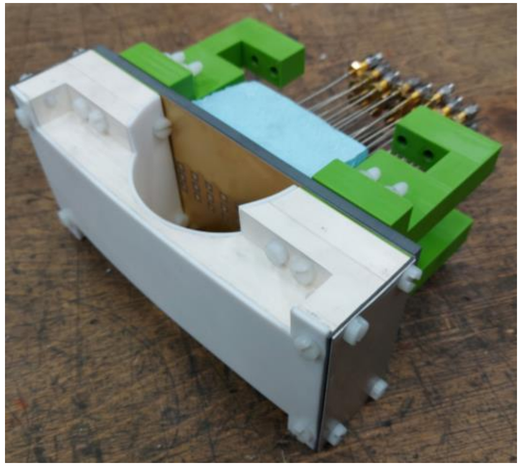
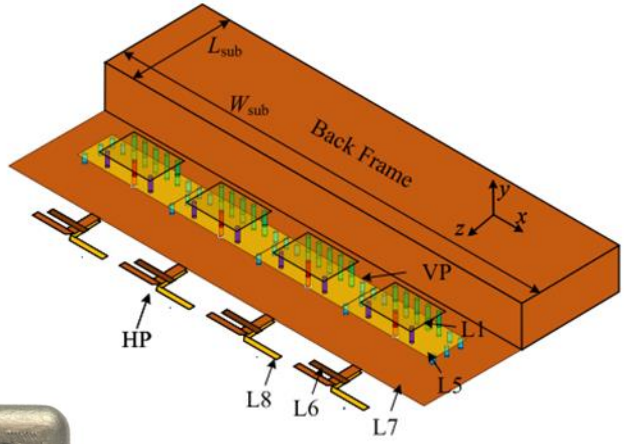
Aalto University, Department of Electronics and Nanoengineering

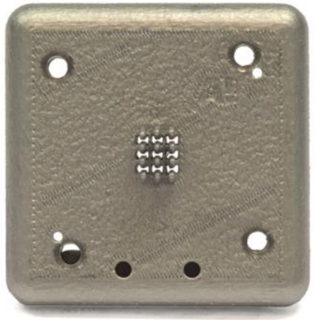
RF Summit Finland, Oulu, March 19, 2025

Outline

- Surface mountable array
- 5G mm-wave arrays
  - Modular array
  - Liquid-cooled array
  - Sparse array and a dielectric dome lens (DDL)
- Mm-wave arrays for mobile devices
  - Broad-side frequency-reconfigurable array
  - Low-profile dual-polarized end-fire array
  - 140-GHz reference array for propagation studies
- Metal 3D-printed array for 100 GHz





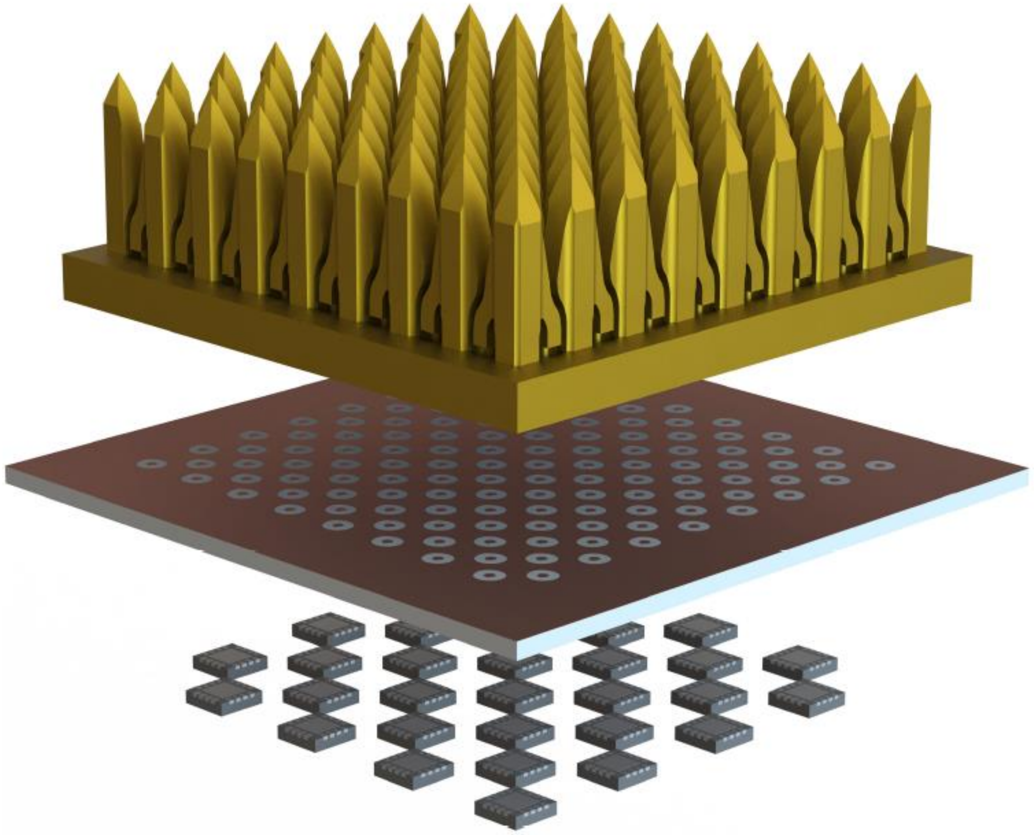


Surface-mountable 3D antenna arrays

Surface-mount antenna array

Single multi-layer PCB

Active components on a PCB



High efficiency (>90%)

Two polarizations

Broadband (26-40 GHz)

Wide beam steering ($\pm 60°$)

Low active reflection (<-10 dB)

H. Kähkönen et. al, "Dual-polarized Ka-band Vivaldi antenna array," *IEEE TAP,* 2020.
H. Kähkönen et. al, "Comparison of additively manufactured and machined antenna array performance at Ka-band," *IEEE AWPL* 2022.
H. Kähkönen et. al, "Surface-mounted Ka-band Vivaldi antenna array," *IEEE OJAP*, 2021.

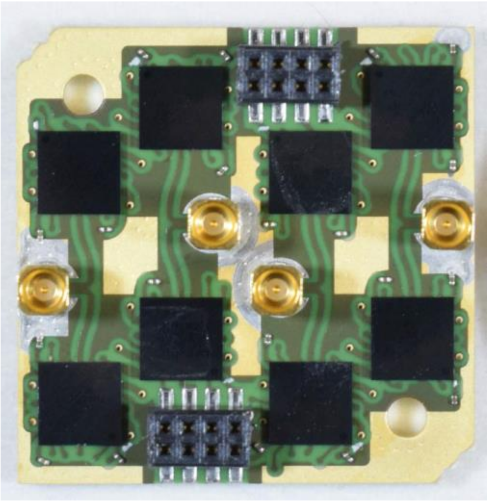
Modular dual-pol 18-30 GHz array

Array module - side

Array module - bottom

PCB module - top

PCB module - bottom

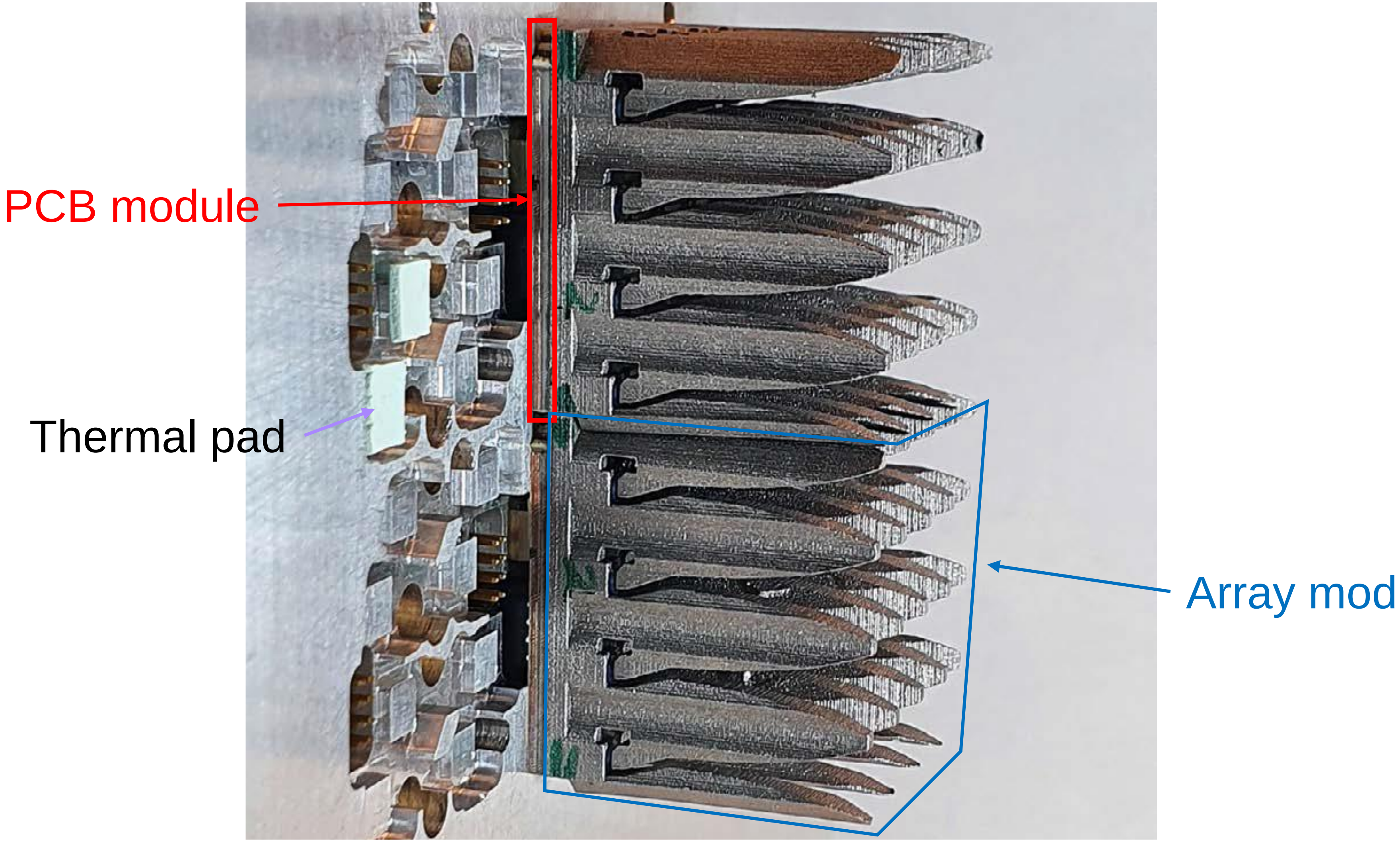


- 4x4 dual-polarized array in one module
- Eight four-channel RFICs connected to 32 antenna elements
- Separate power-divider network

H. Kähkönen et. al, “A Modular Dual-Polarized Ka-Band Vivaldi Antenna Array,” *IEEE Access*, 2022

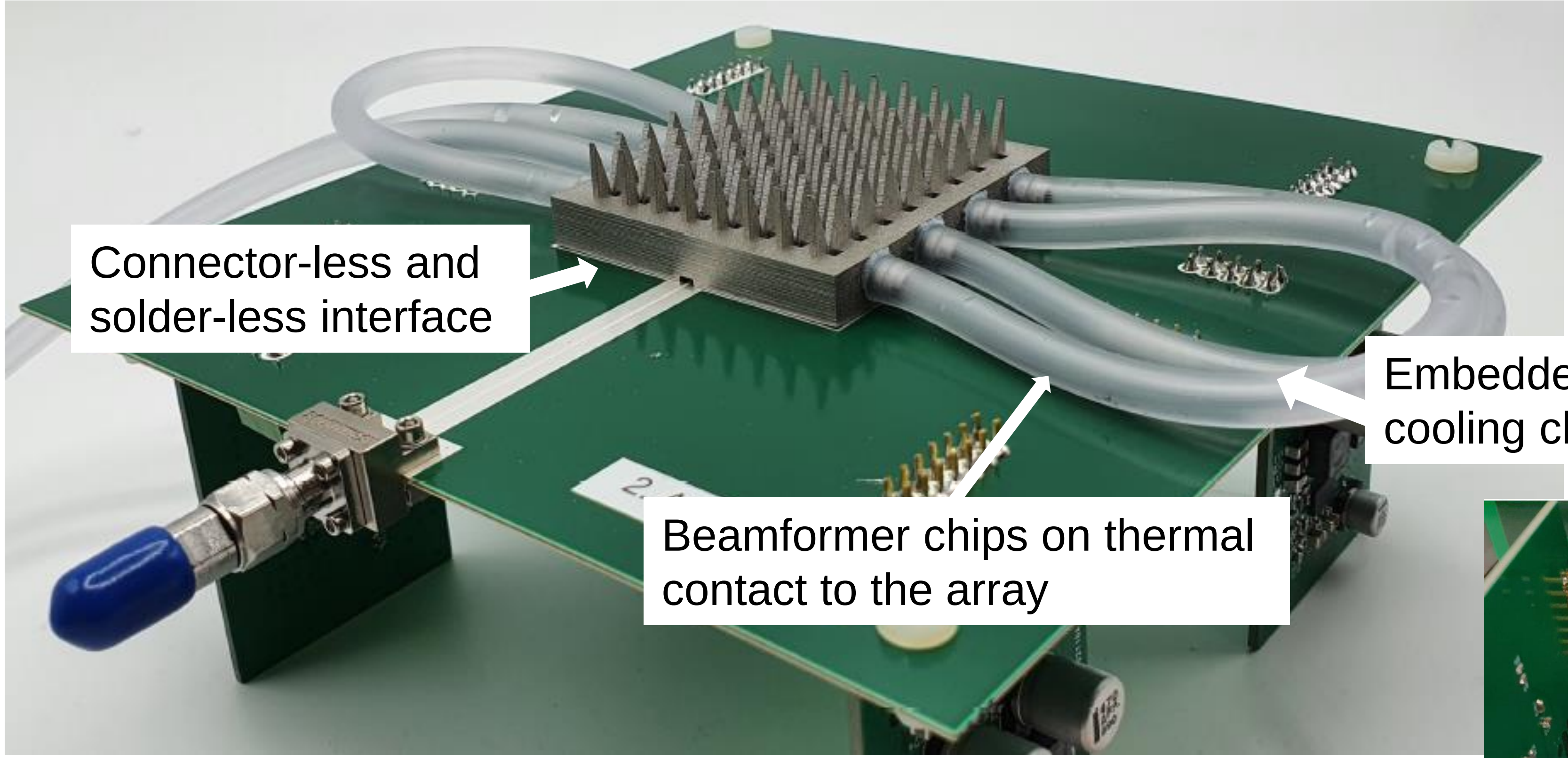
Modular dual-pol 18-30 GHz array

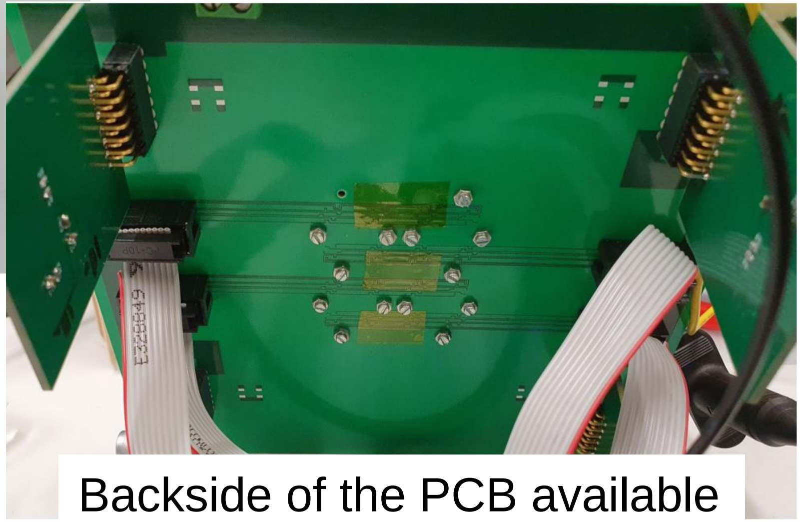
Platform for combining four 4x4 array modules



H. Kähkönen et. al, “A Modular Dual-Polarized Ka-Band Vivaldi Antenna Array,” *IEEE Access*, 2022.

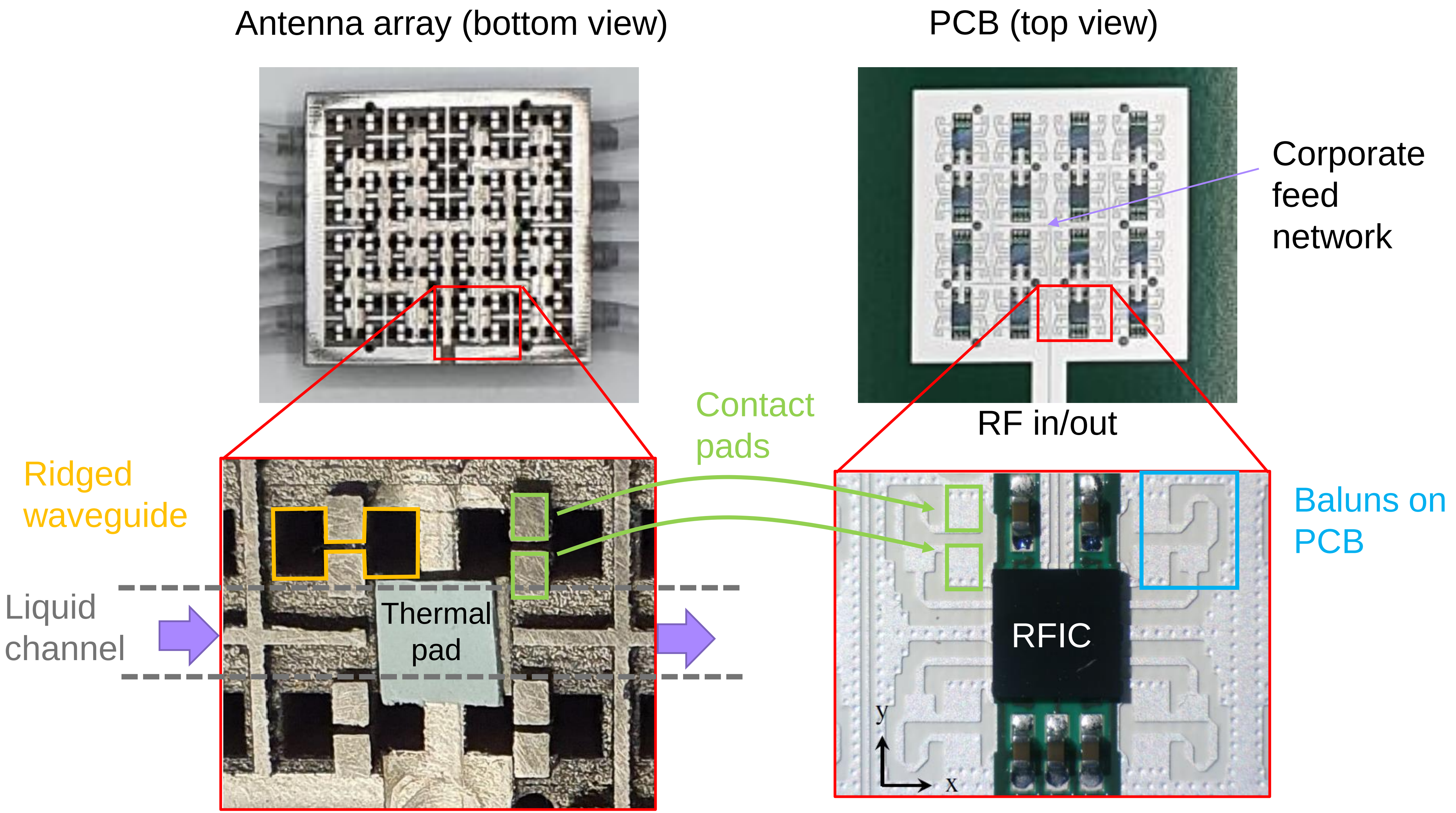
Scalable 8x8 liquid-cooled 24-29.5 GHz array





J. Haarla et. al., “Scalable 3D-printable antenna array for 28 GHz with liquid cooling,” *IEEE TAP*, 2023.

Antenna-PCB interface



J. Haarla et. al., "Scalable 3D-printable antenna array for 28 GHz with liquid cooling," *IEEE TAP*, 2023.

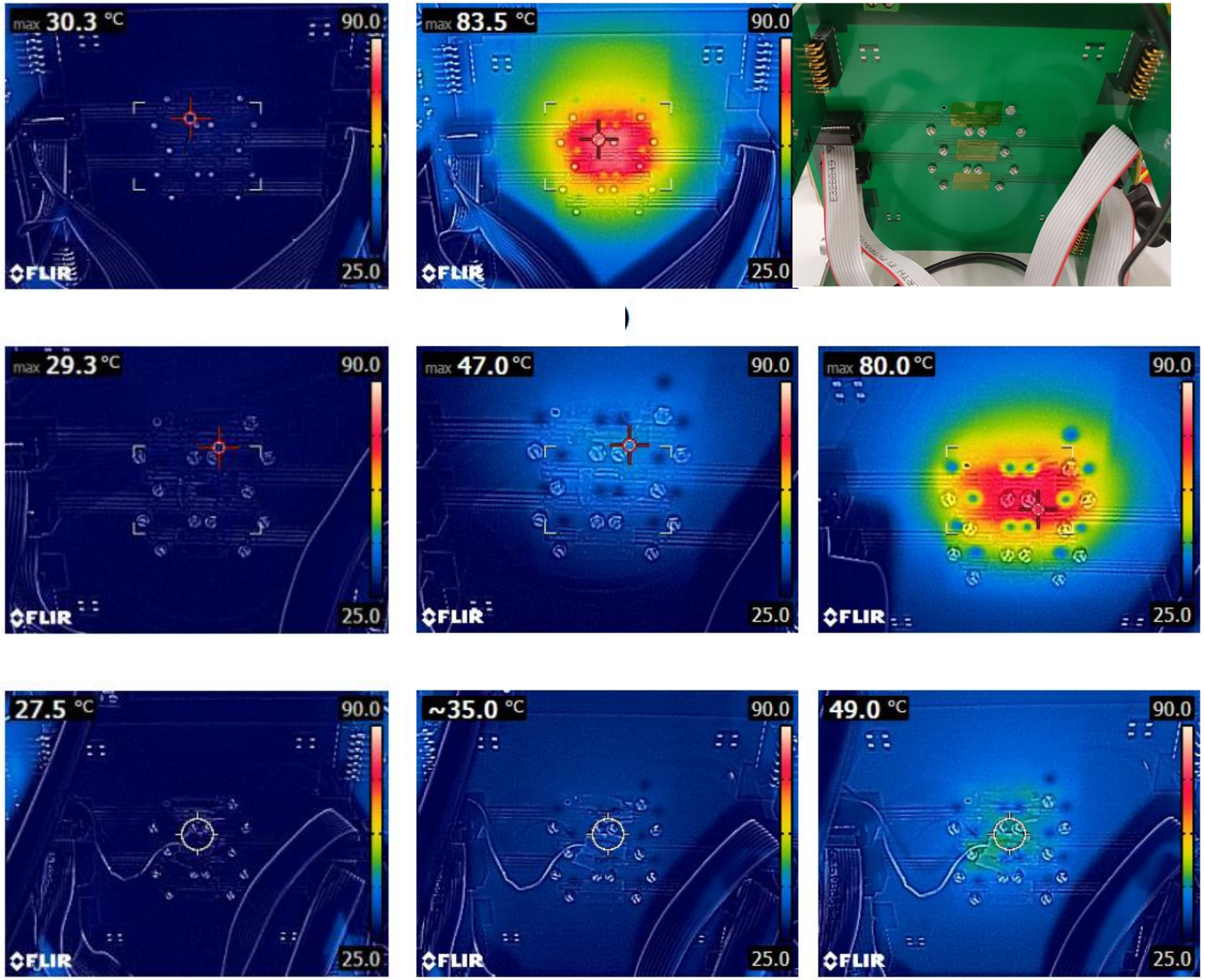
Different cooling approaches

Standby | Receiver on | Transmitter on

No fan
No liquid cooling
- No continuous use of receiver or transmitter

Fan – air cooling (forced convection)
- No continuous use of transmitter

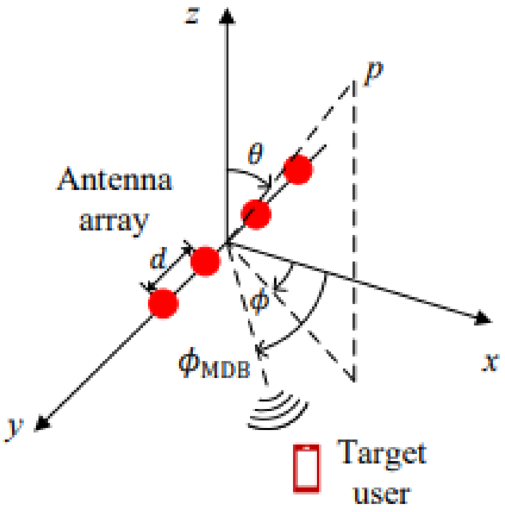
Liquid cooling
- Continuous use of receiver and transmitter



J. Haarla et. al., "Scalable 3D-printable antenna array for 28 GHz with liquid cooling," *IEEE TAP*, 2023.

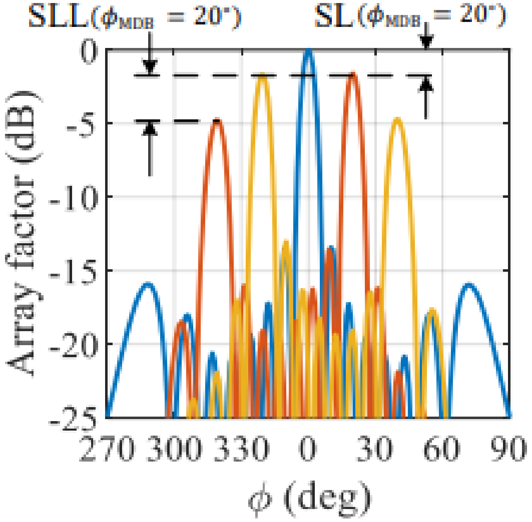
Sparse arrays

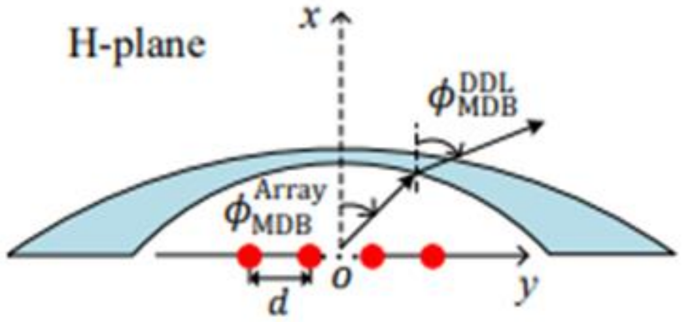
- Active components can be placed further away from each other – reduced heating per area
- Grating lobes

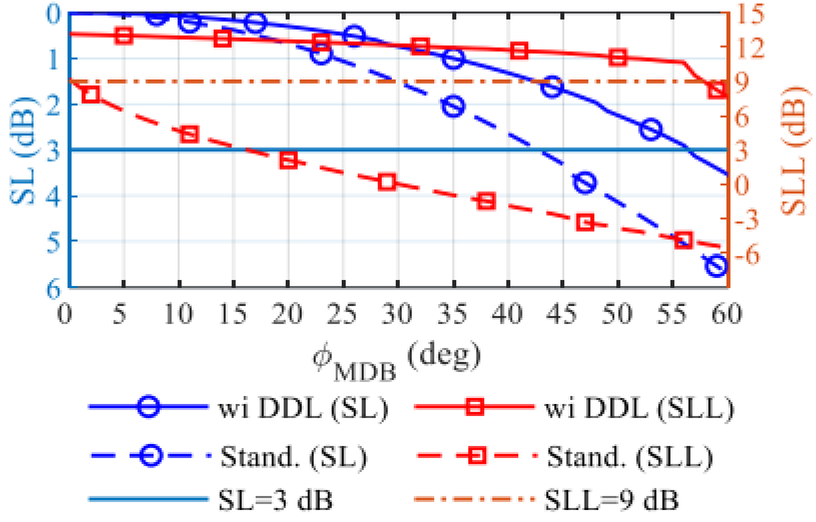


Side-Lobe (or grating-lobe) Level

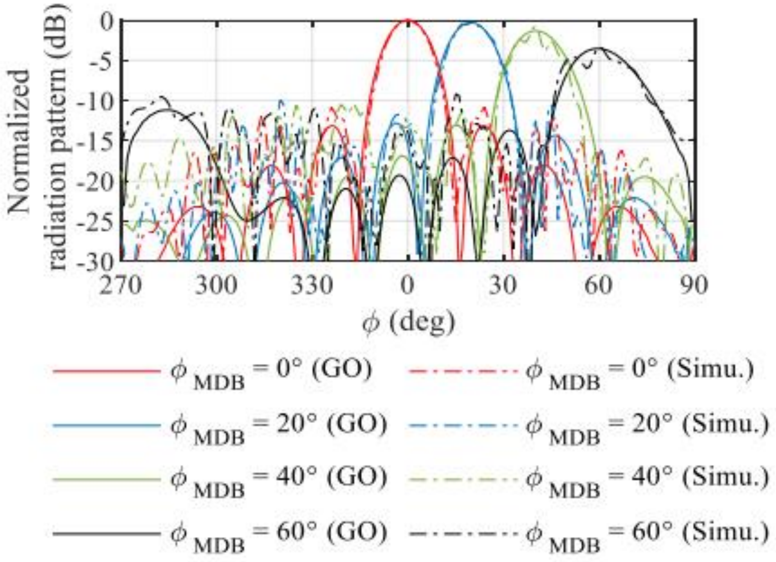
Scan Loss

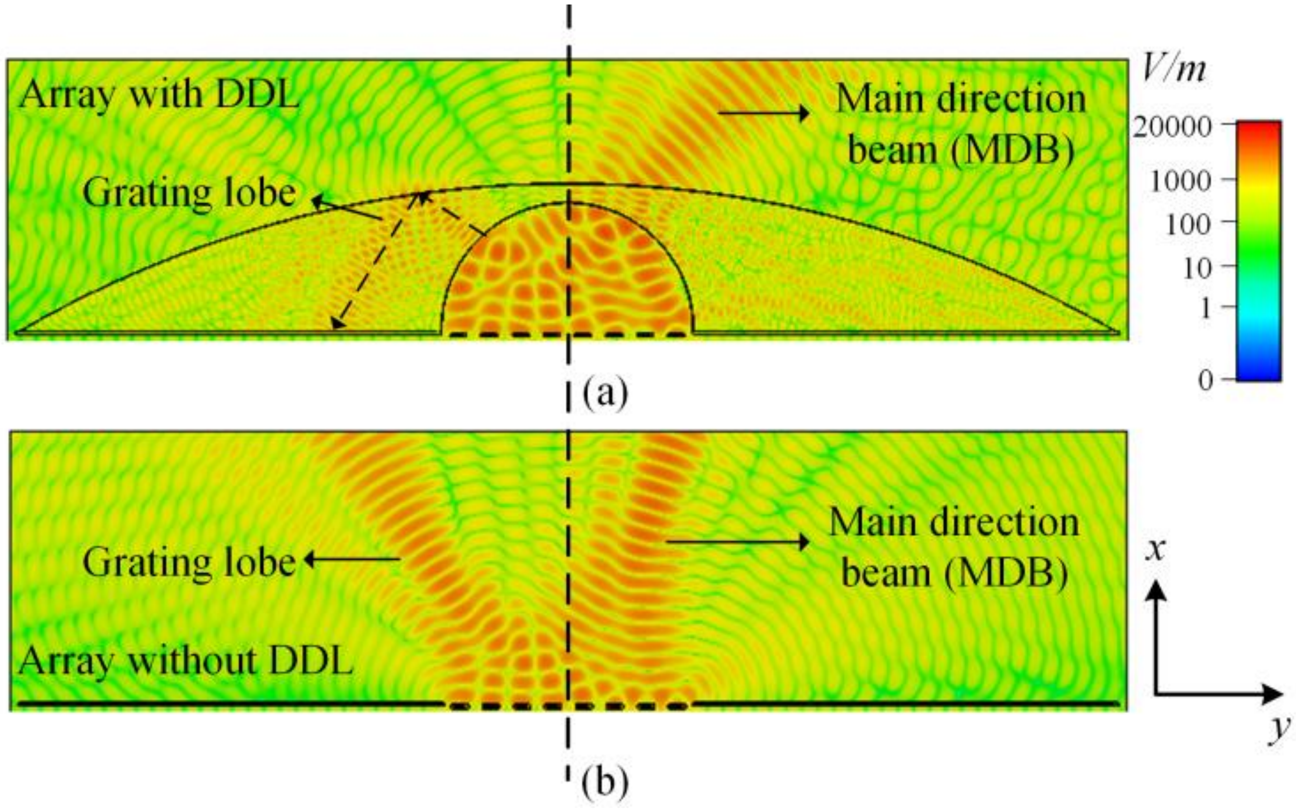






Dielectric dome dens with a sparse array

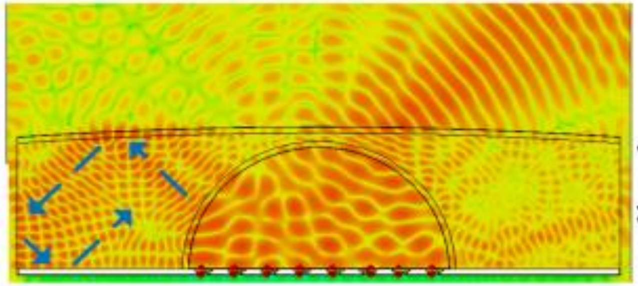




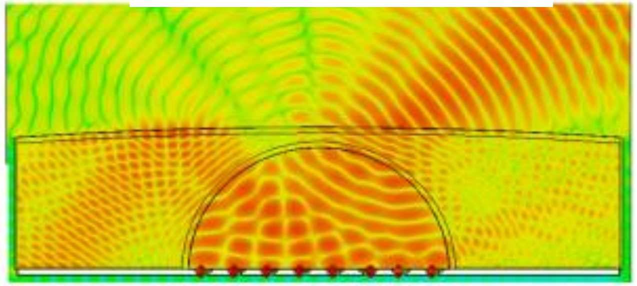
Y. Wang *et al*., "Grating-Lobe Reduction for Uniform Under-Sampled Phased Array Using Dielectric Dome Lens," in *IEEE Transactions on Antennas and Propagation*, 2024.

Dielectric dome lens at 28 GHz

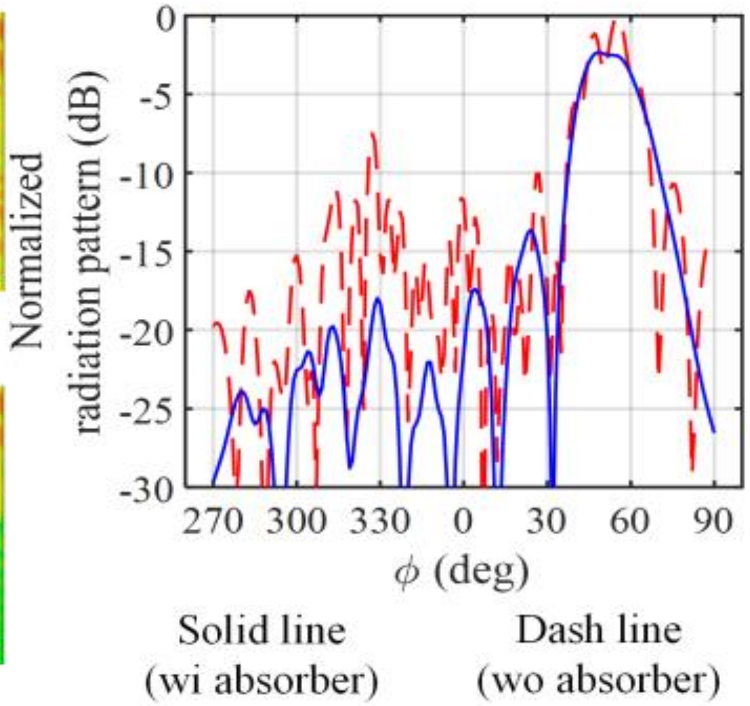
No absorbers

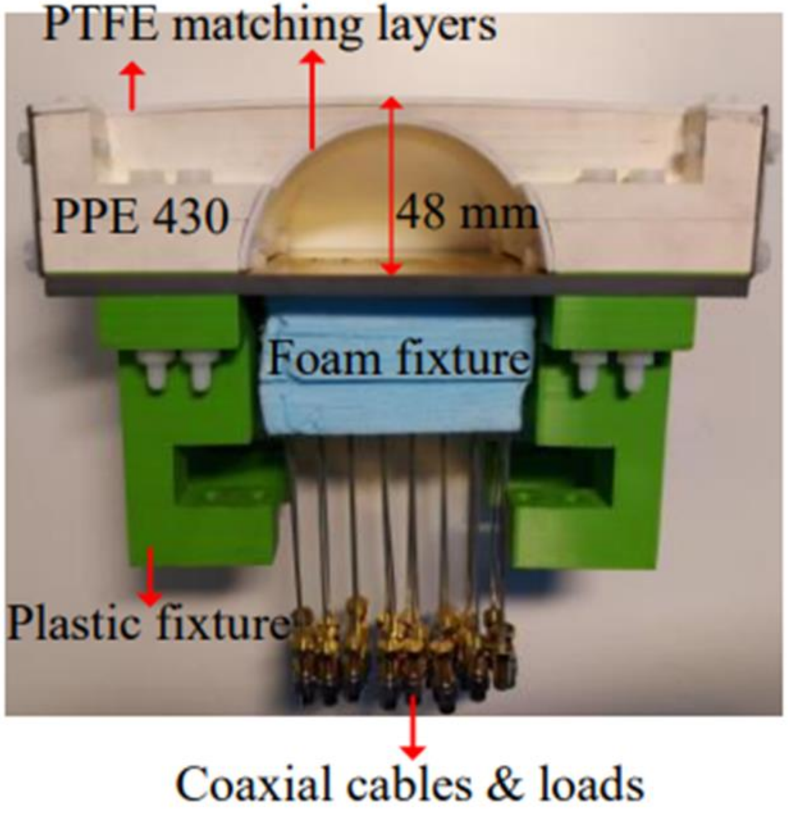


With absorbers



Reduction of internal reflections





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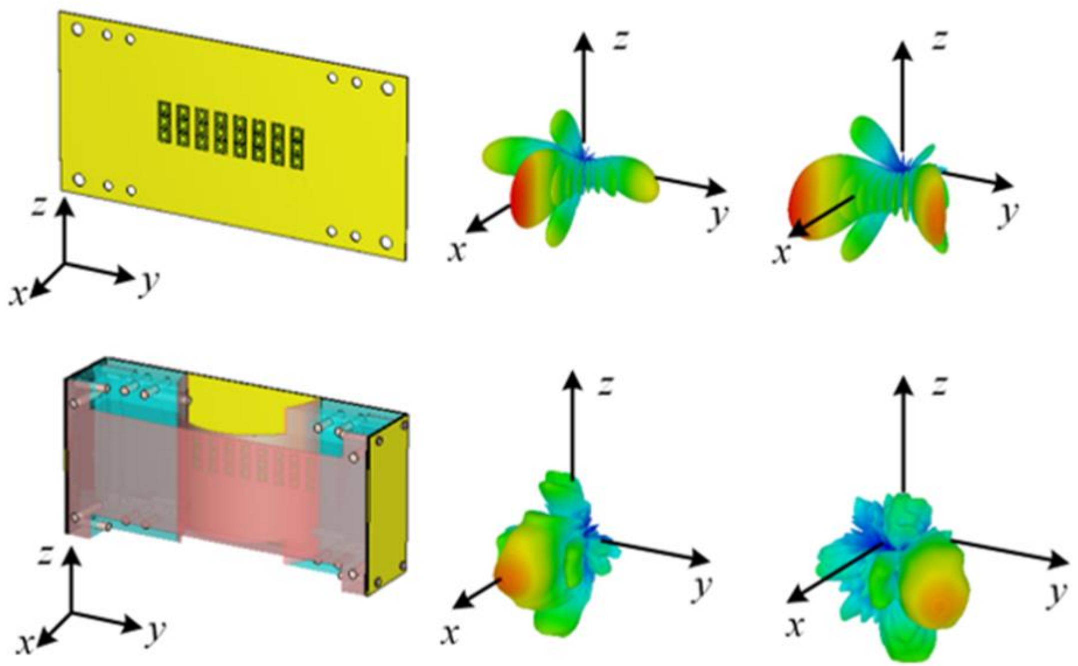
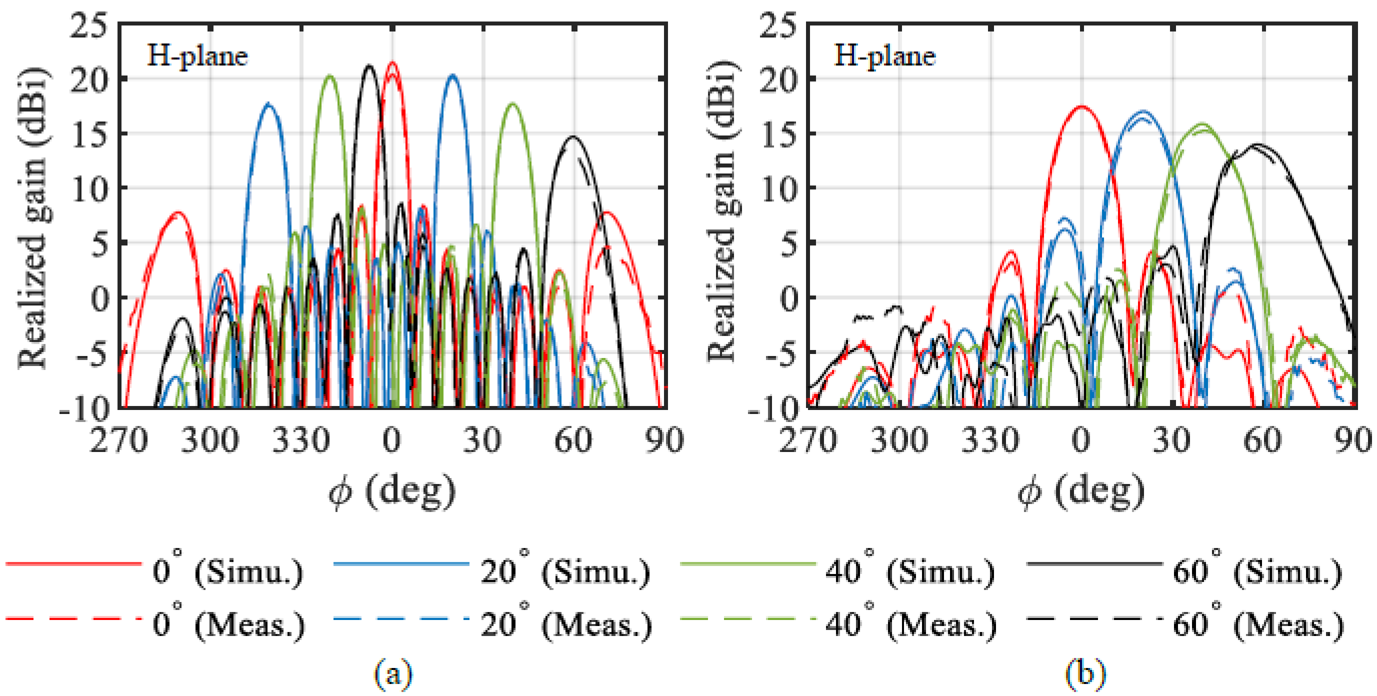
Dielectric dome lens at 28 GHz



3x8-array alone

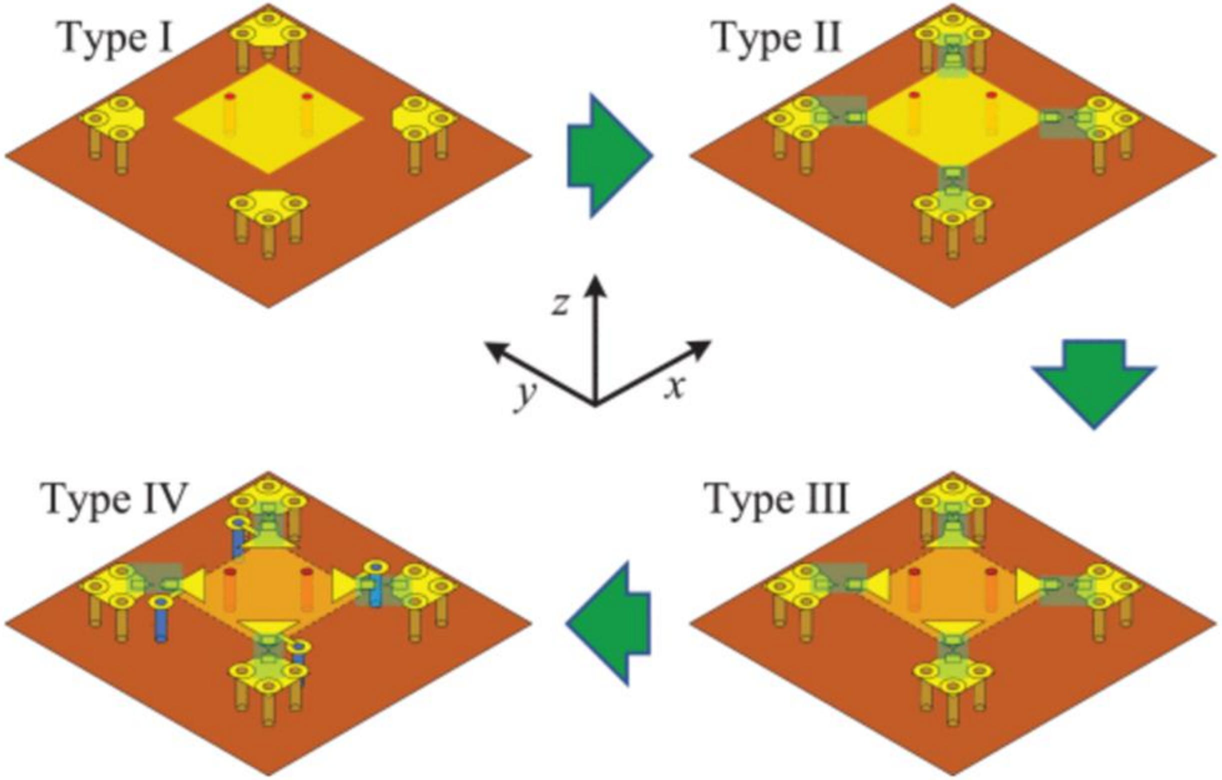
3x8-array with DDL



Y. Wang *et al*., "Grating-Lobe Reduction for Uniform Under-Sampled Phased Array Using Dielectric Dome Lens," in *IEEE Transactions on Antennas and Propagation*, 2024.

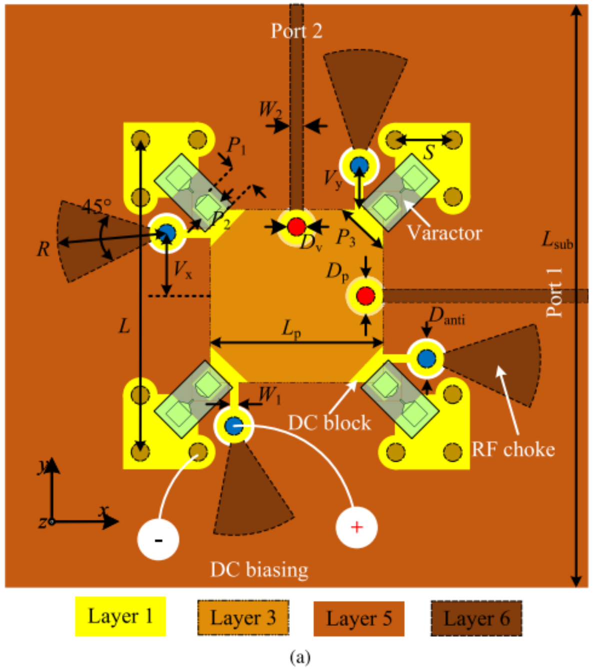
Mm-wave antenna arrays for mobile devices

- Large bandwidths available
- High-capacity short-range communication
- Low-latency
- Beam forming capabilities

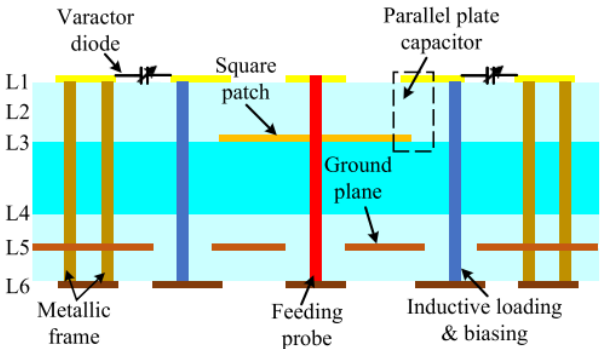


Q. Chen et al., "Varactor-Based Frequency-Reconfigurable Dual-Polarized mm-Wave Antenna Array for Mobile Devices," in *IEEE Transactions on Antennas and Propagation*, Aug. 2023.

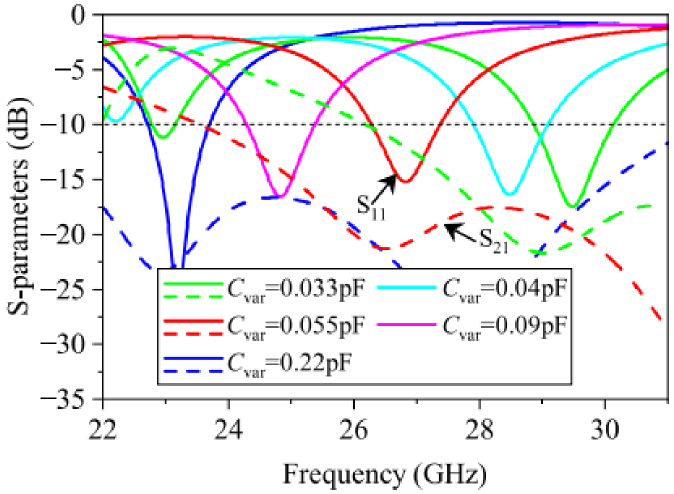
Varactor-loaded reconfigurable array



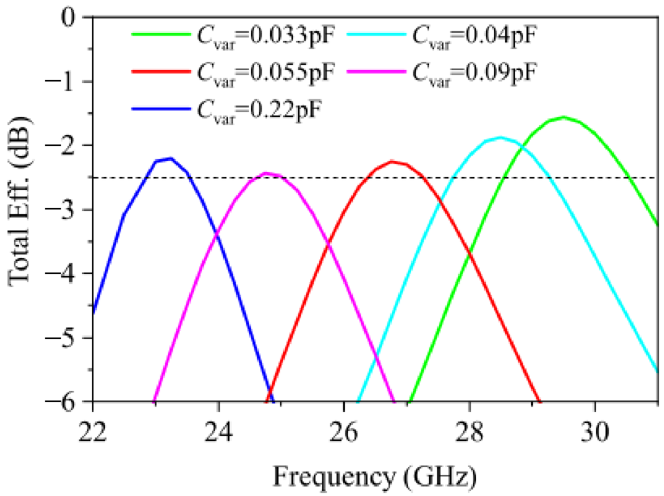
(a)



Matching and coupling



Total efficiency



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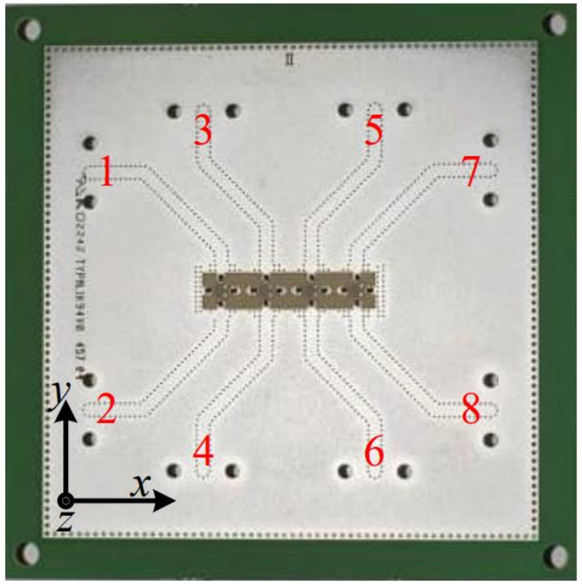
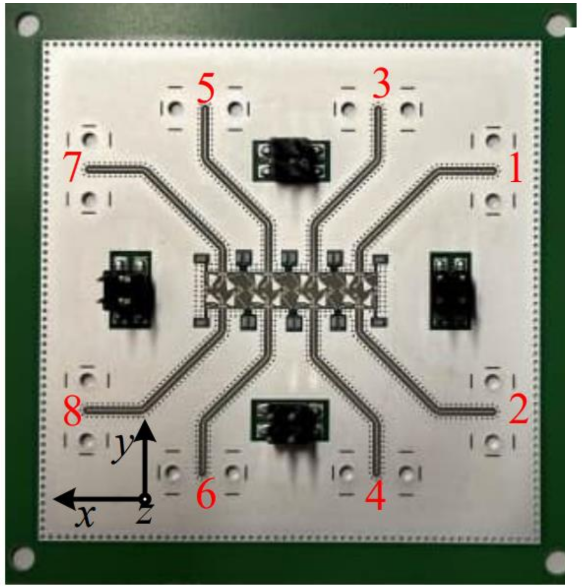
Varactor-loaded reconfigurable array

Antenna side



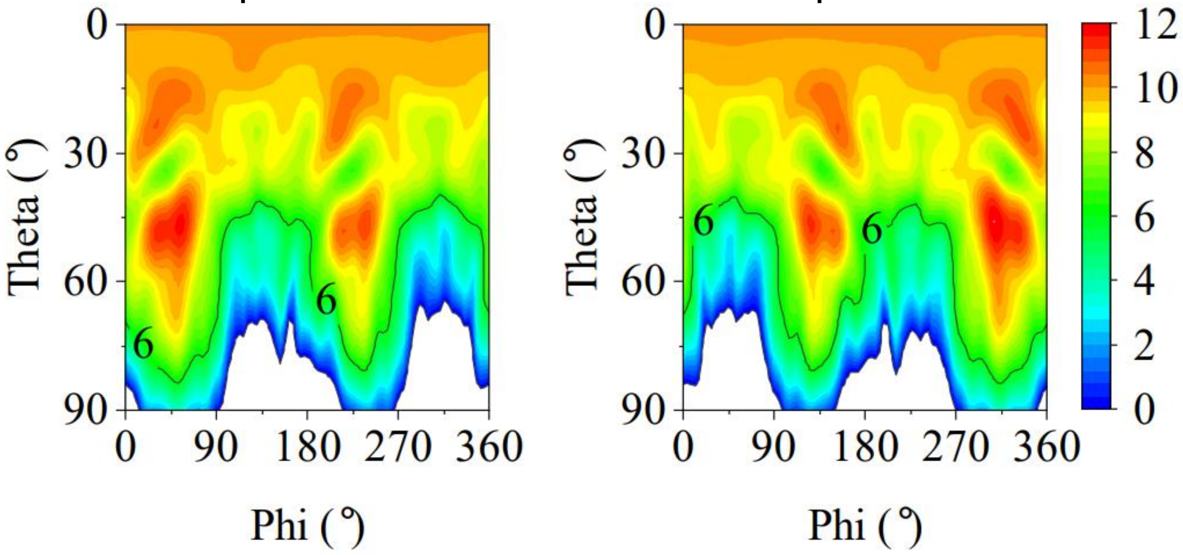
Back side



Total scan patterns at 29.5 GHz (dBi)

–45° polarization

+45° polarization



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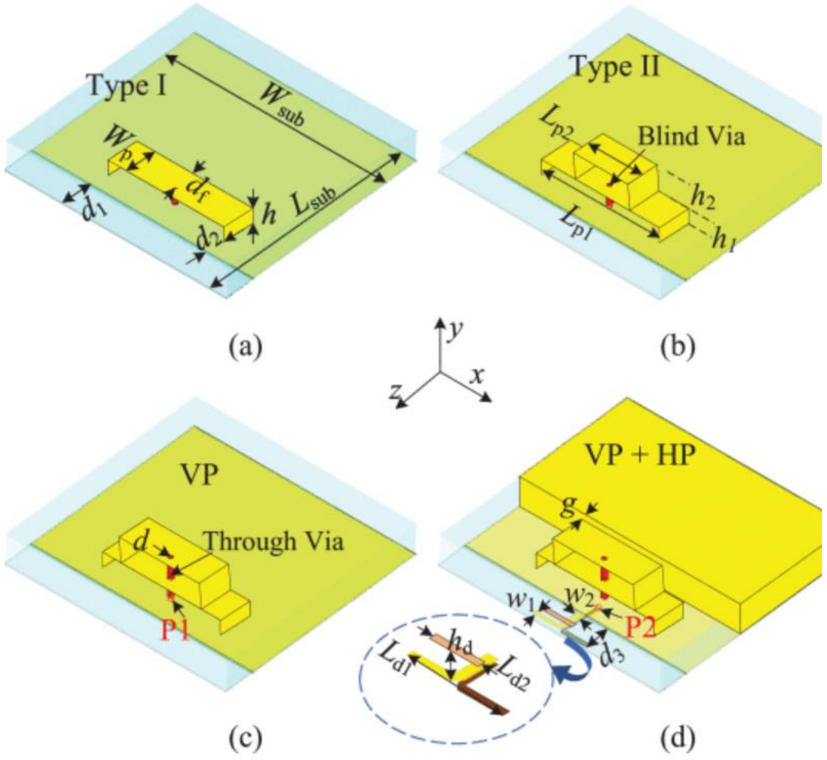
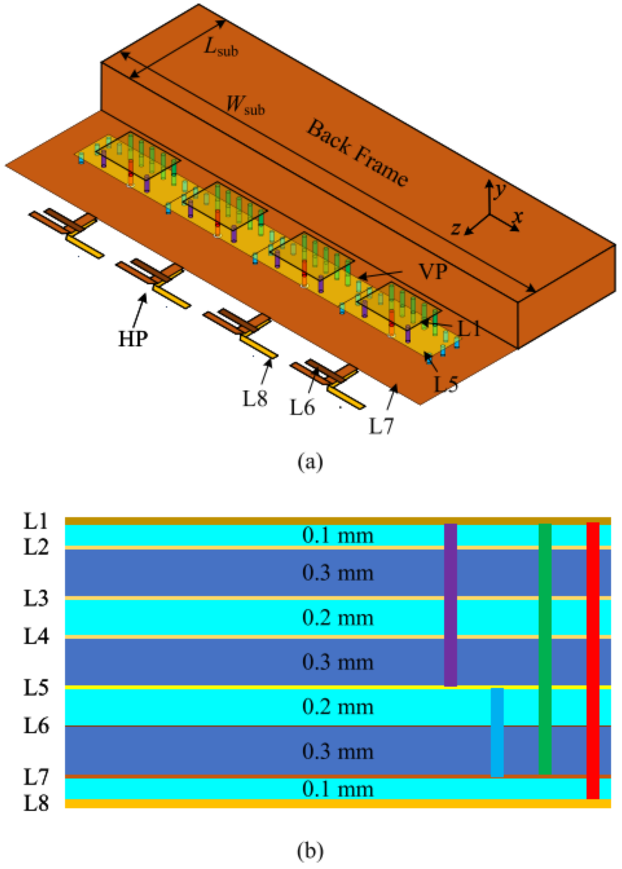
Dual-polarized end-fire array

- Vertical polarization difficult to achieve for end-fire direction in low profile
- Magnetic dipole (MD) used for vertical polarization
- Stacked-MD to improve bandwidth
- Parasitic dipole antenna for horizontal polarization
- Operation at 24.25-29.5 GHz and 37-43 GHz bands
- Total thickness about 1.6 mm





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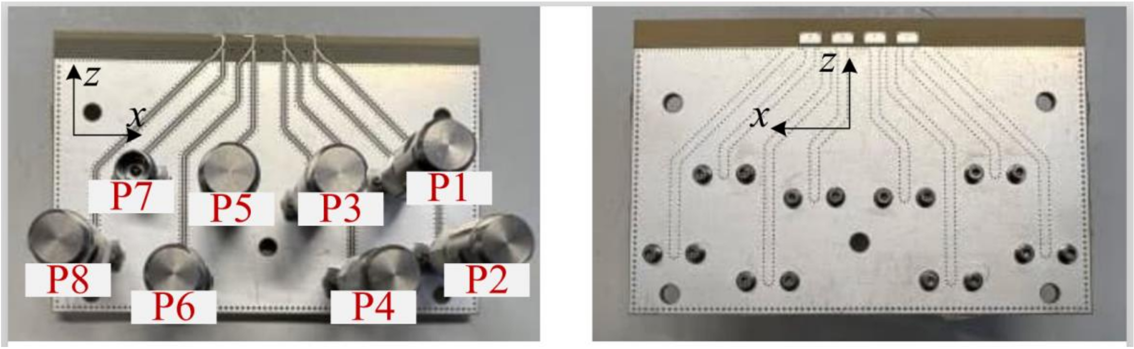
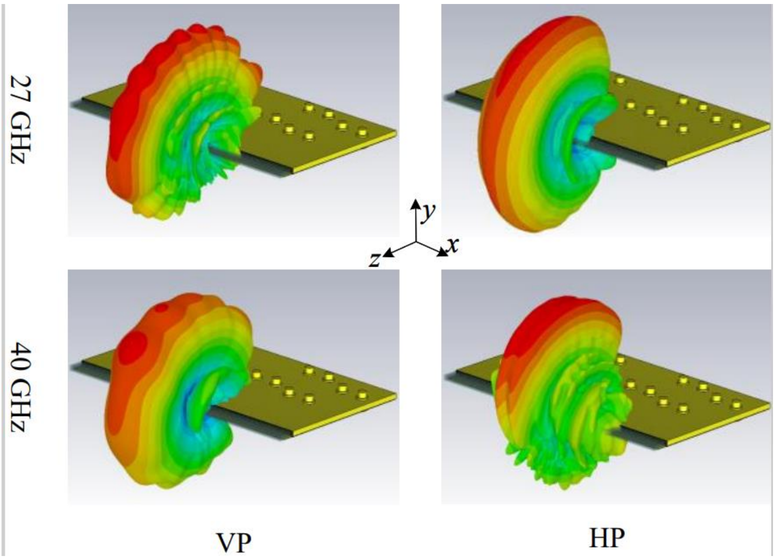
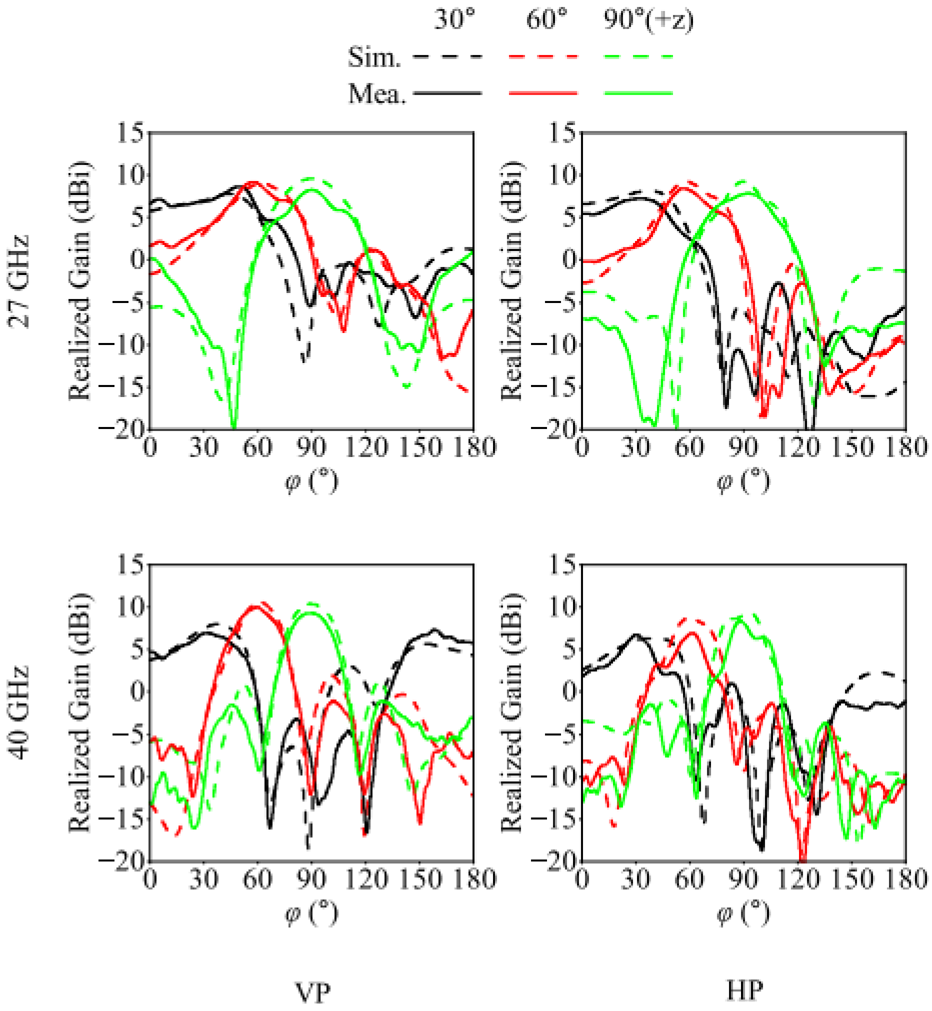
Dual-polarized end-fire array







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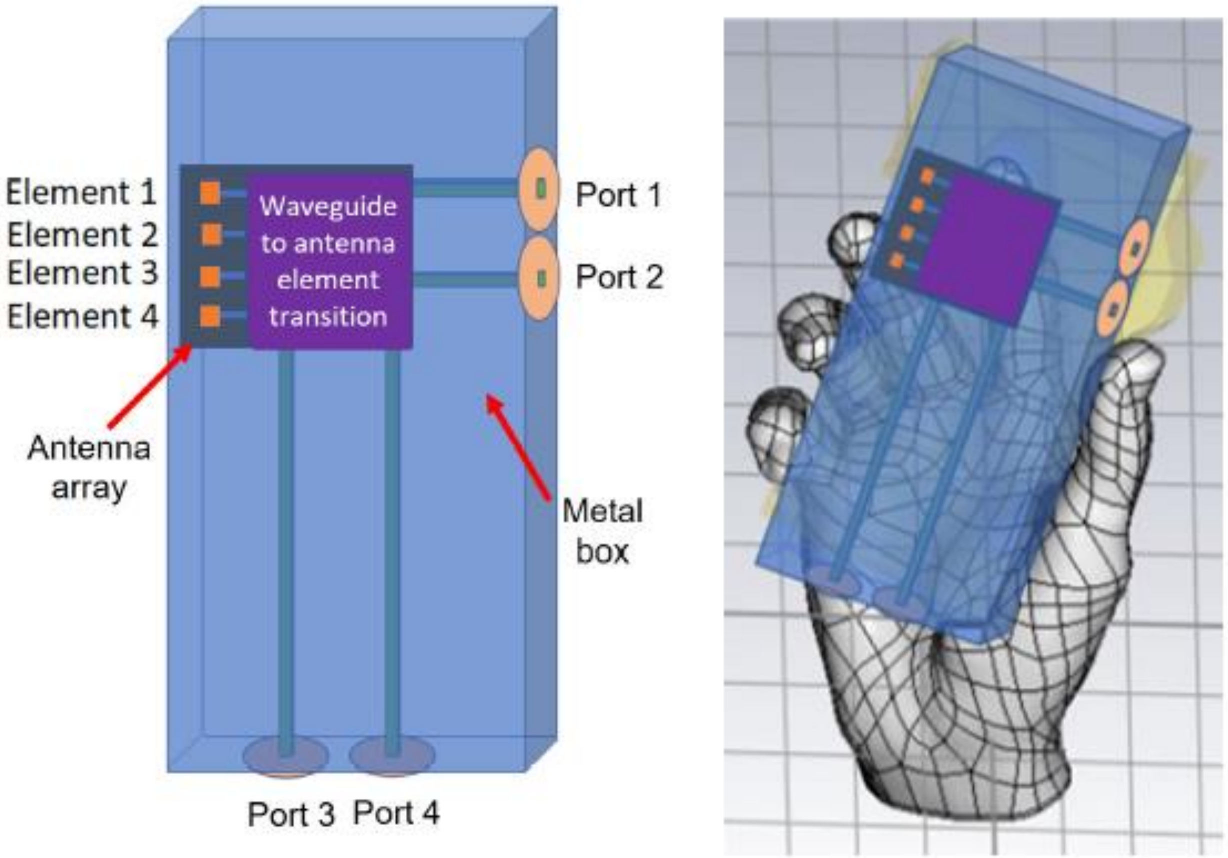
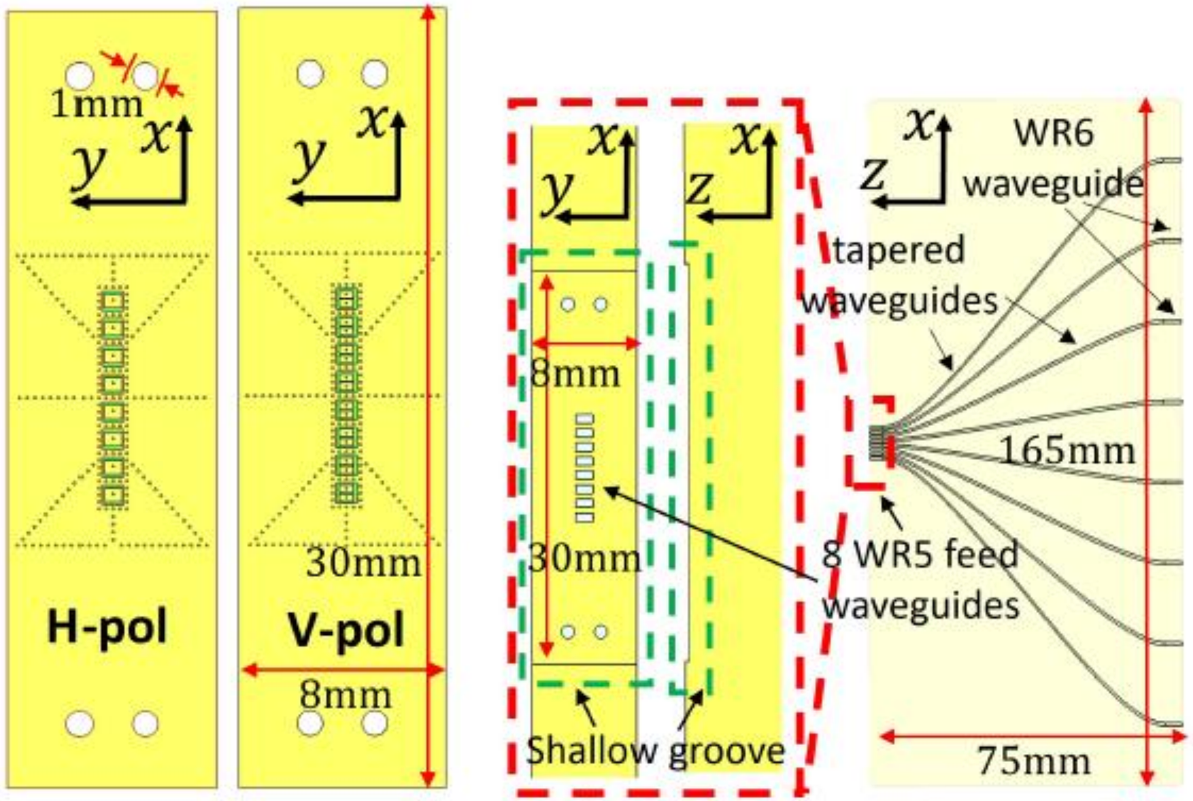
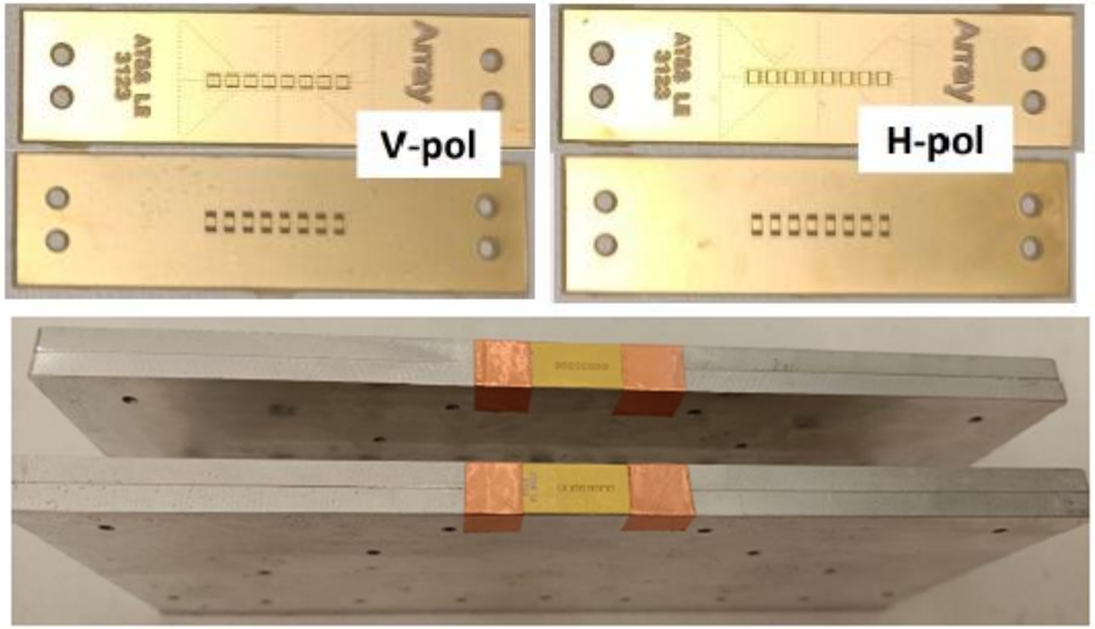
Mobile reference antenna for 140-GHz propagation measurements



B. Xue et al. "Handset Reference Antenna Array Design, Fabrication, and Application to Hand Effect Study at Sub-THz," in *IEEE Transactions on Antennas and Propagation*, 2025.

Mobile reference antenna for 140-GHz propagation measurements





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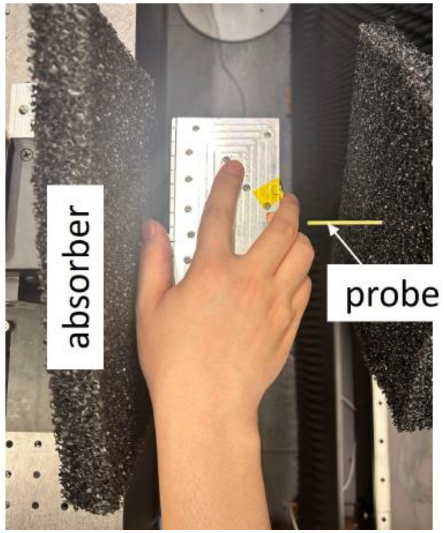
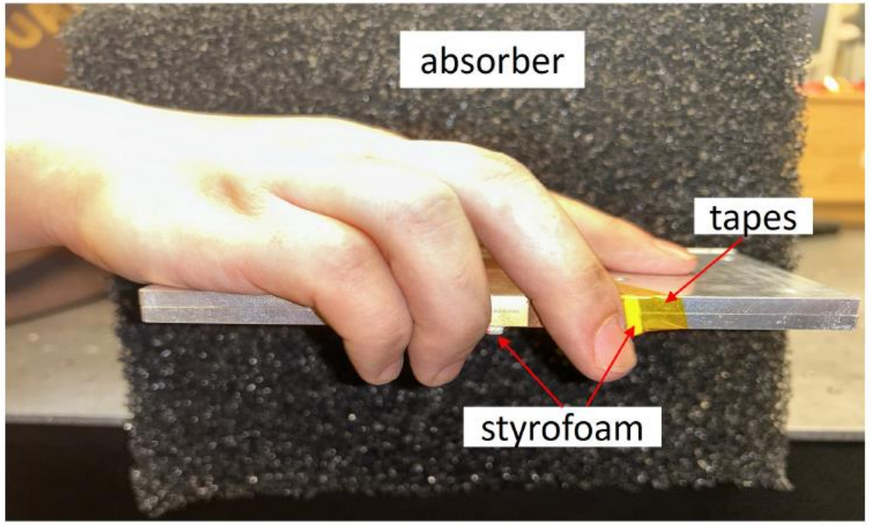
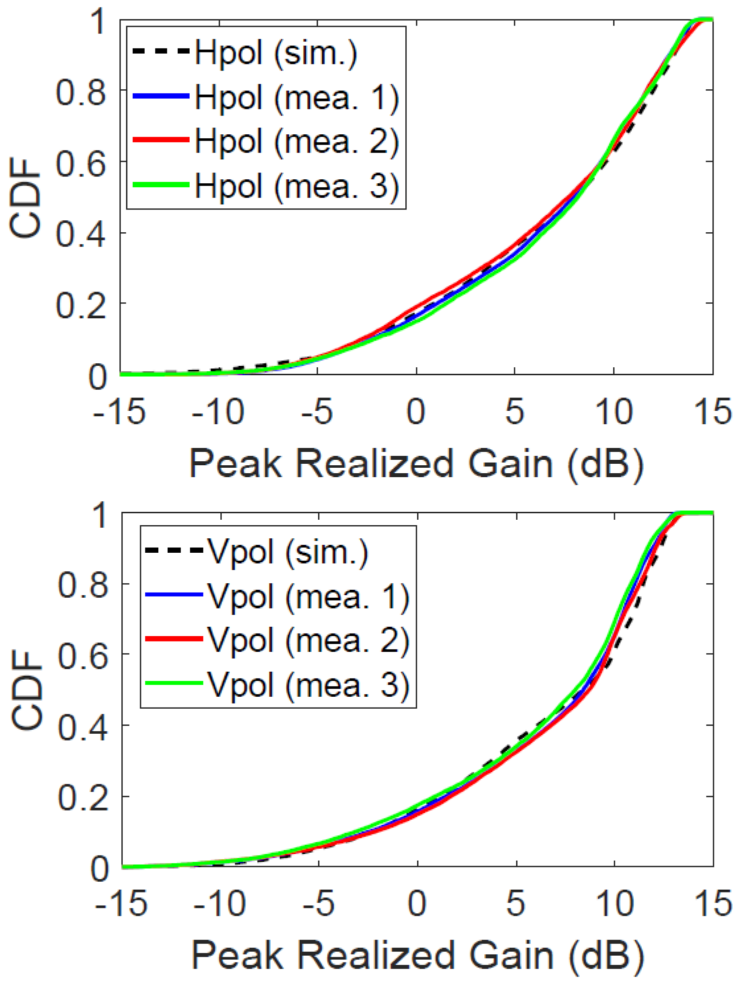




Spherical coverage



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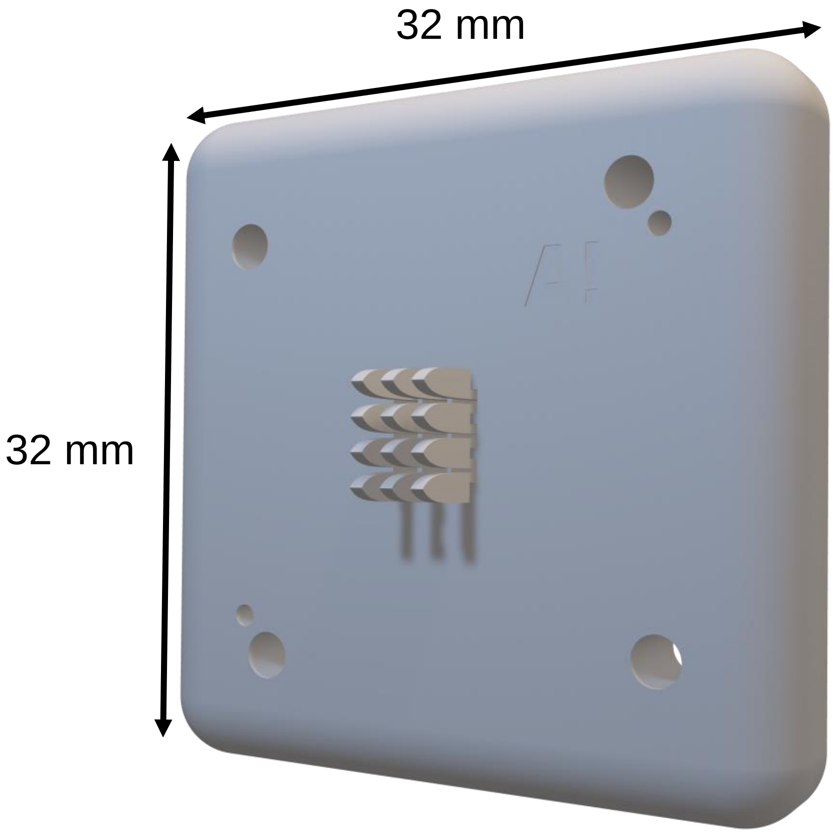
Metal 3D-printed array for 100 GHz

3-by-3 Vivaldi array

- Frequency range: W-band (75–110 GHz)
- Ground-plane size: 32 × 32 [mm]
- Element size: 1.5 × 1.5 × 4 [mm]



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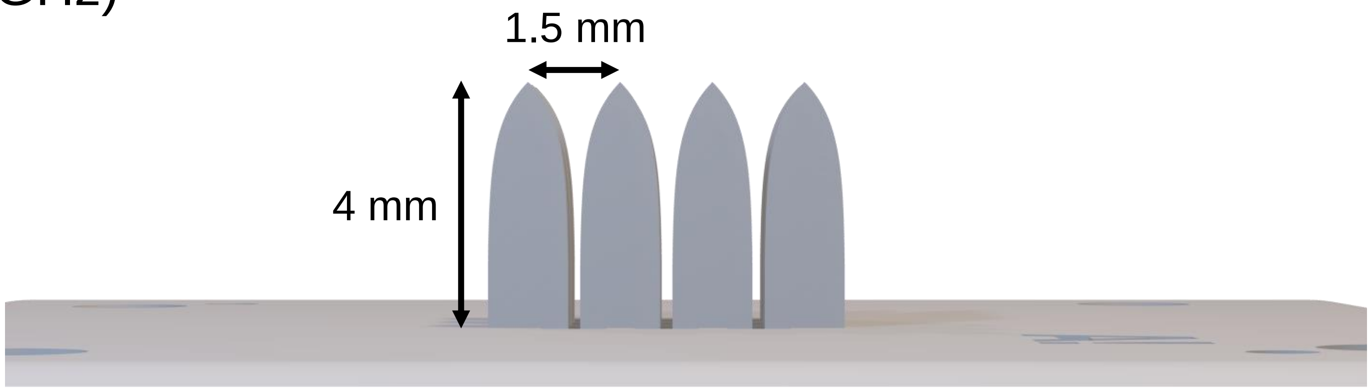

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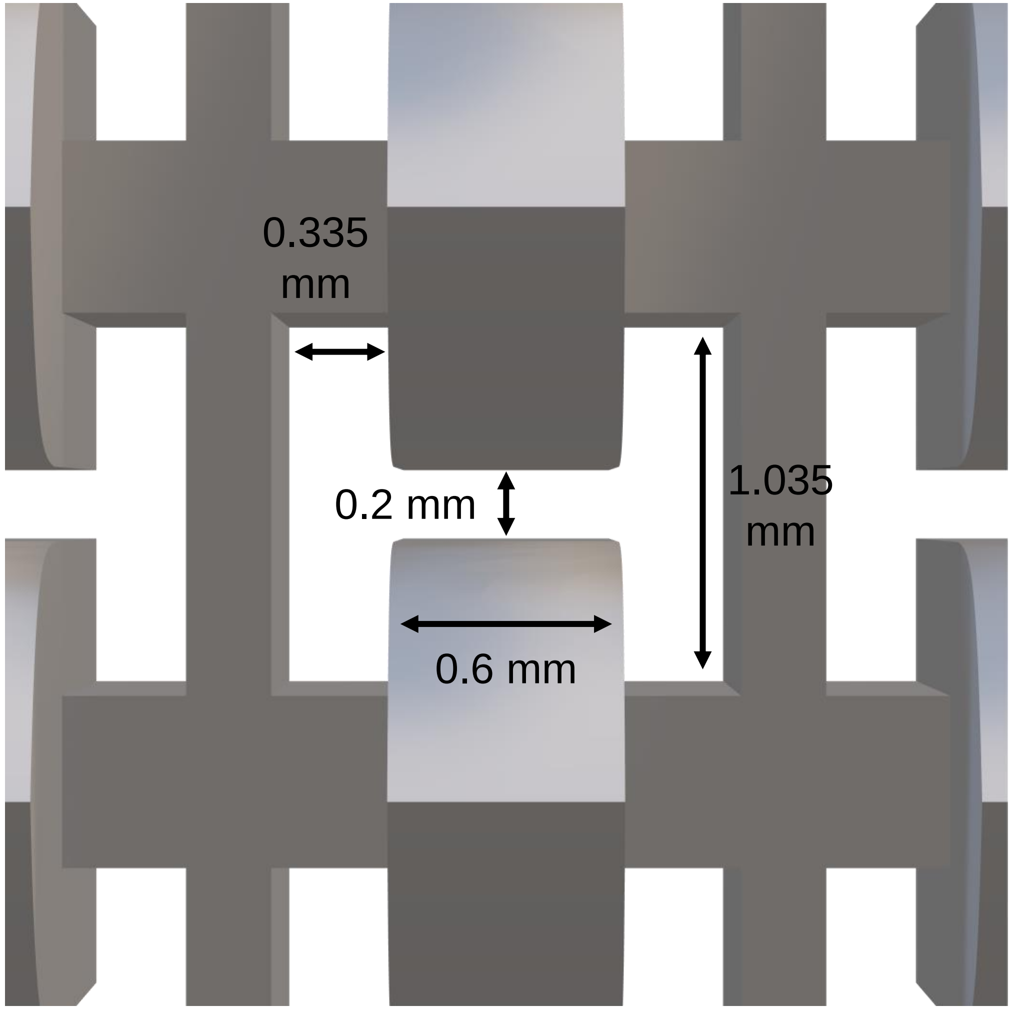
Metal 3D-printed array for 100 GHz

3-by-3 Vivaldi array

- Frequency range: W-band (75–110 GHz)
- Ground-plane size: 32 × 32 [mm]
- Element size: 1.5 × 1.5 × 4 [mm]
- Elements have ridged waveguides (RWG) terminated to Vivaldi antennas
  - Smallest dimension: 0.2 mm



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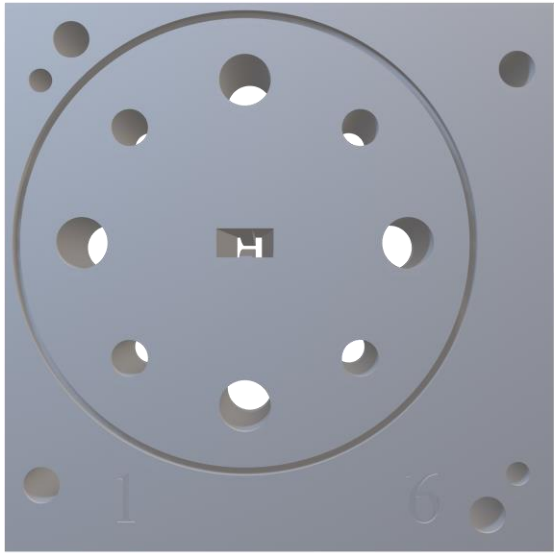
Metal 3D-printed array for 100 GHz

WR10-to-RWG transition

- One element excited at a time
  - Others terminated to a short circuit
- One transition used for one or two elements
  - Elements 1&9, 2&8, 3&7, 4&6, 5

Front of the array.

Transition for Elements 1&9



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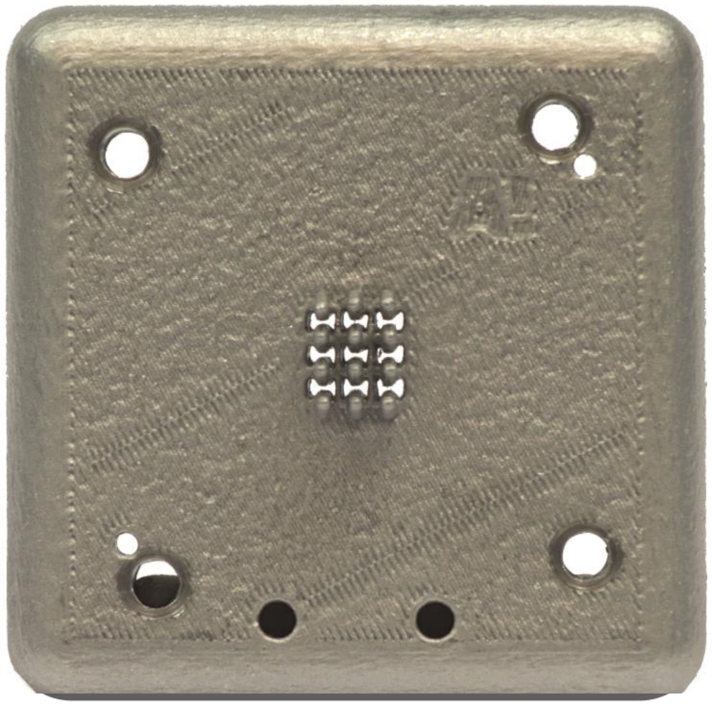
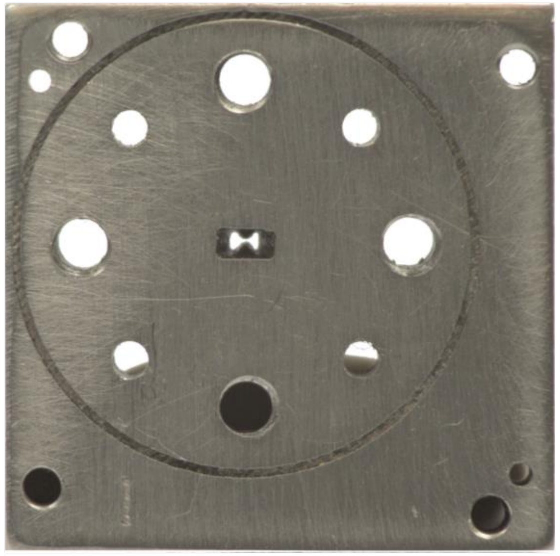
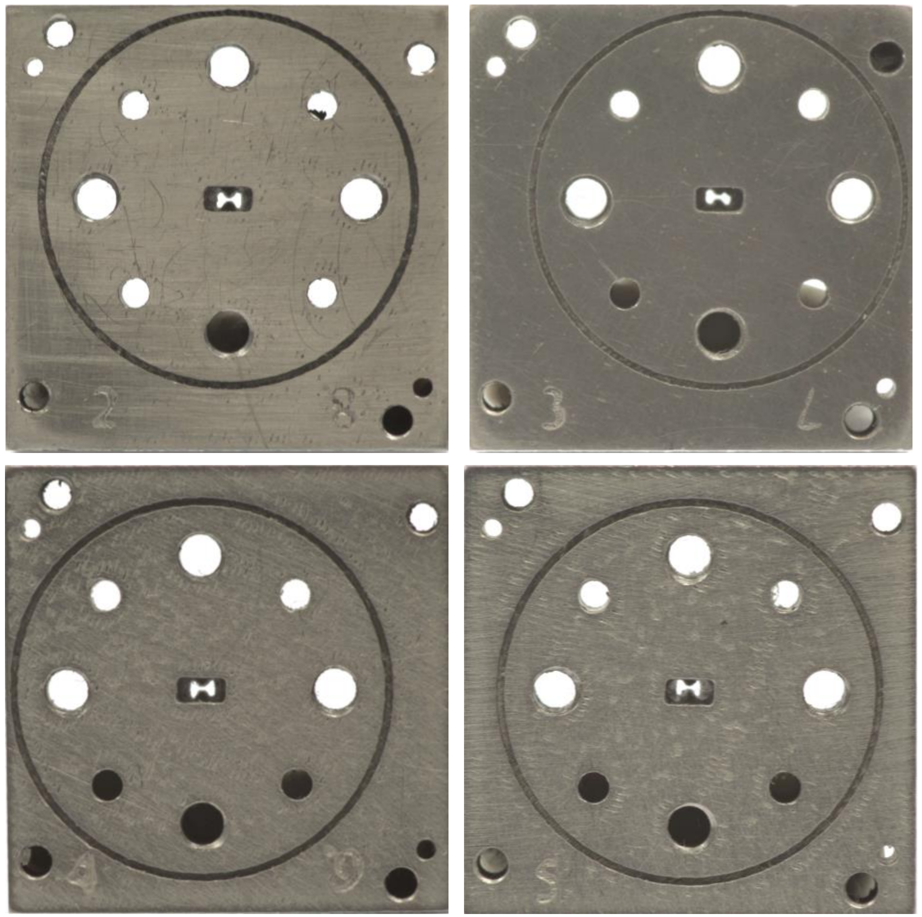
Metal 3D-printed array for 100 GHz

Manufactured prototype







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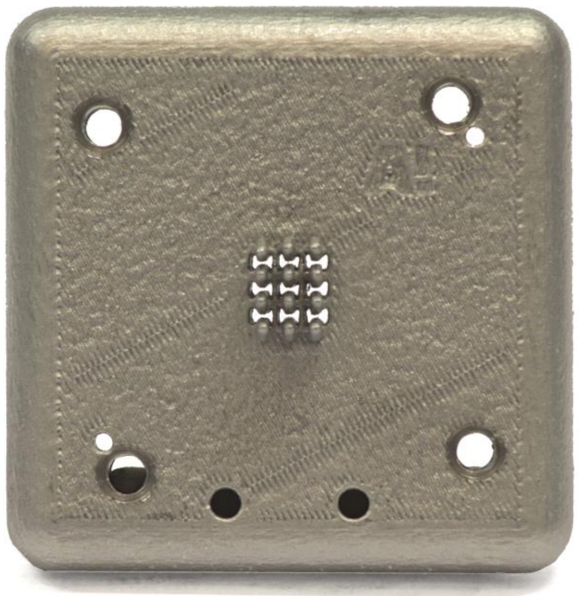
Metal 3D-printed array for 100 GHz

Aluminum (AlSi10Mg alloy)

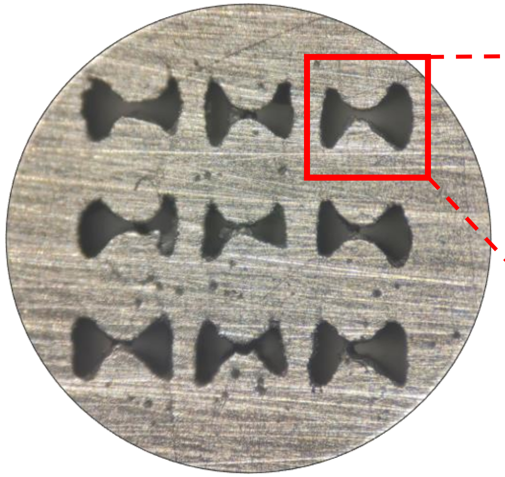
- $\sigma \approx 3.5 \times 10^7 \, \frac{\mathrm{S}}{\mathrm{m}}$
- Weight of the array: **13 g**

Quality of the print

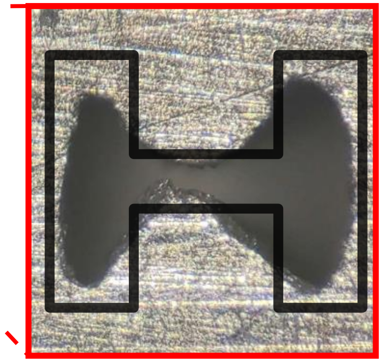
- Shapes are distorted
- Some elements were shorted
- Uniform along the RWG axis
- Postprocessing was required



Front of the array.



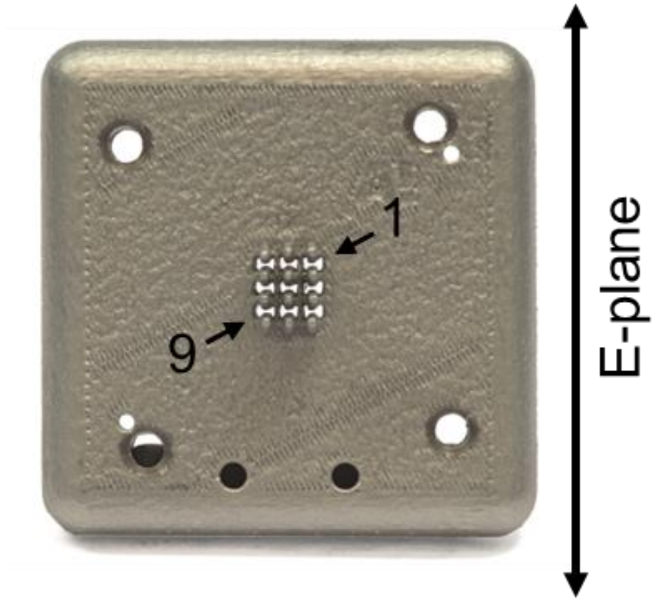
Closeup of the back.



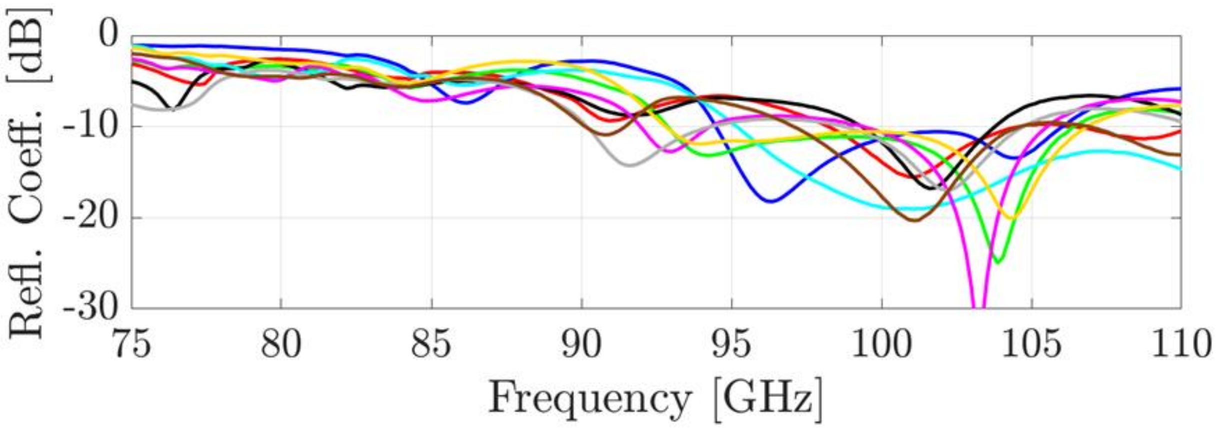
Manufactured RWG and outline of the intended shape.

J. Bergman et al., "Fully Metallic 3D-printed Vivaldi-antenna Array at 100 GHz," in *42nd ESA Antenna Workshop* (2024).

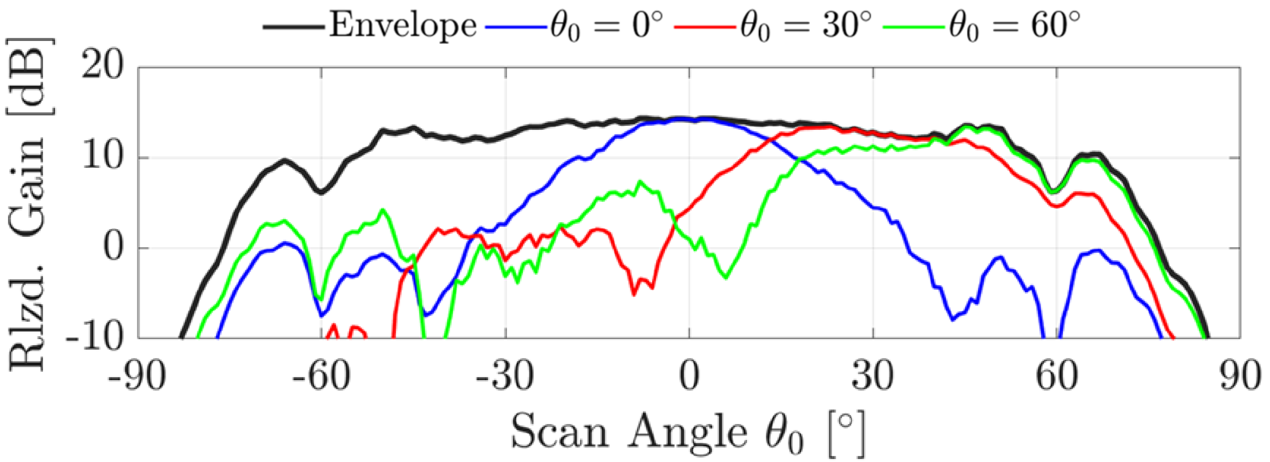
Metal 3D-printed array for 100 GHz



Measured results



Scan gain E-plane cuts at 100 GHz



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Summary

- Recent research on mm-wave antenna arrays at Aalto University was presented
- Surface mountable antenna arrays
  - Modularity, Cooling
- Dielectric dome lens for sparse arrays
- Arrays for mobile devices
- Metal 3D printing for W-band antennas

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Kiitos

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