We1B-2

Integrated Silicon Lens-Antenna based on a Top-Hat Leaky-Wave feed for Quasi-Optical Power Distribution at THz Frequencies

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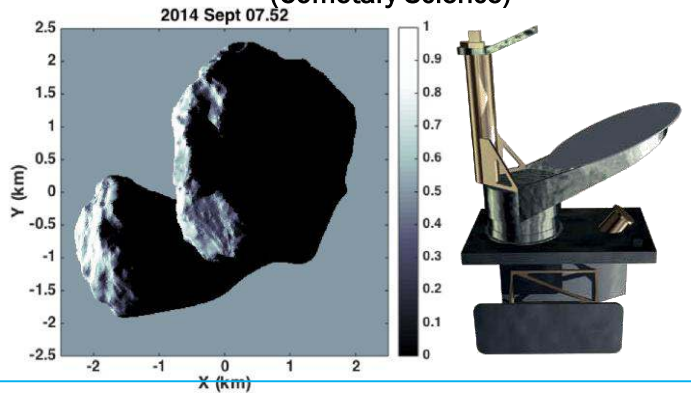
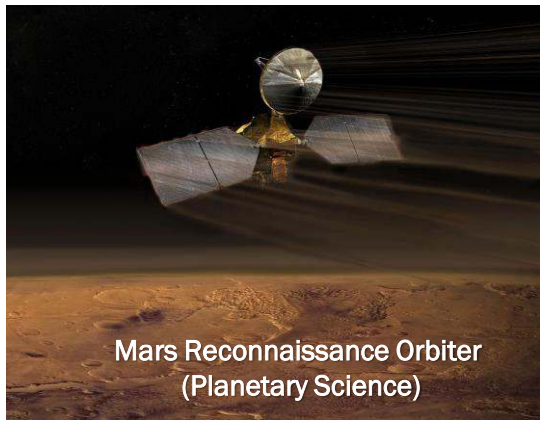
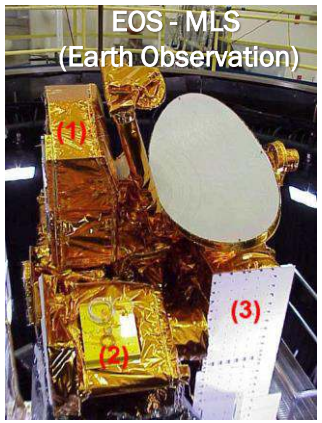
Heterodyne Instrument Requirements at Submillimeter Wavelengths

Rosetta / MIRO
(Cometary Science)

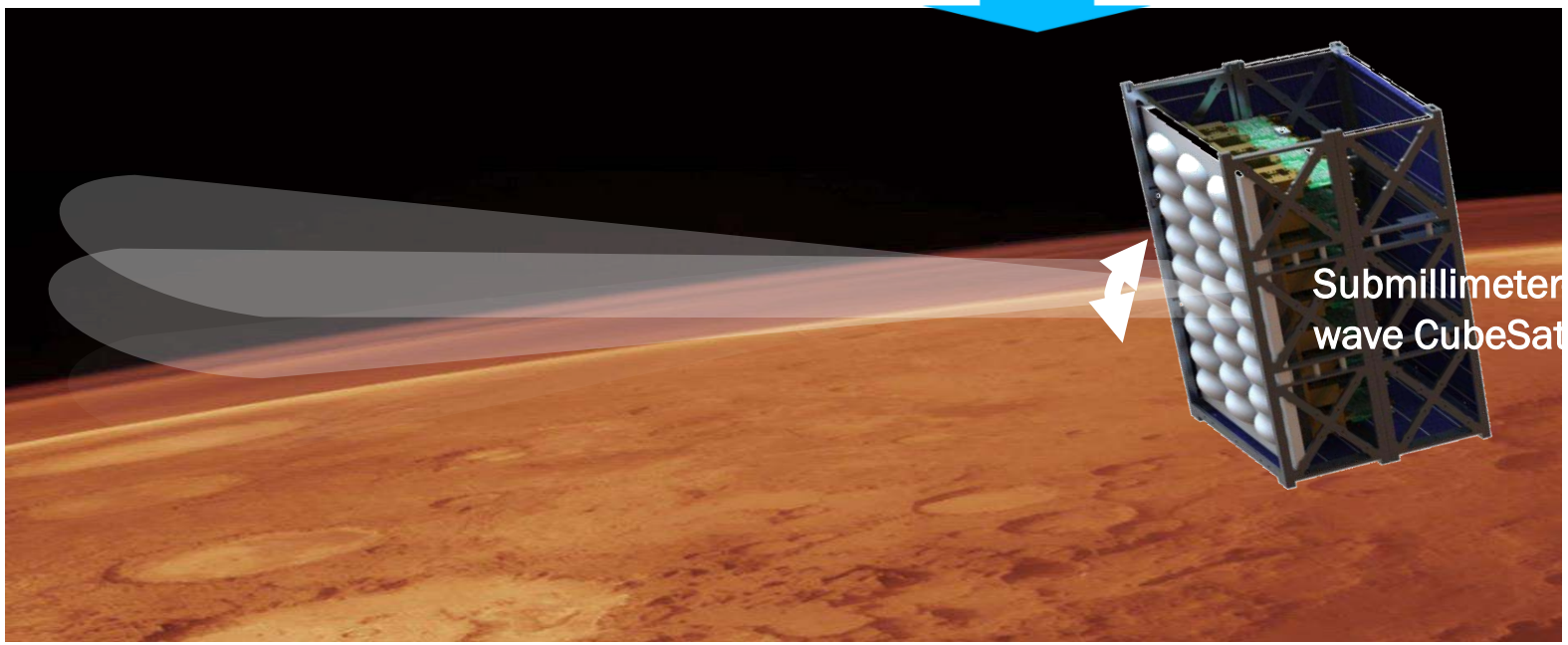






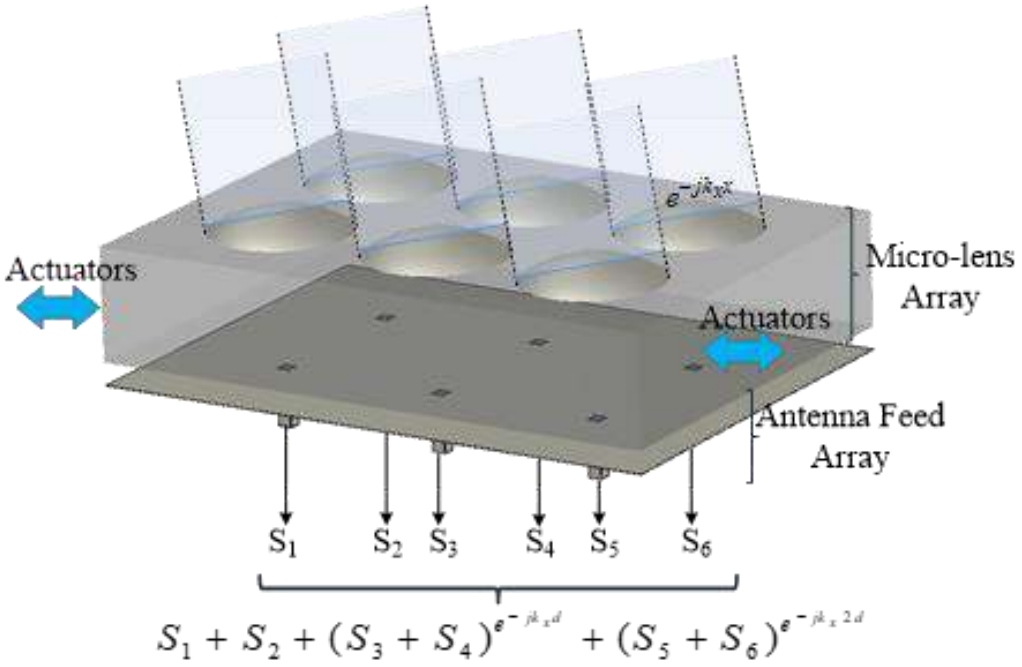
Opto-mechanical reflectors

- Bulky
- Slow
- Power consumption



- High-Gain (50 dBi)
- Bandwidth > 25 %
- Steerable ($\pm 25°$)
- Compact Antennas for Small-Sat Platforms

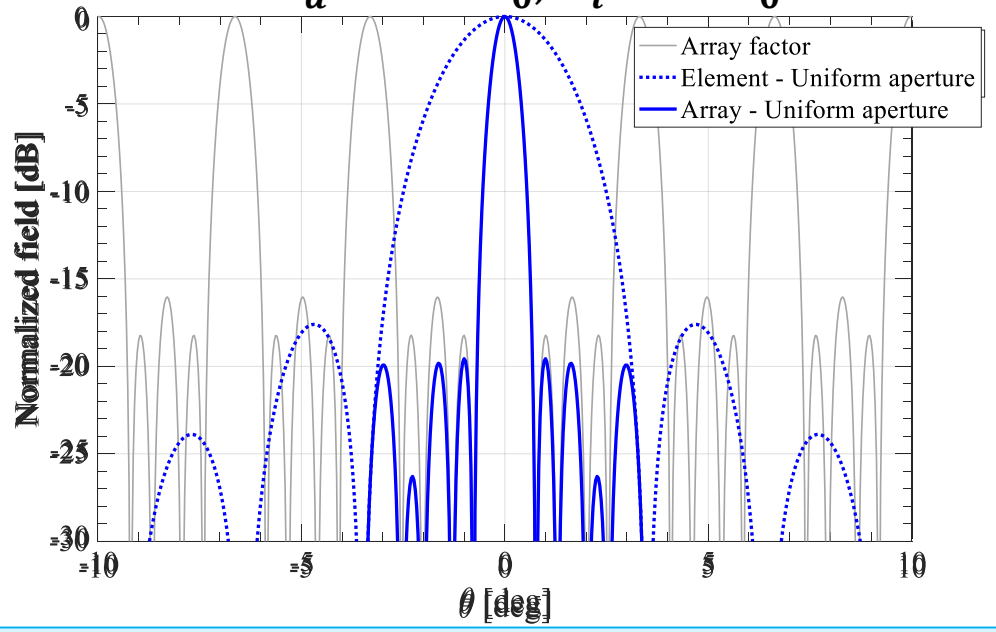
High Gain via Scanning Lens Phased Array



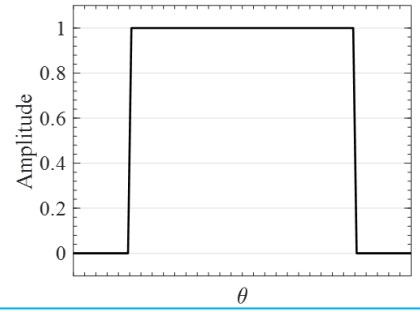
→ Low profile antenna with few active elements
→ Facilitates integration, reduces thermal problems

Lens Feed Requirement

$D_a = 100\lambda_0, D_l = 20\lambda_0$

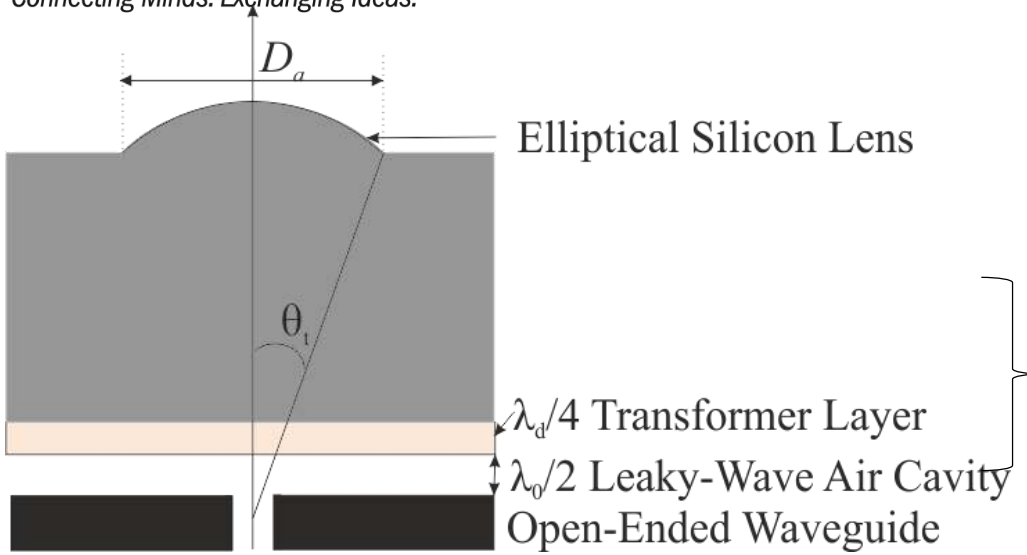


Low GLL → ***Uniform Aperture*** → Top Hat Lens Feed

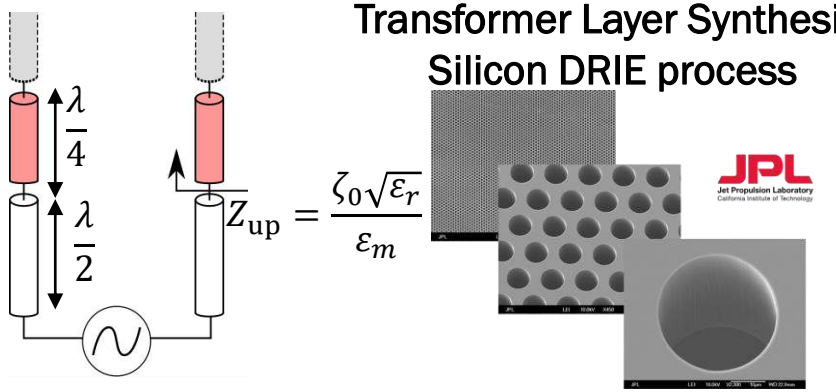


M. Alonso-delPino, S. Bosma, C. Jung-Kubiak, G. Chattopadhyay and N. Llombart, "Wideband Multimode Leaky-Wave Feed for Scanning Lens-Phased Array at Submillimeter Wavelengths," in *IEEE TTST*, March 2021

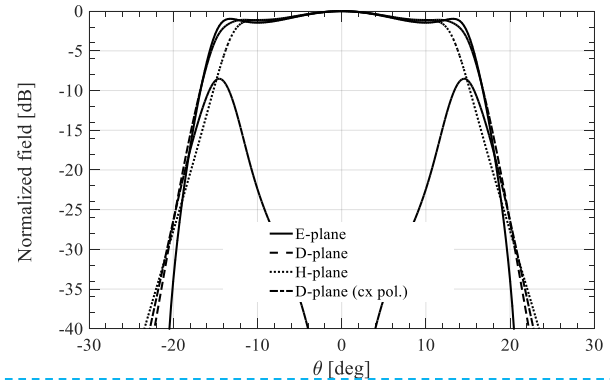
Multi-Mode LW Antenna at 550GHz

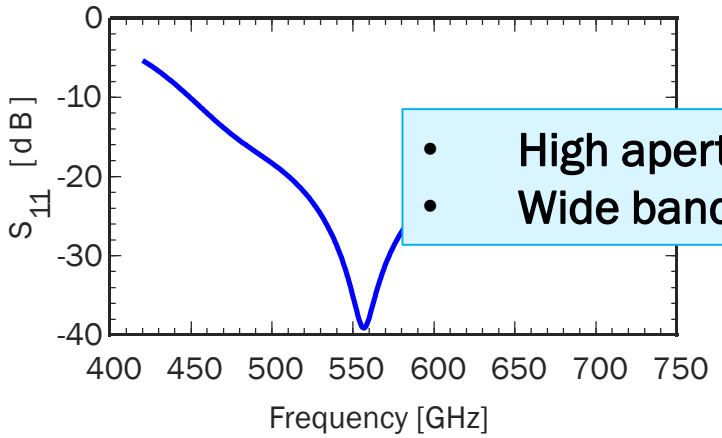


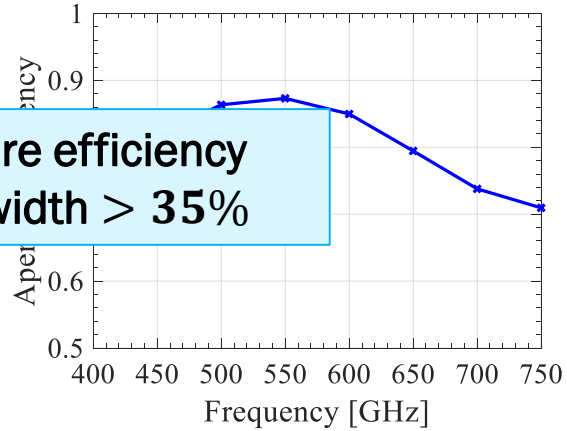
Multi-mode Leaky Wave Feed



Transformer Layer Synthesis: Silicon DRIE process

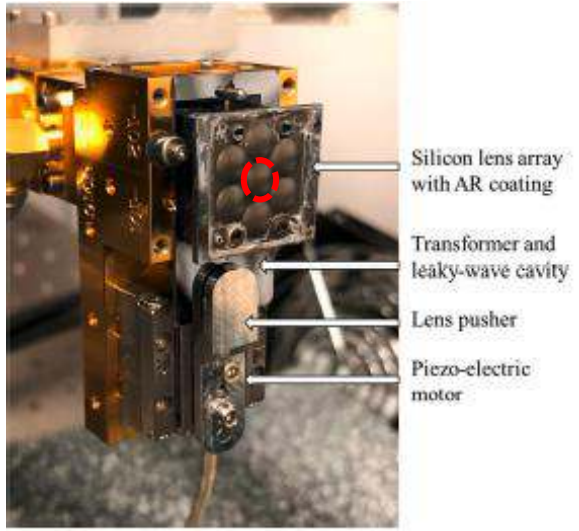


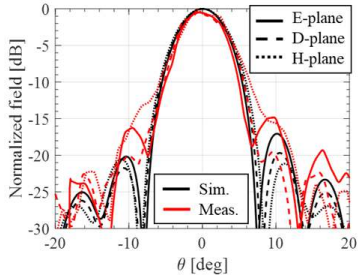


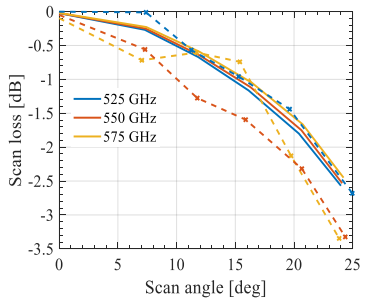


- High aperture efficiency
- Wide bandwidth > 35%

Demonstration of Embedded Element Pattern



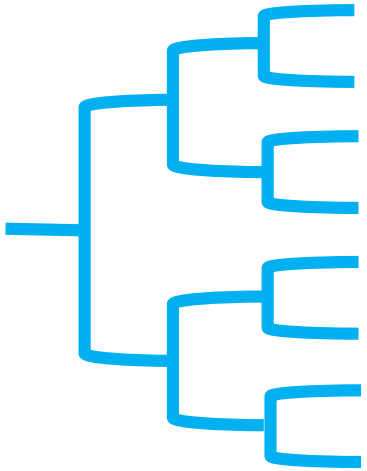




M. Alonso-delPino, S. Bosma, C. Jung-Kubiak, G. Chattopadhyay and N. Llombart, "Wideband Multimode Leaky-Wave Feed for Scanning Lens-Phased Array at Submillimeter Wavelengths," in *IEEE TTST*, March 2021

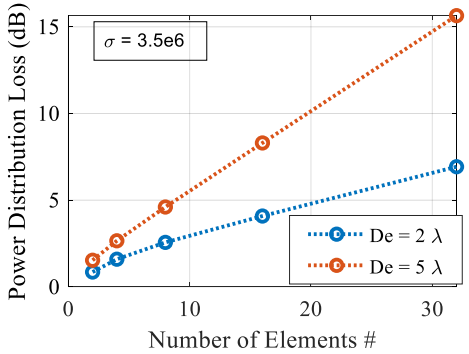
Power Distribution of Heterodyne Instrument at Submillimeter Wavelengths

Guided Power Distribution



Waveguide Based Distributions

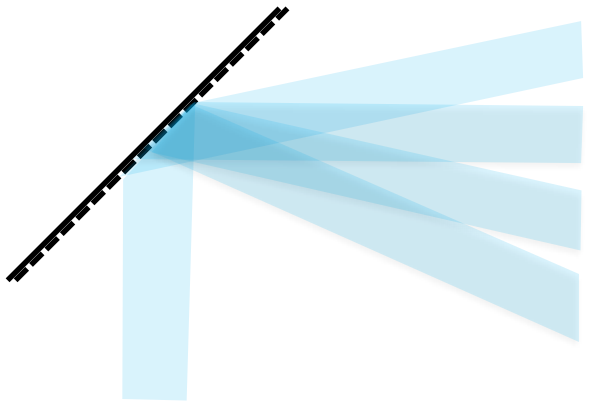
@ 550 GHz losses are around $0.2dB/\lambda$ [1]for $\sigma = 3.5e6$



☹ High loss
☹ Not scalable for large number of pixels

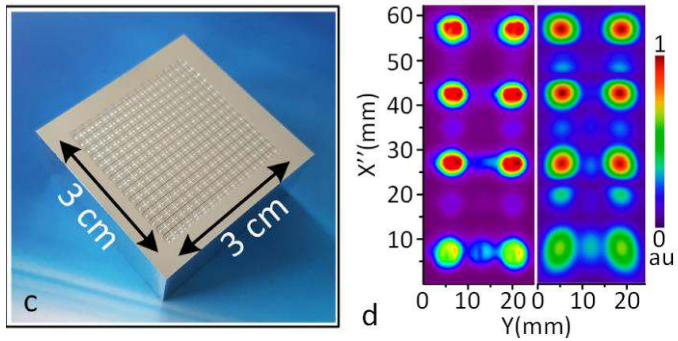
[1] M. Alonso-del Pino, et al "Micromachining for Advanced Terahertz: Interconnects and Packaging Techniques at Terahertz Frequencies," in *IEEE Microwave Magazine*, vol. 21, no. 1, pp. 18-34, Jan. 2020, doi: 10.1109/MMM.2019.2945157.

QO Power Distribution



Phase gratings

1.4 THz Grating 1 to 8 beams



☹ Narrow band (<5% bandwidth)
☹ Not scalable for large number of pixels

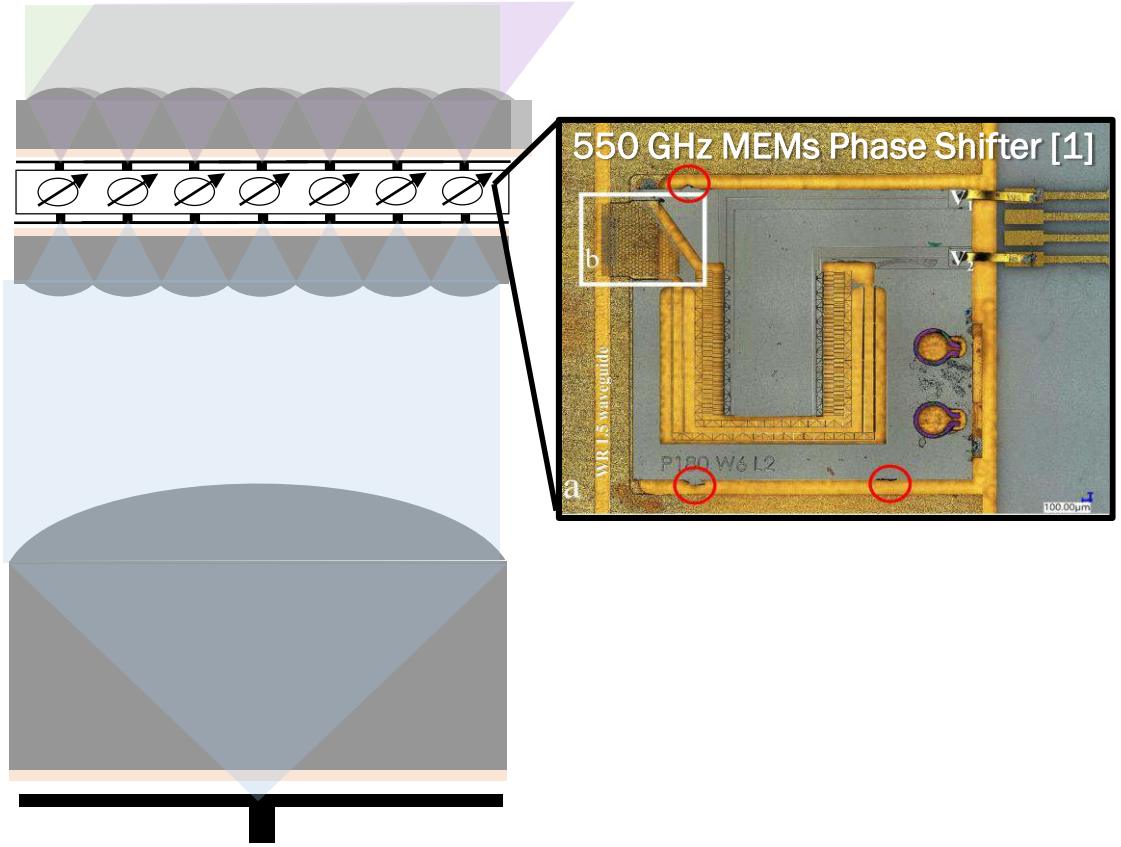
B. Mirzaei, et.al., "Efficiency of multi-beam Fourier phase gratings at 1.4 THz," Opt. Express 25, 6581-6588 (2017)

Proposed QO Coupling Architecture For arrays

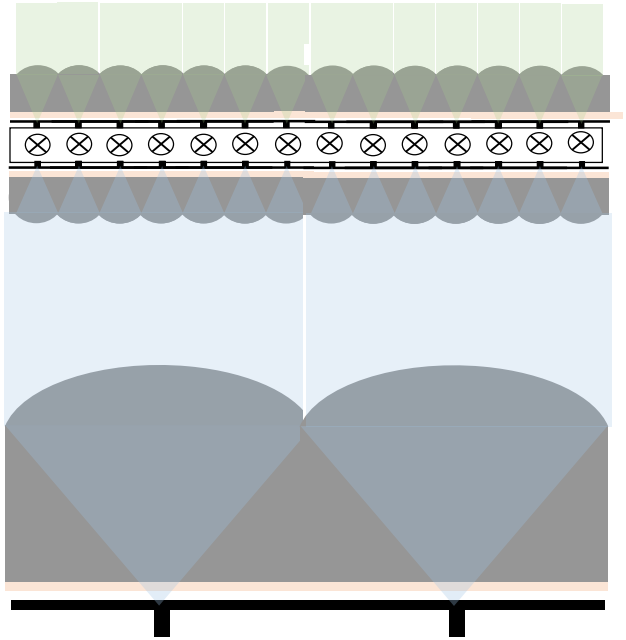
☺ Wide Bandwidth
☺ Low Loss
☺ Scalable for large number of pixels

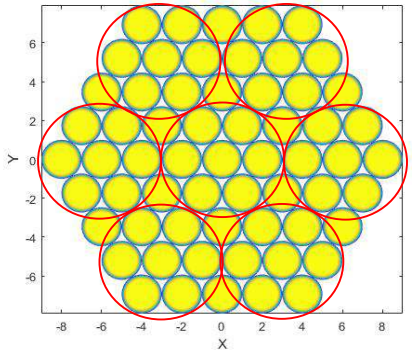
Lens Transmit Arrays for Submillimeter-Wave Instruments

Scanning Lens Phased Arrays



Focal Plane Arrays





A 550GHz source of 30mW[2] can feed around:

- 15 Schottky mixers
- >1000 SIS mixers

[1] S. Rahiminejad, M. Alonso-delPino, T. Reck, A. Peralta, R. Lin, C. Jung-Kubiak, G. Chattopadhyay,"A Low-Loss Silicon MEMS Phase Shifter Operating in the 550-GHz Band," in *IEEE Transactions on Terahertz Science and Technology*, vol. 11, no. 5, pp. 477-485, Sept. 2021, doi: 10.1109/TTHZ.2021.3085123.

[2] J. V. Siles, K. B. Cooper, C. Lee, R. H. Lin, G. Chattopadhyay and I. Mehdi, "A New Generation of Room-Temperature Frequency-Multiplied Sources With up to 10× Higher Output Power in the 160-GHz–1.6-THz Range," in IEEE Transactions on Terahertz Science and Technology, vol. 8, no. 6, pp. 596-604, Nov. 2018, doi: 10.1109/TTHZ.2018.2876620.

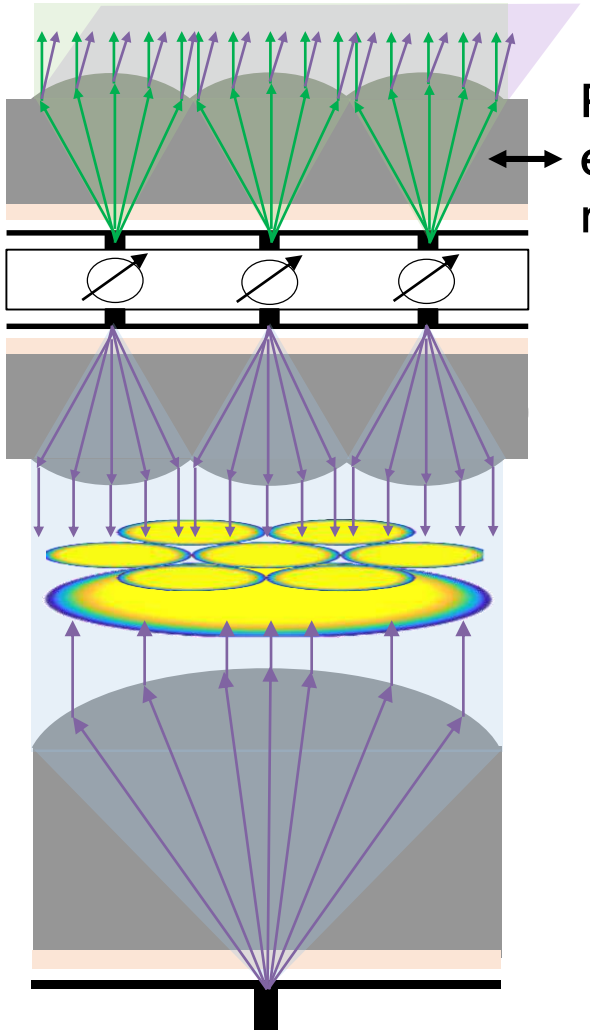
Proof of Concept at 550GHz in Silicon micromachining

Scanning Lens Phased Array

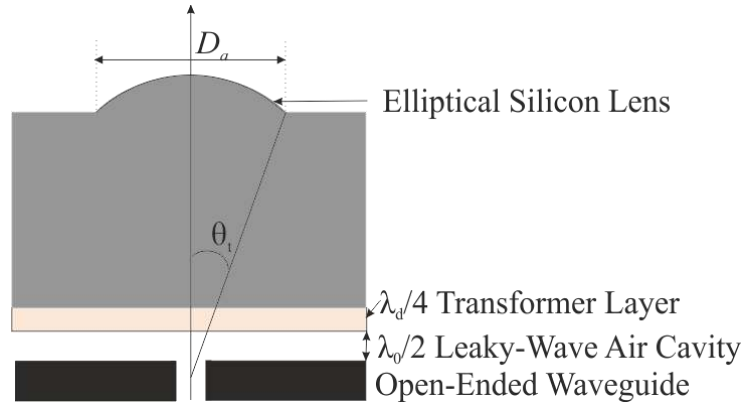
Phase shifter array

Lens Array

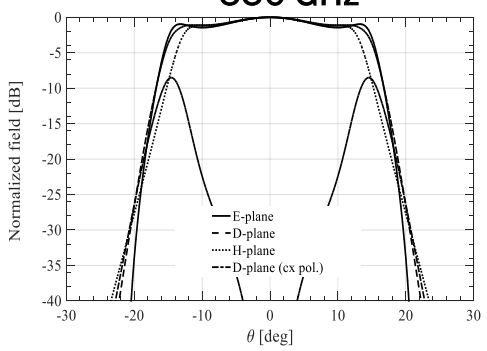
QO Power Distribution via Lens Antenna

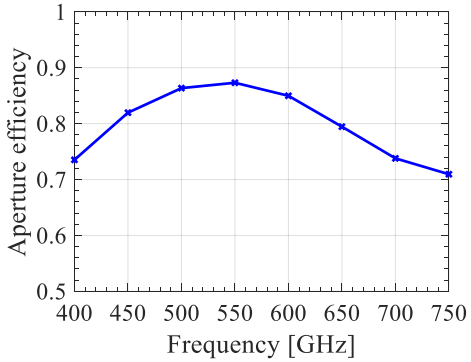


Multi-Mode LW Antenna



550 GHz





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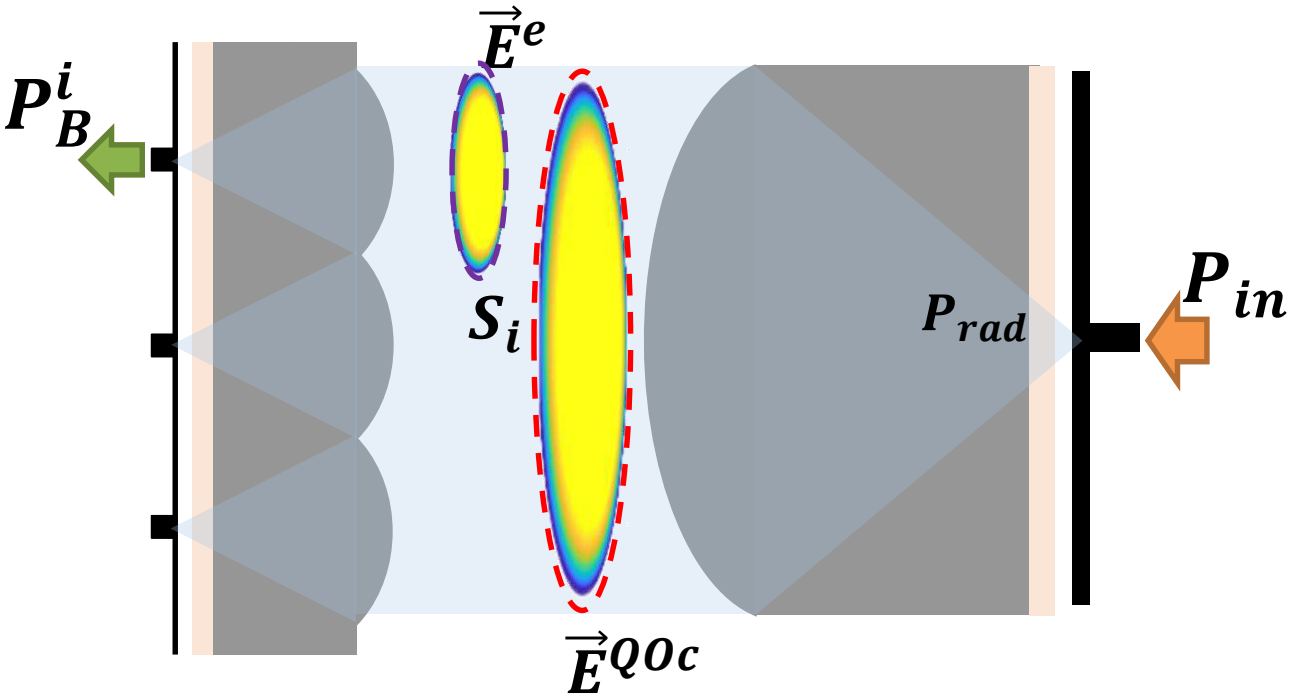
Analysis of the Power distribution into the Array



- Coupling efficiency from a single lens antenna to the array of waveguides:

$$\eta_P = \frac{1}{P_{in}} \sum_{i=1}^{N} P_B^i$$

- Power received on the lens array element *i*:

$$P_B^i = \frac{\left|(V_{oc}I)^{(i)}\right|^2}{16P_{rad}}$$

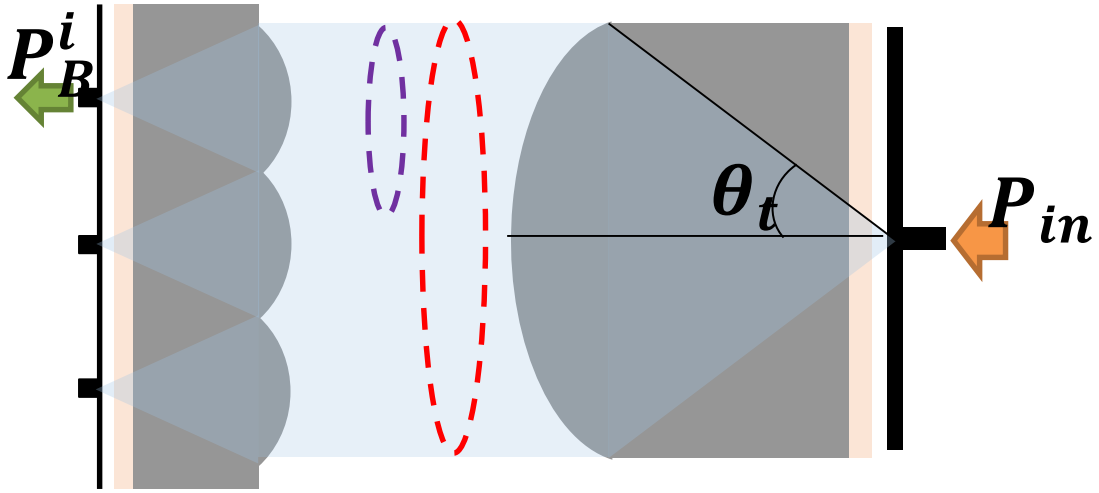
$\vec{E}_i^e$ and $\vec{E}^{top\ hat}$ obtained using a GO field propagation in the near-field and far-field from [2]

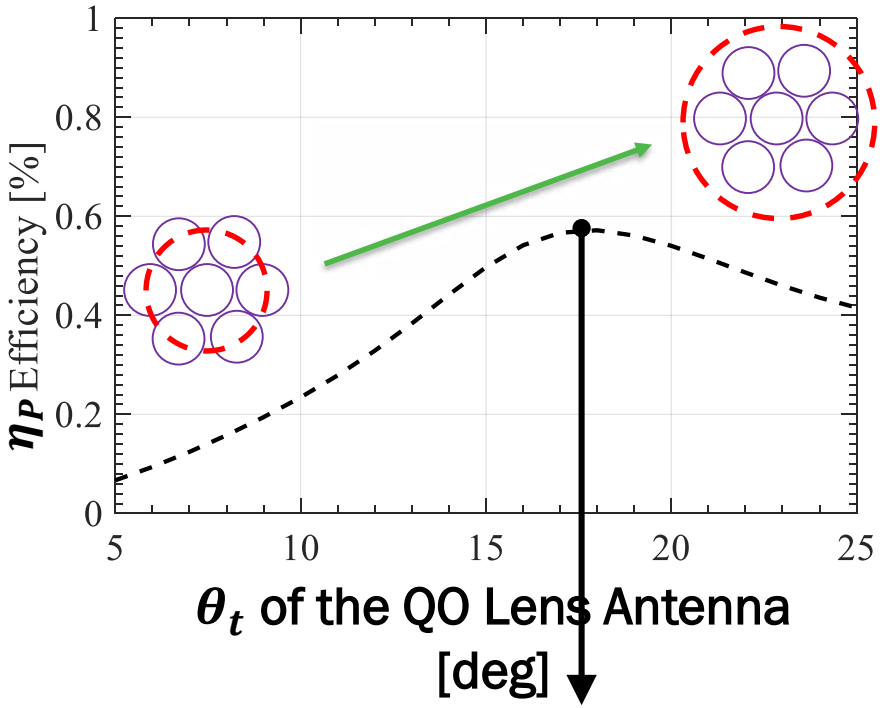
$$(V_{oc}I)^{(i)} = \frac{2}{\zeta_0} \iint_{S^i} \vec{E}_{\mathrm{i}}^e \cdot \vec{E}^{QOc}\, \mathrm{d}\boldsymbol{S}$$

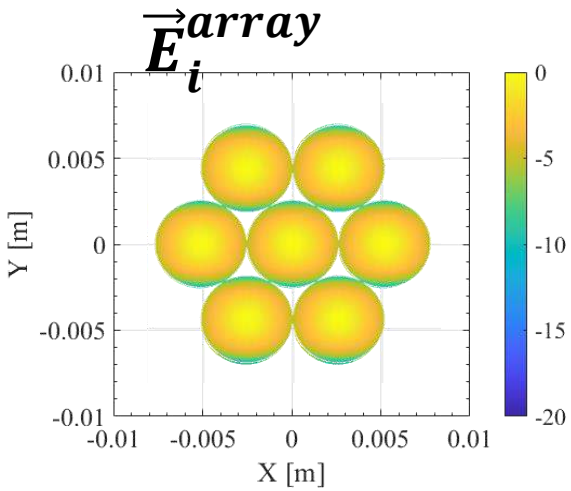
[1] M. Arias Campo, D. Blanco, S. Bruni, A. Neto and N. Llombart, "On the Use of Fly's Eye Lenses with Leaky-Wave Feeds for Wideband Communications," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 4, pp. 2480-2493, April 2020, doi: 10.1109/TAP.2019.2952474

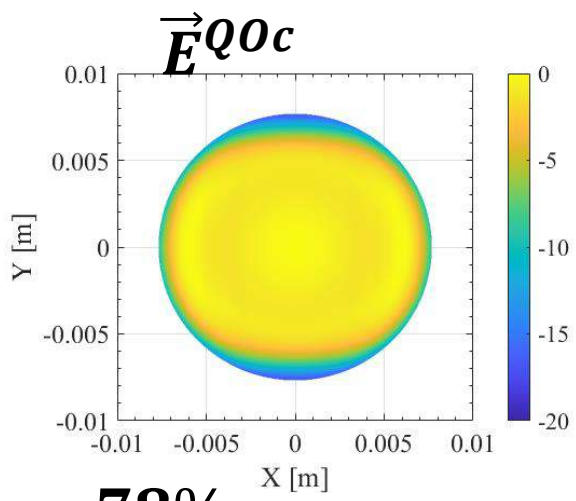
[2] H. Zhang, S. O. Dabironezare, G. Carluccio, A. Neto and N. Llombart, "A GO/FO Tool for Analyzing Quasi-Optical Systems in Reception," 2019 44th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), Paris, France, 2019, pp. 1-2, doi: 10.1109/IRMMW-THz.2019.8873950.

Optimization of the Power distribution into the Array

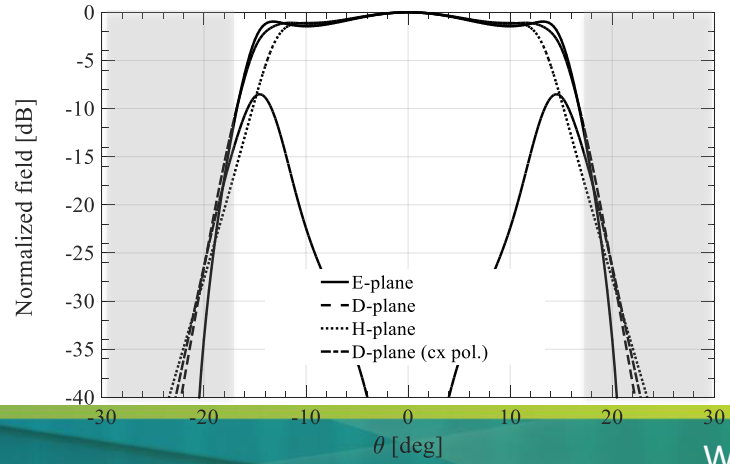




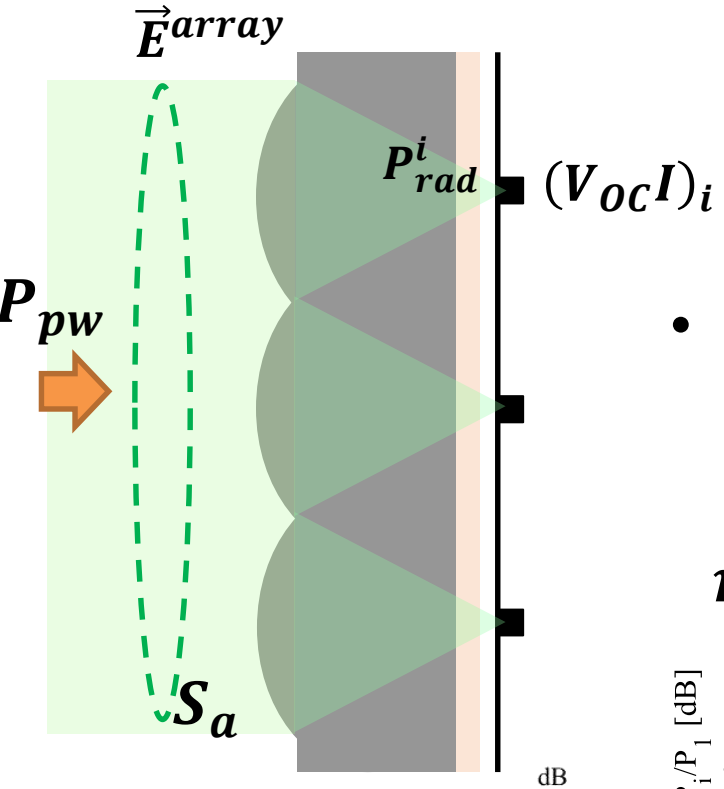




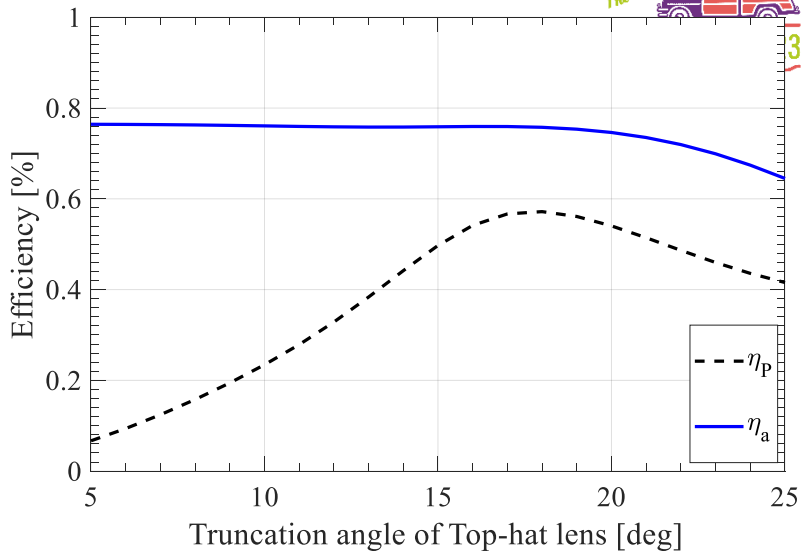
$$\eta_{fill-factor} \approx 78\%$$



Lens Transmit Array Analysis



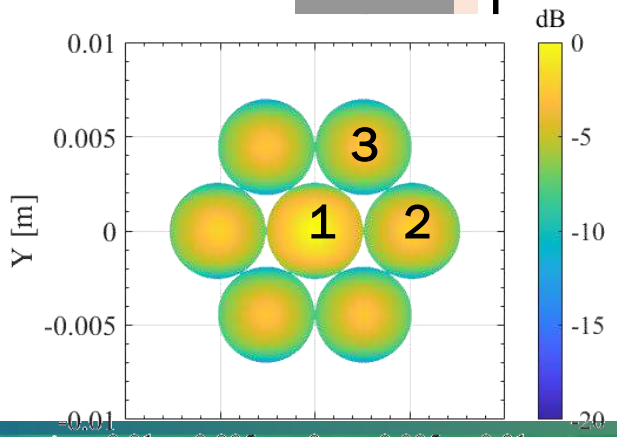
$$\vec{E}^{array} = \sum_{i=1}^{7} \vec{E}_i^e \cdot (V_{OC}I)_i$$

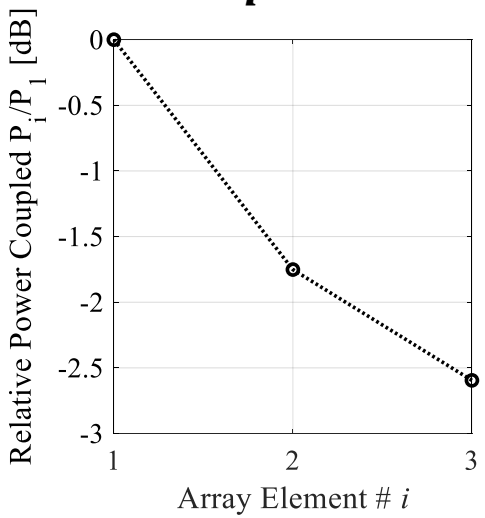


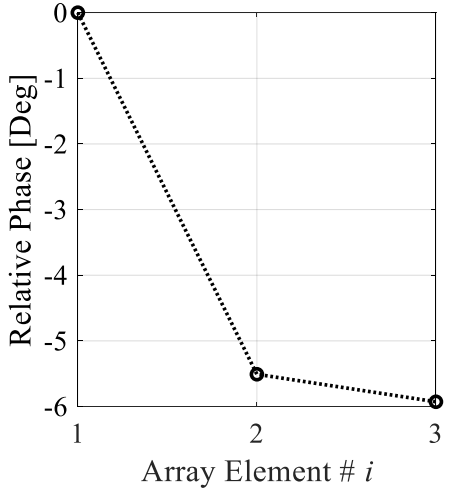
- Aperture efficiency of the lens phased array:

$$\eta_a = \frac{1}{P_{pw}} \frac{\left|(V_{oc}I)_{array}\right|^2}{16\sum_{i=1}^{N} P^i_{rad}}$$

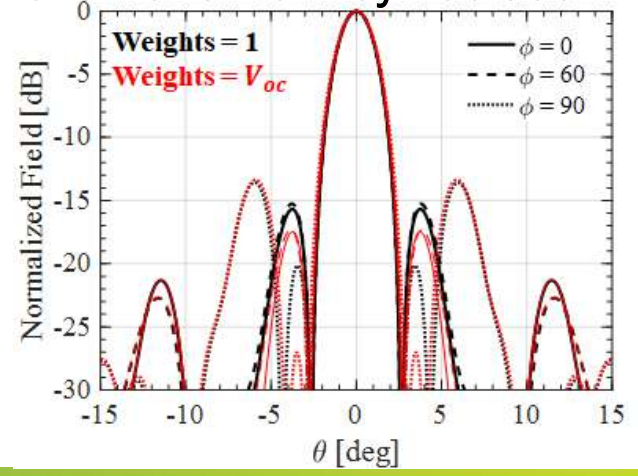
$$(V_{oc}I)_{array} = \frac{2}{\zeta_0} \iint_{S_a} \vec{E}^{array} \cdot \vec{E}^{pw}\, dS$$



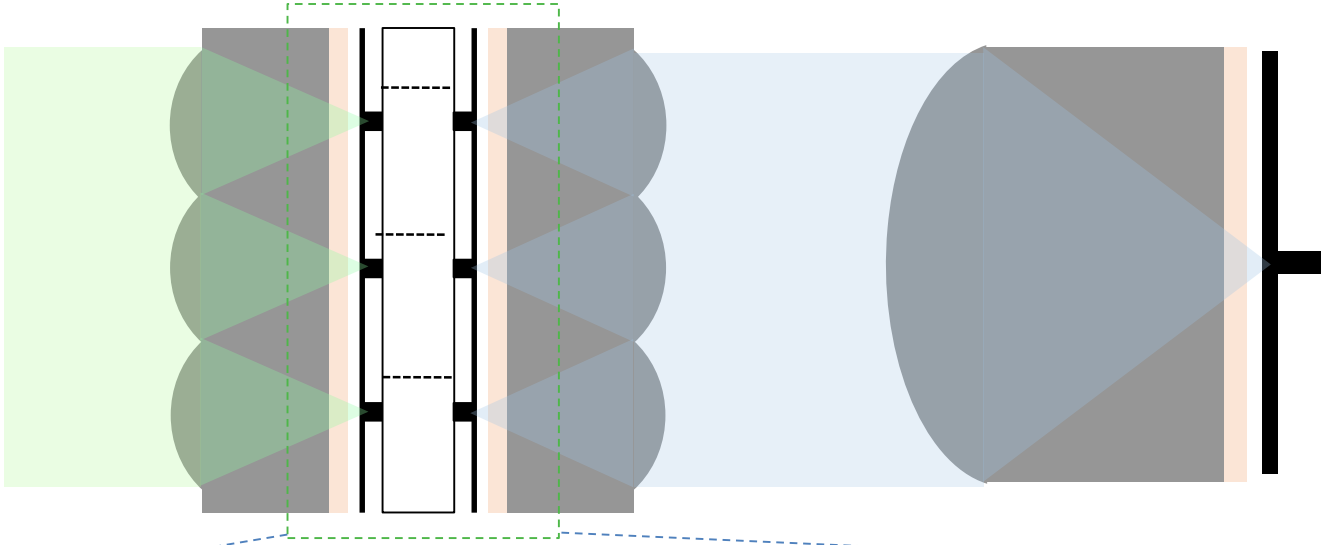




Lens Transmit Array Radiation Pattern



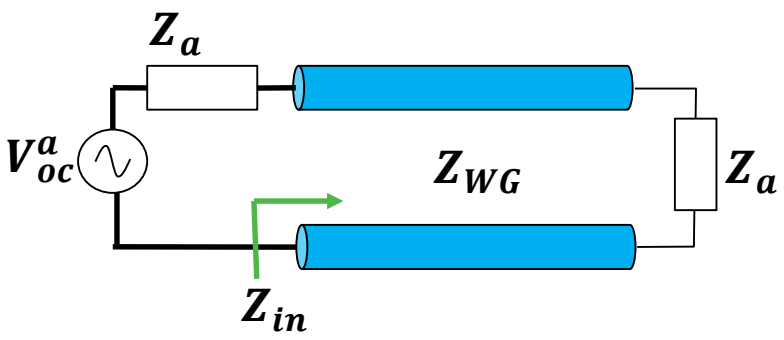
Lens Transmit Array Performance

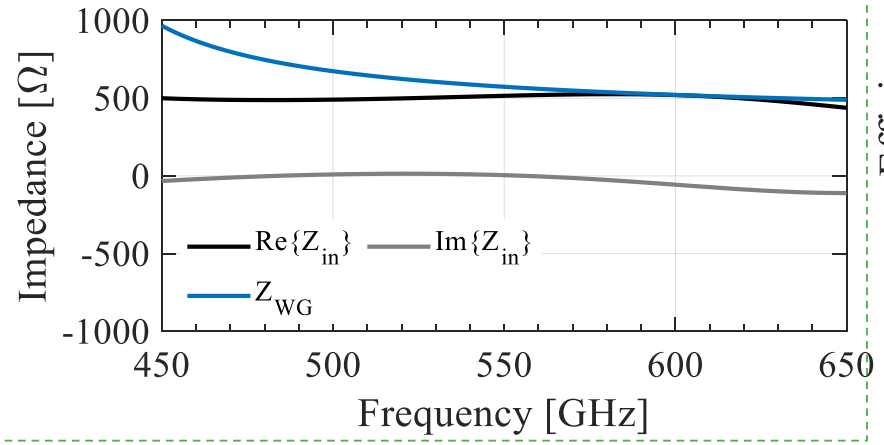


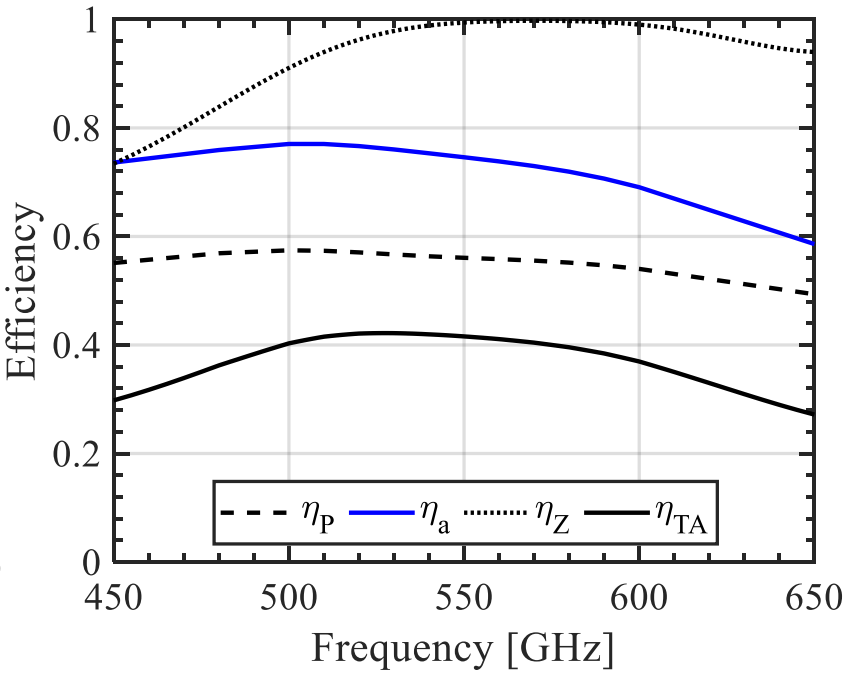
- Aperture Efficiency of the lens transmit array:

$$\eta_{TA} = \eta_P \cdot \eta_a \cdot \eta_z$$

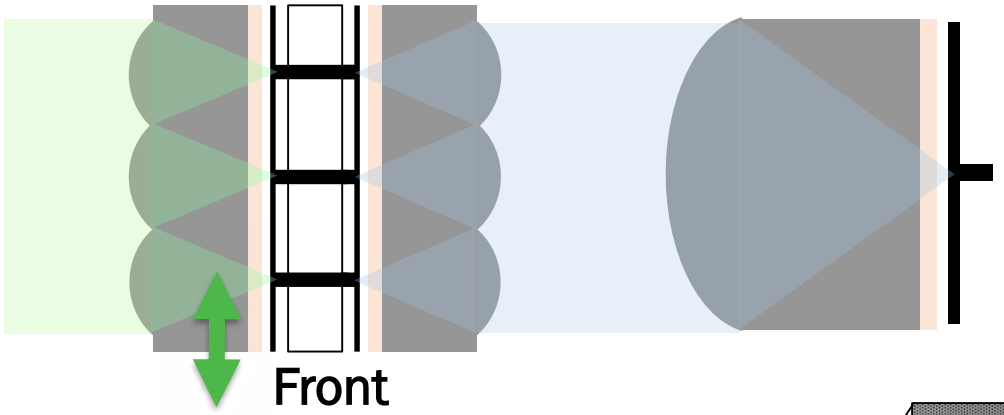
Equivalent transmission line model of the transmit array:



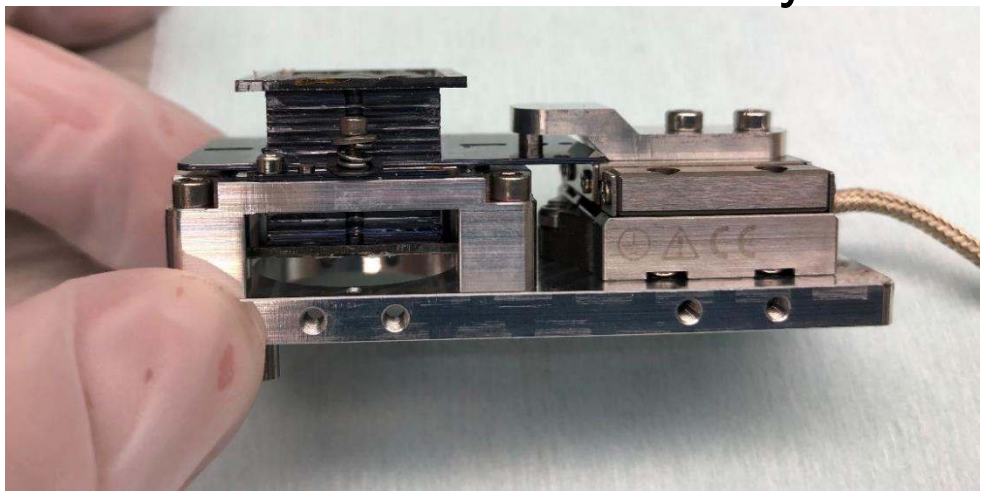


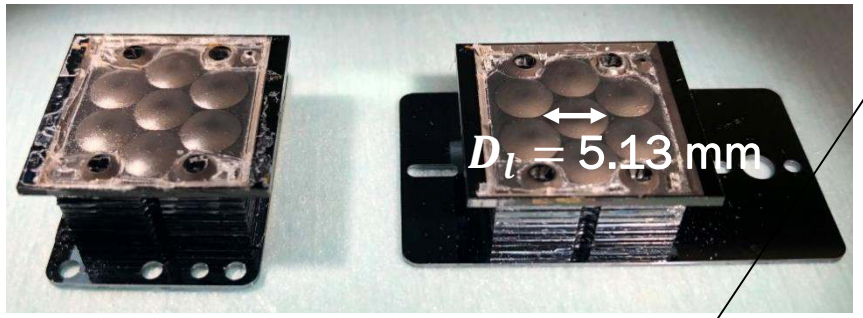


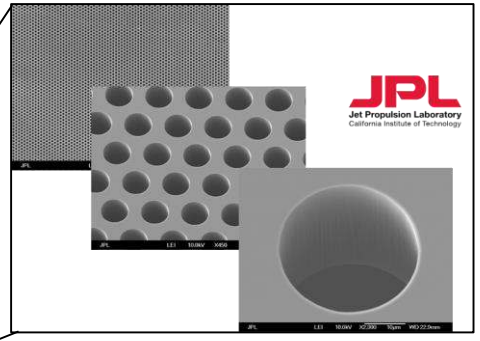
Coherent Proof of concept demonstration at 450-650GHz

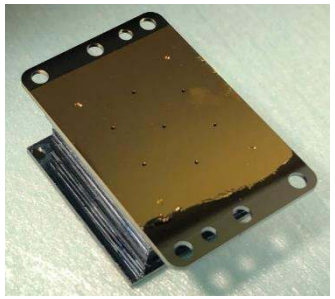


Transmit Phased Array

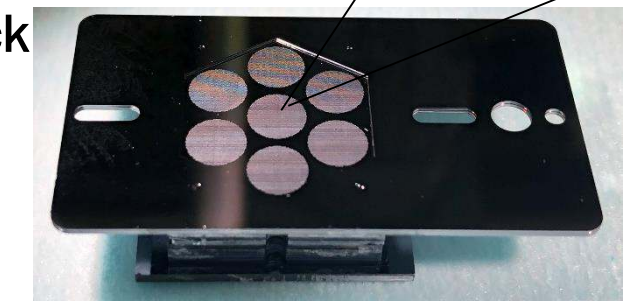




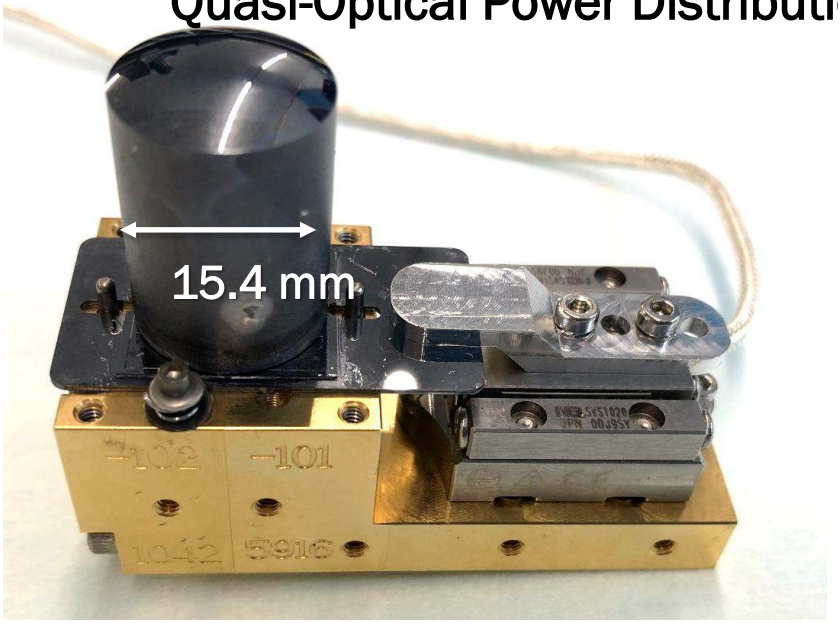




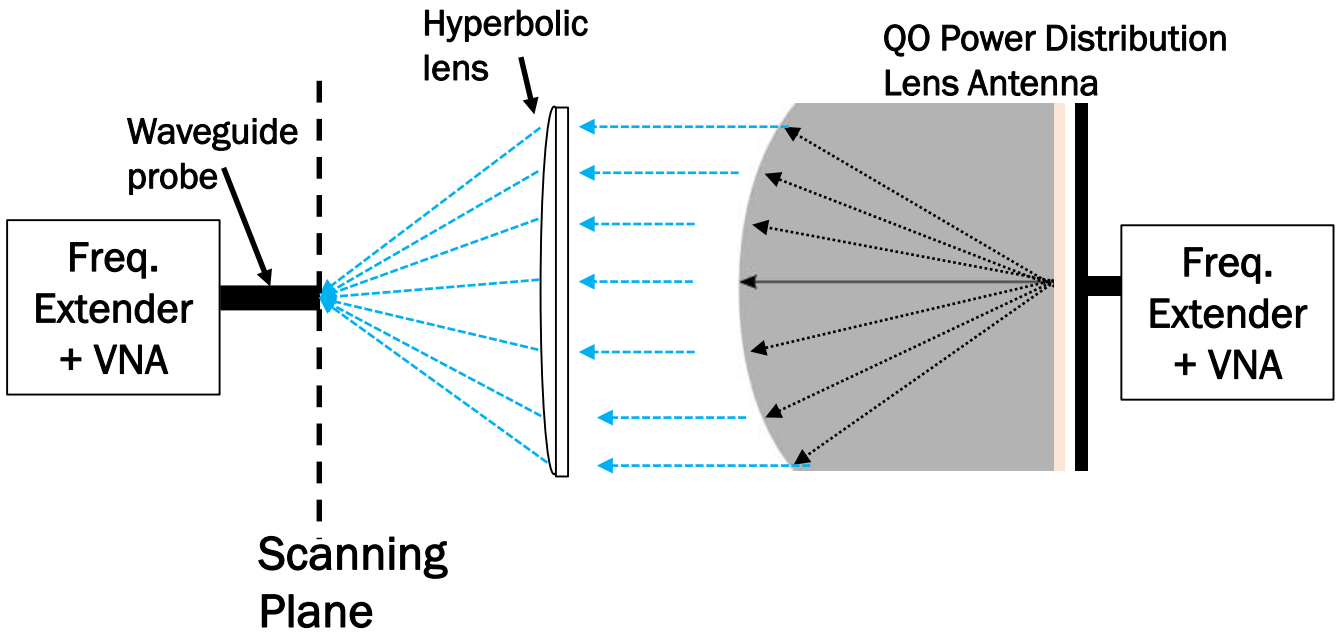
Back

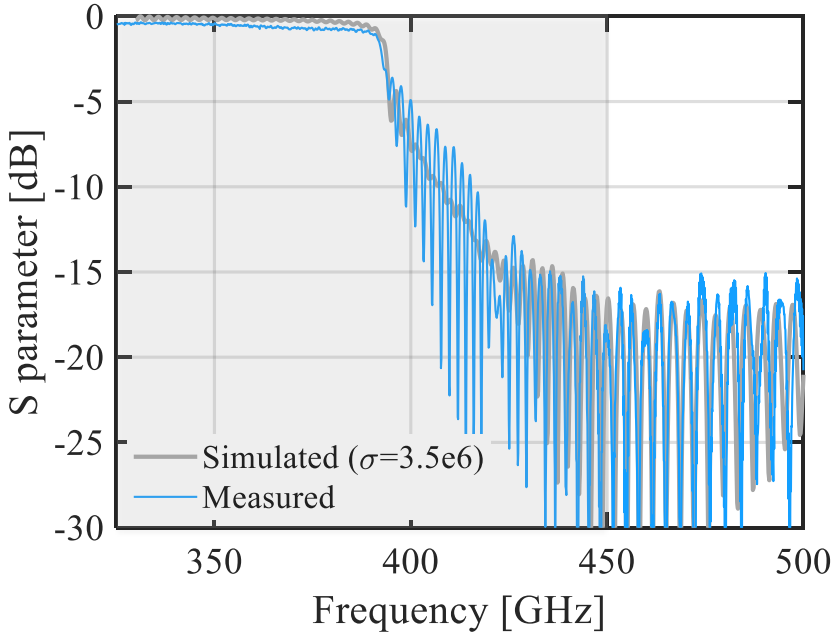


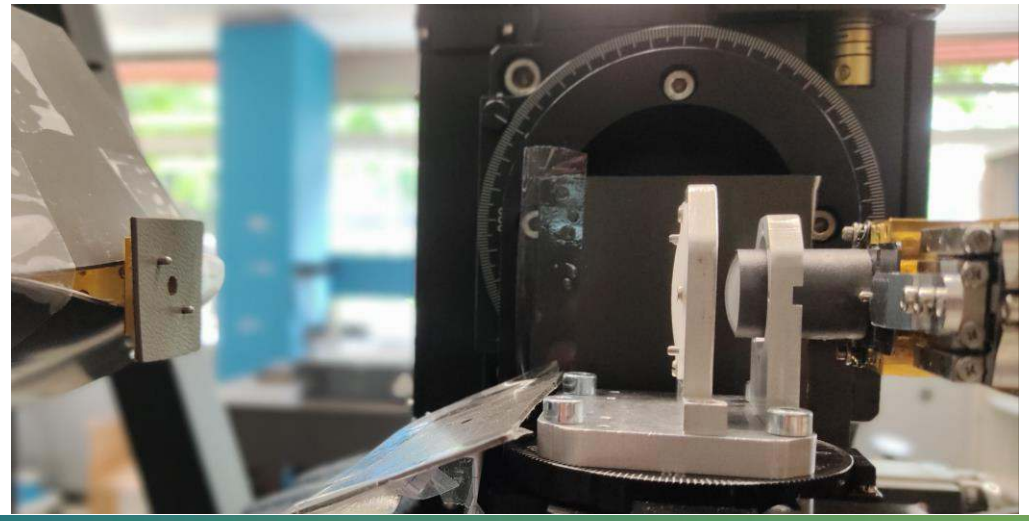
Quasi-Optical Power Distribution

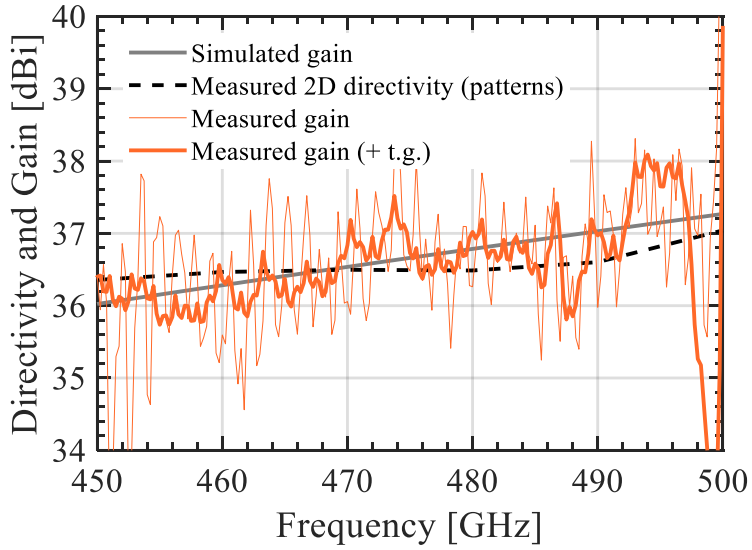


QO Power Distribution Lens Measurements

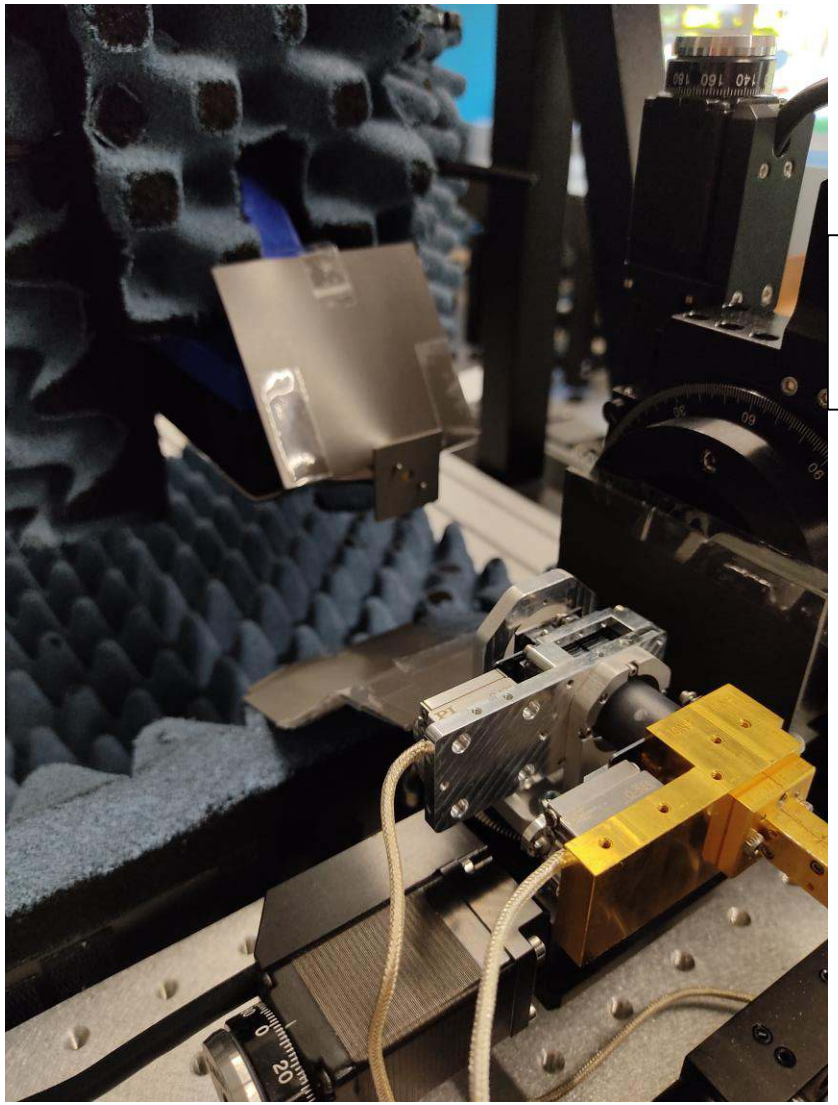


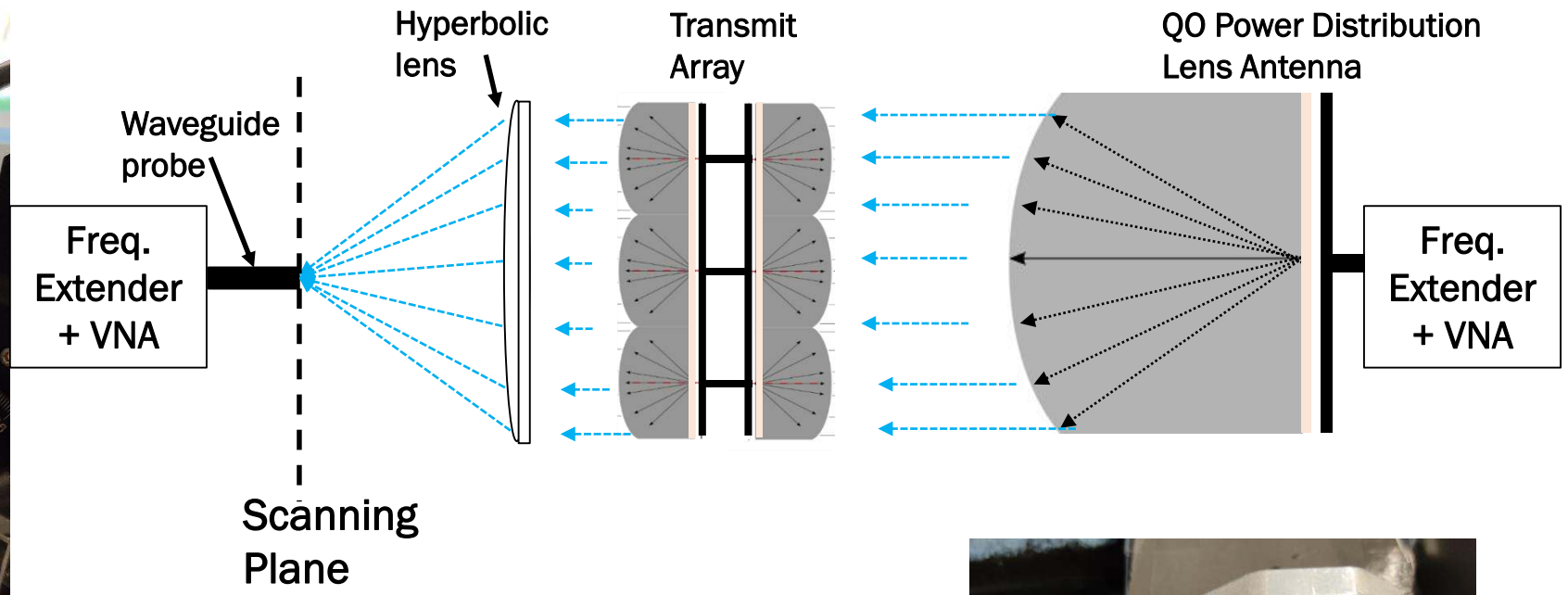


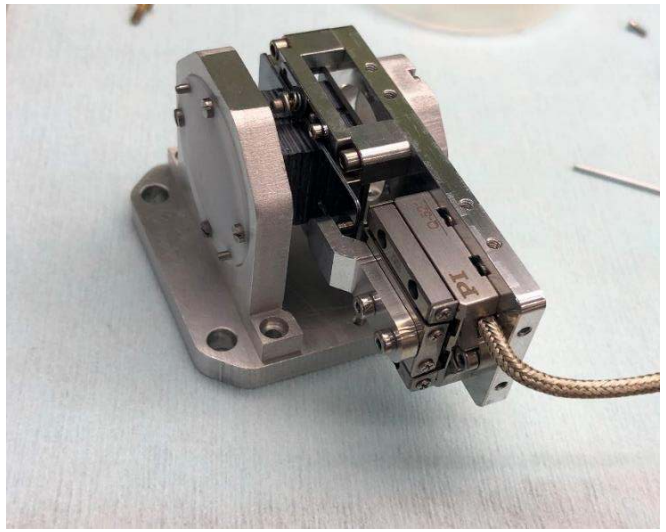


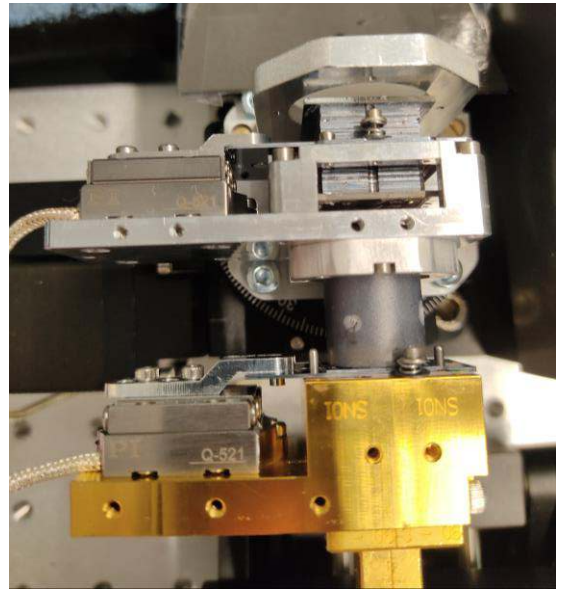


Transmit Lens Array Measurements

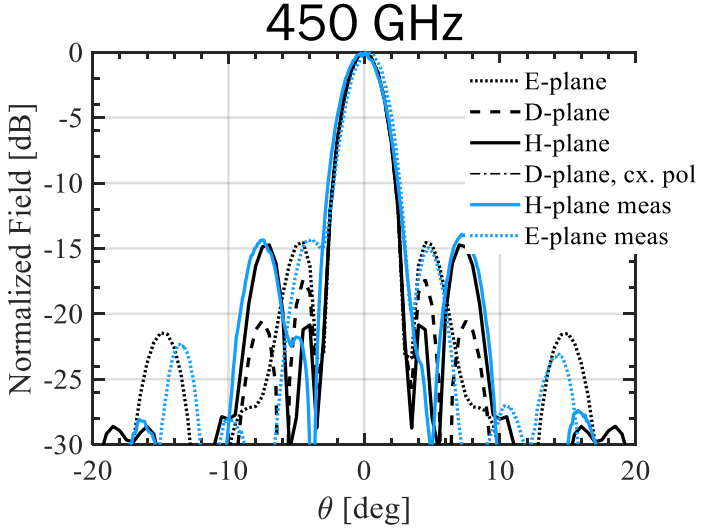


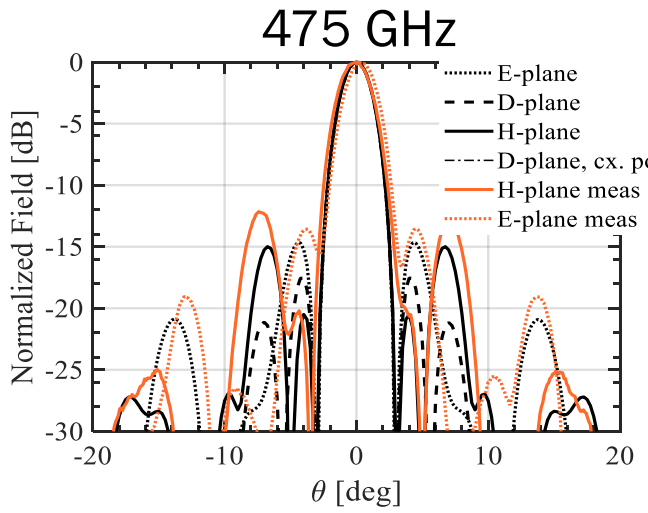


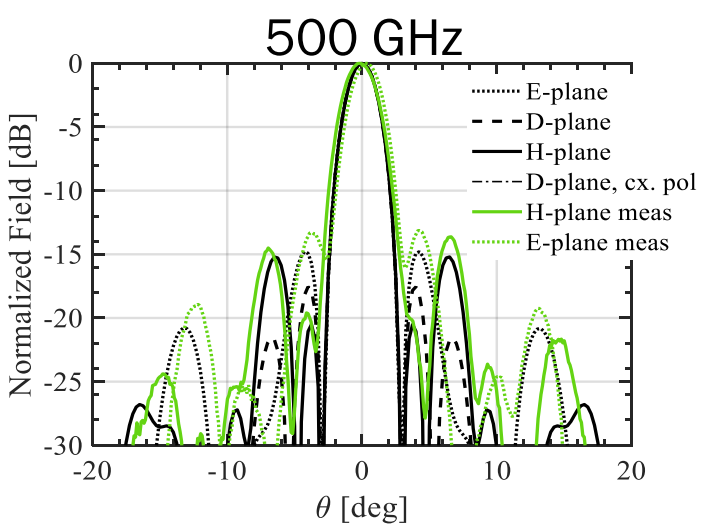


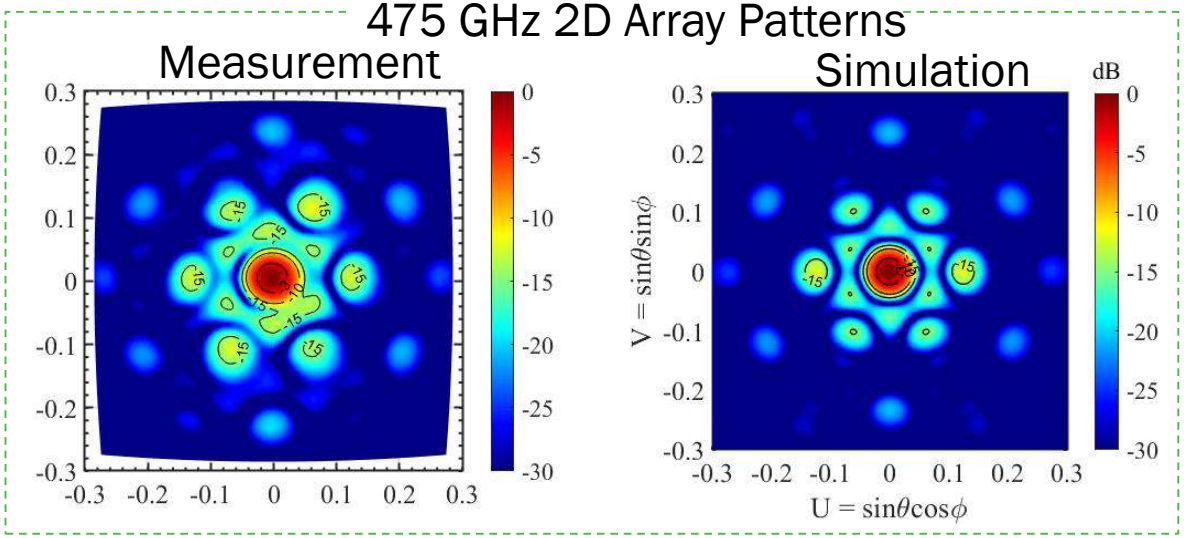


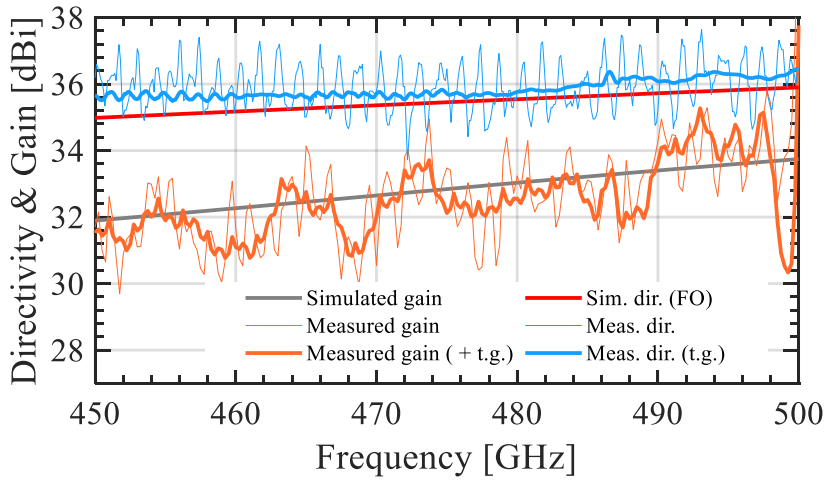
Broadside radiation patterns of the lens transmit array





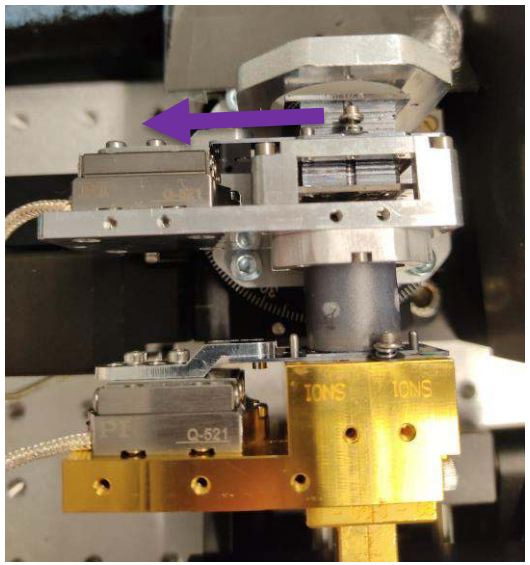


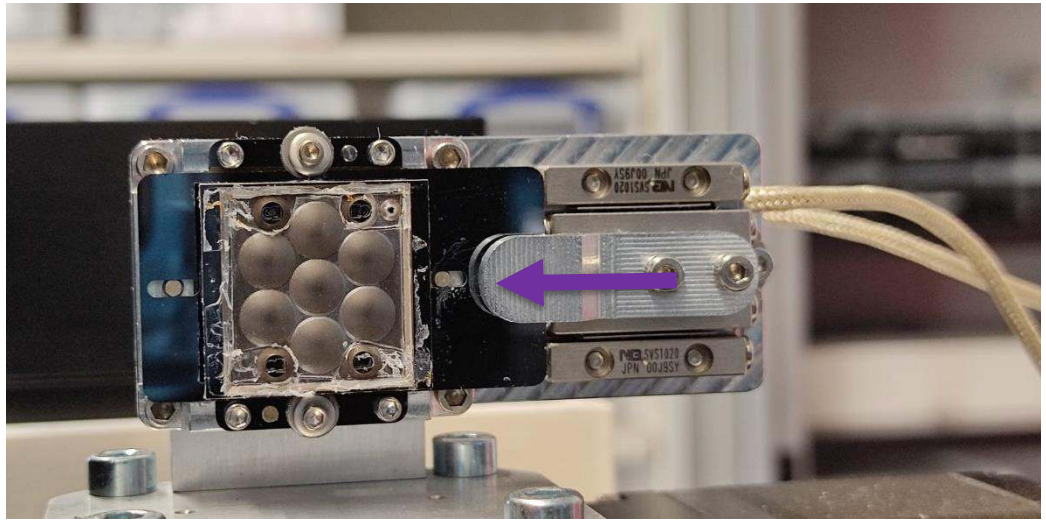


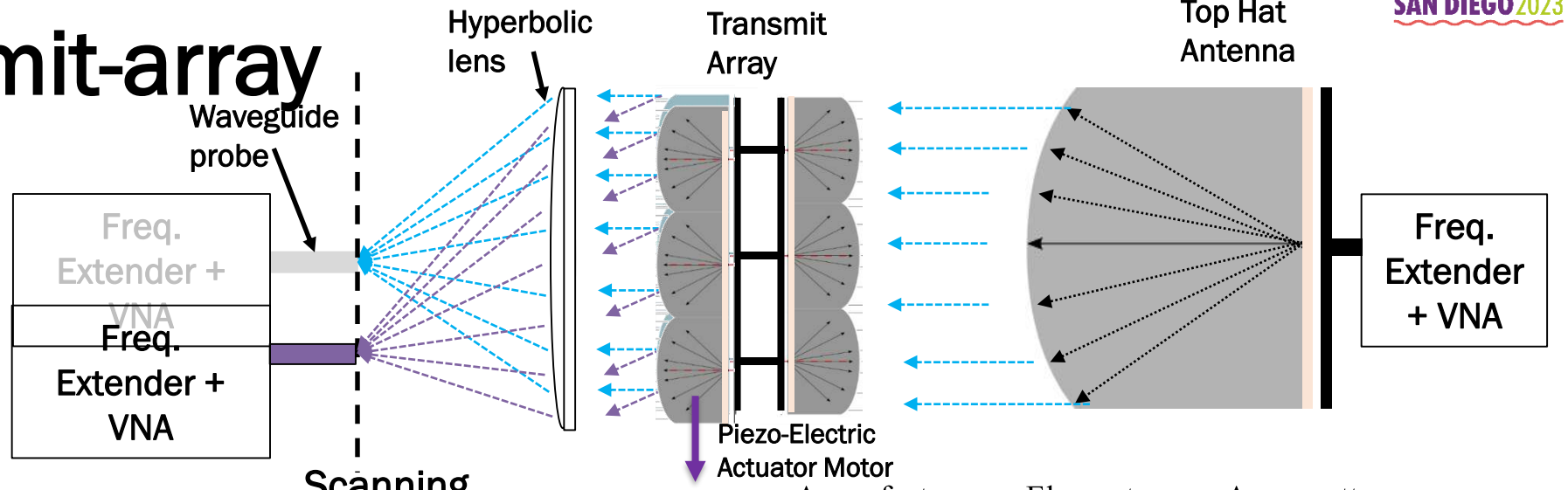


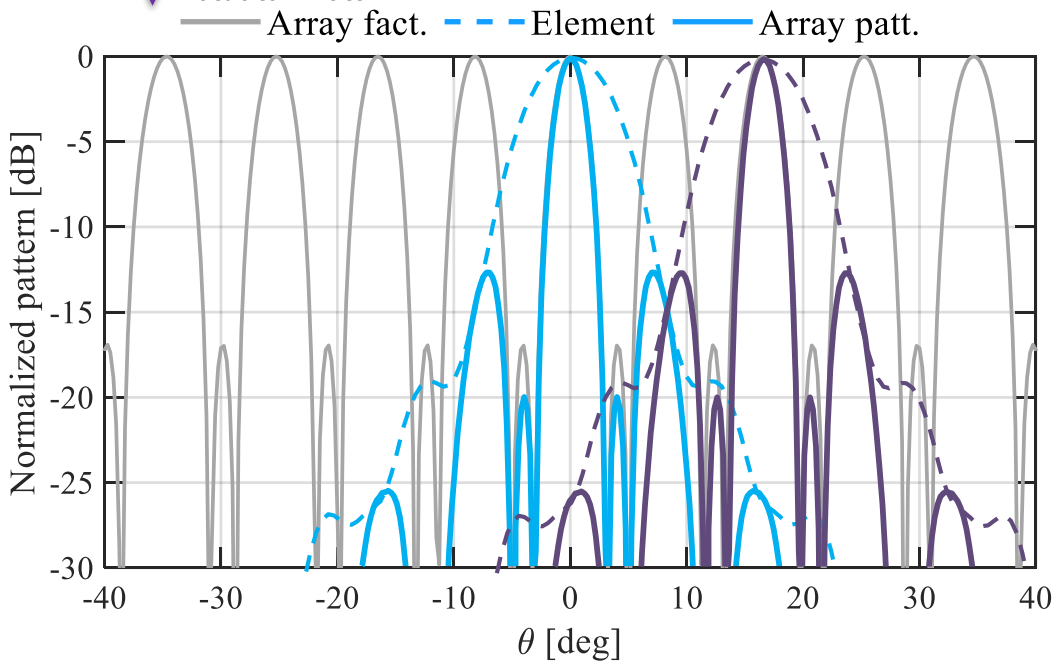
* Simulations performed with the analysis aforementioned

Scanned Radiation patterns of the lens transmit-array

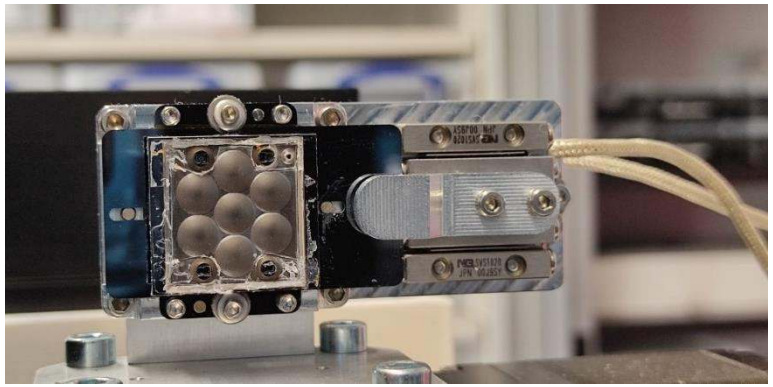




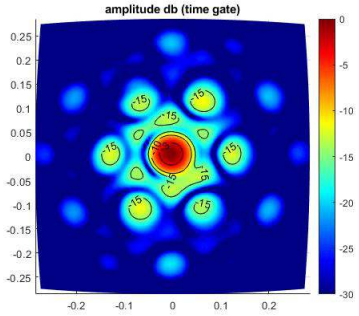




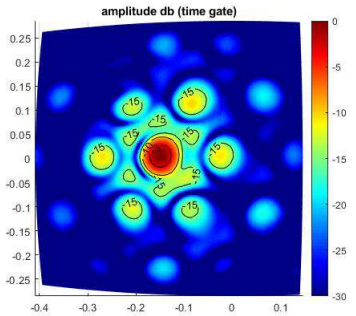
Scanned Radiation patterns of the lens transmit-array



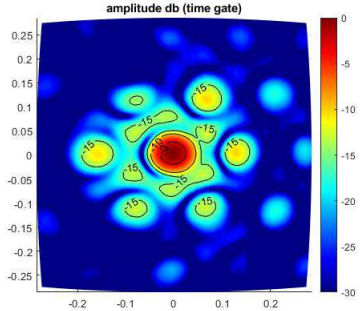
Broadside



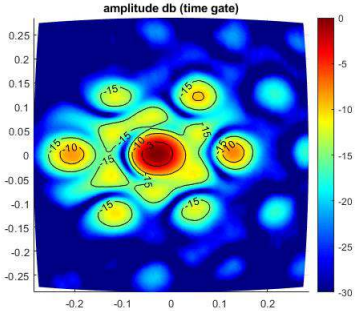
GL1: 8.5 deg

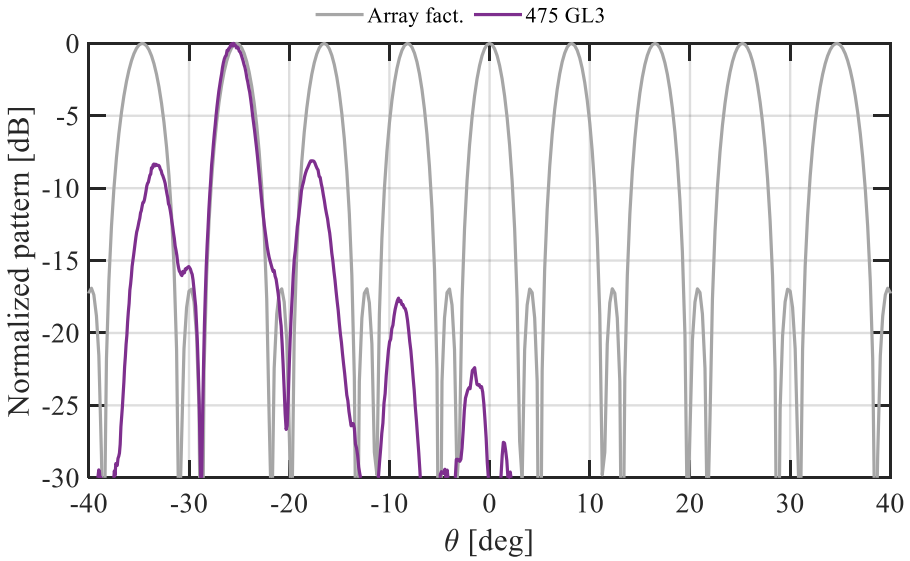


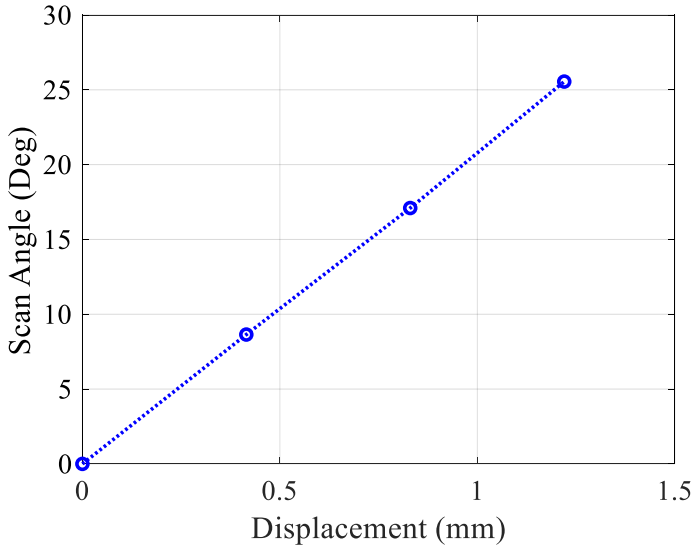
GL 2: 16.7 deg

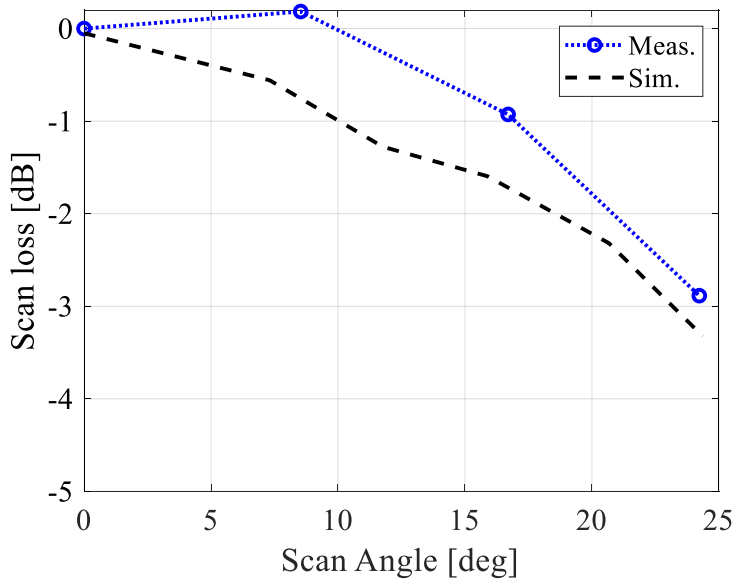


GL3: 25.6 deg







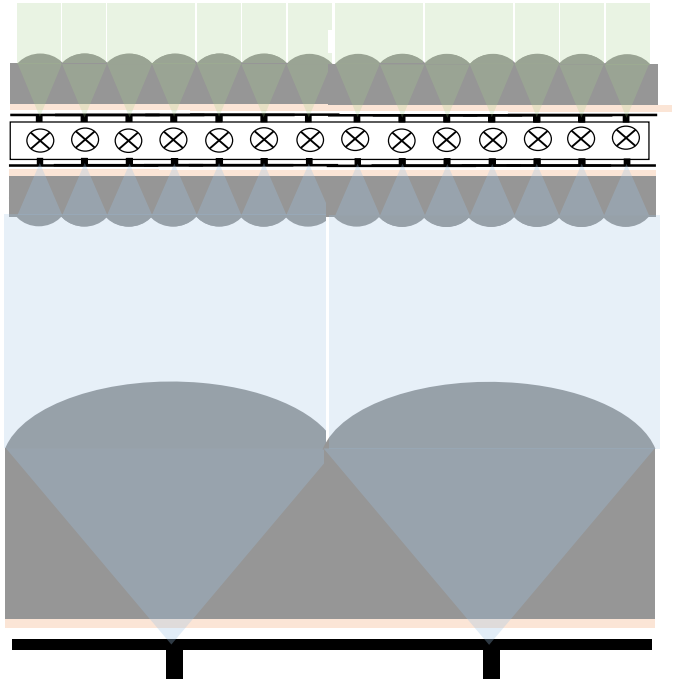


Conclusions

Connecting Minds. Exchanging Ideas.

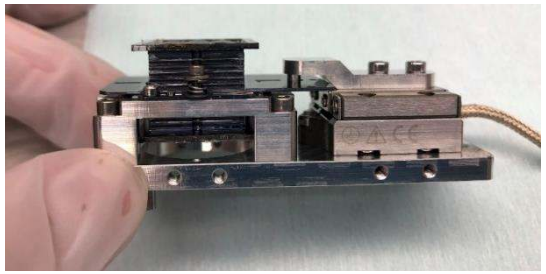
The Coolest Ideas Under the Sun
SAN DIEGO2023

Transmit Lens Arrays for Broadband THz Power Distribution and Beam-Steering



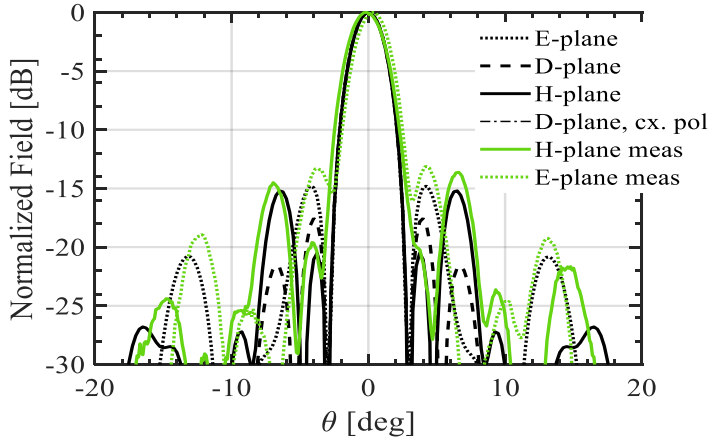
QO Modelling techniques

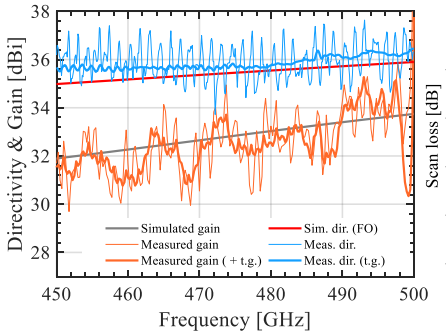
450GHz – 650GHz 7 Element Phased Array Prototype

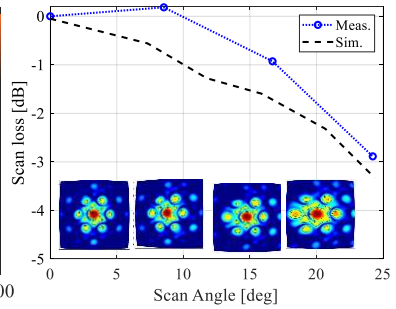


36dB directivity
33dB gain
+/-25deg scanning

Excellent agreement between measurements and QO model







Great potential for future sub-mm space instruments based on Focal Plane Arrays & Phased Arrays

We1B-2

Integrated Silicon Lens-Antenna based on a Top-Hat Leaky-Wave feed for Quasi-Optical Power Distribution at THz Frequencies

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