Beamforming and how does it make wireless better?

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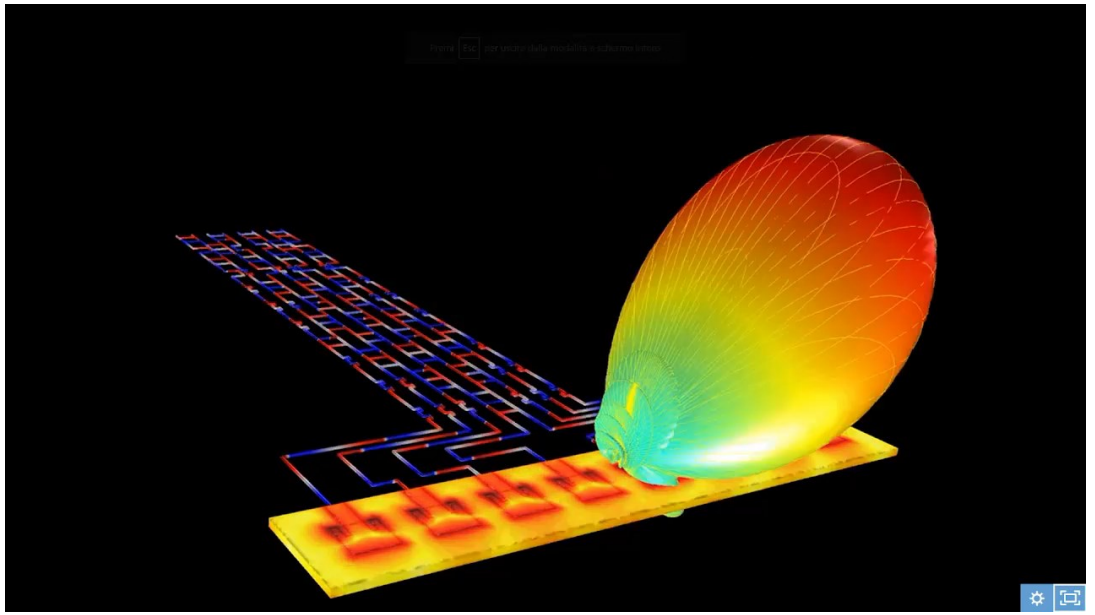
Outline

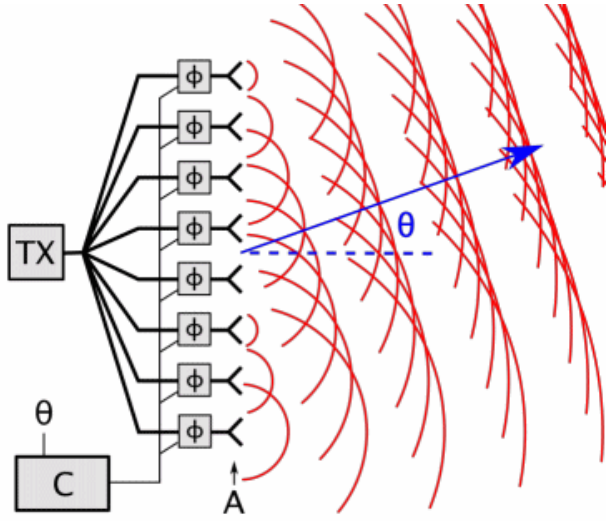
- Introduction
- What is beamforming
- Beamforming technicques
- Some beamforming applications in biomedical, communication and THz implementations
- Beamforming using Sparse Antenna Arrays
- Conclusion

What is beamforming?

Beamforming *(in wireless applications)* is the act of controlling the **shape and direction** of an **antenna's radiation pattern** to focus the propagation of electromagnetic waves towards a preferential direction.

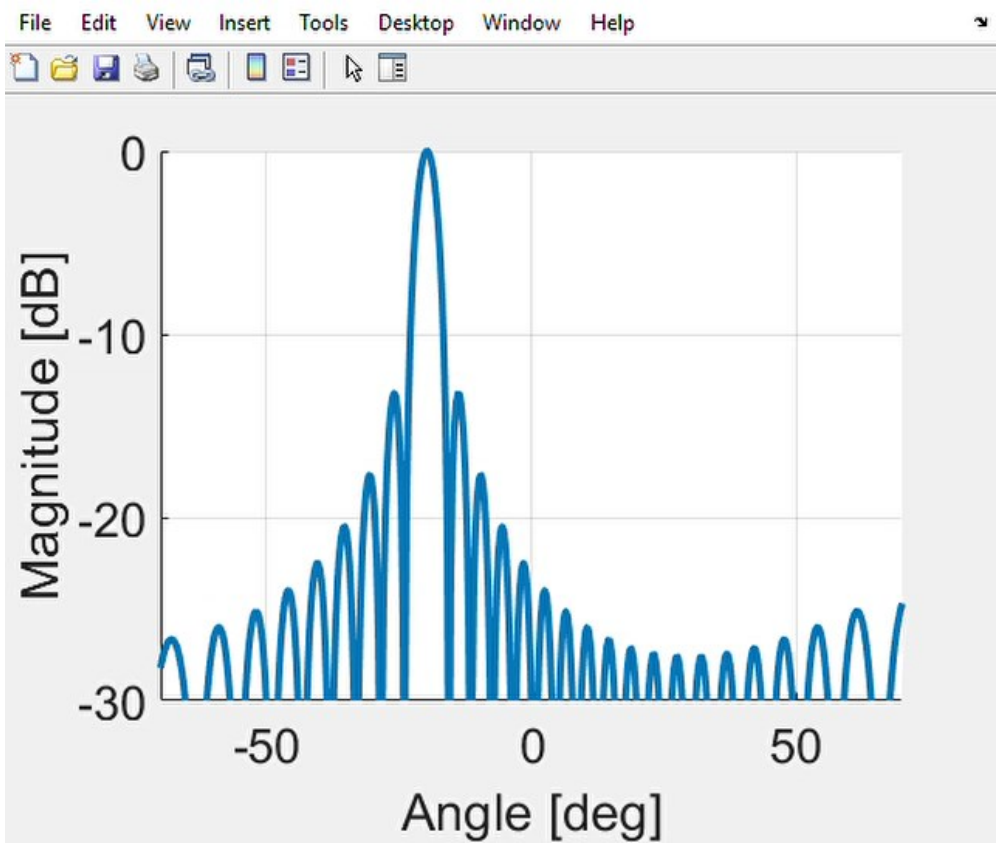


COMSOL Blog, Designing a Butler Matrix Beamforming Network with RF Modeling, Caty Fairclough, June 27, 2017.

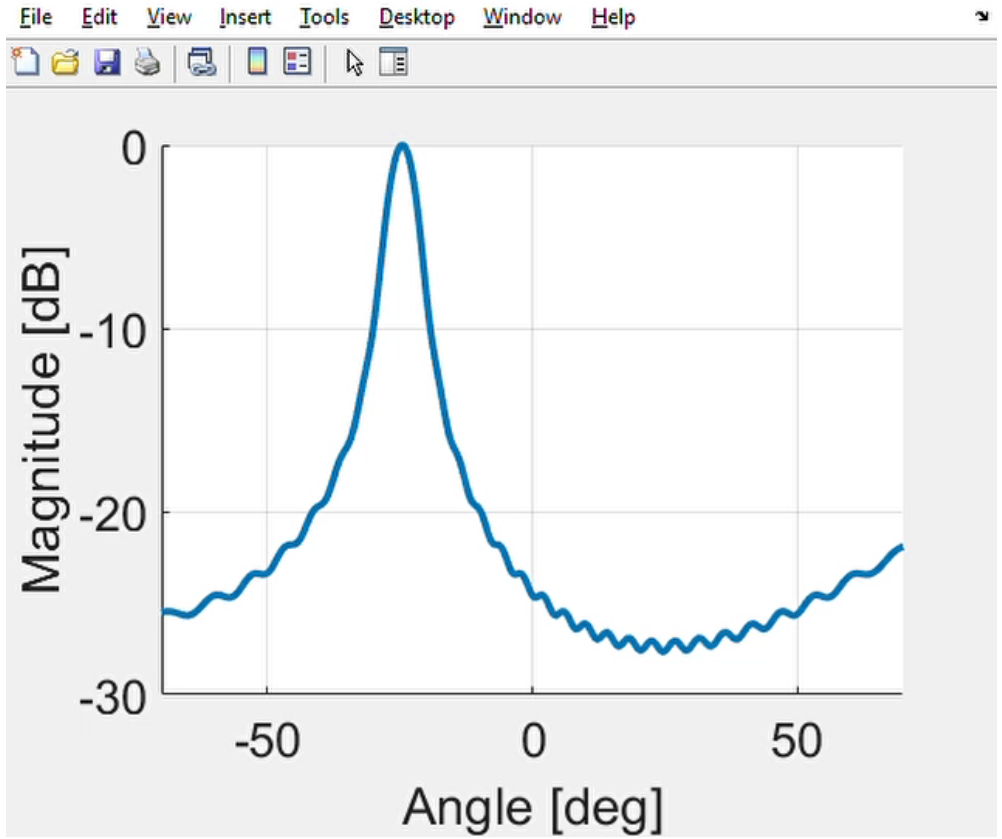


Antenna **arrays elements** are supplied with appropriate **phase** and **amplitude** to achieve a desired main propagation direction and shape.

Example: Linear antenna beamsteering and beamforming



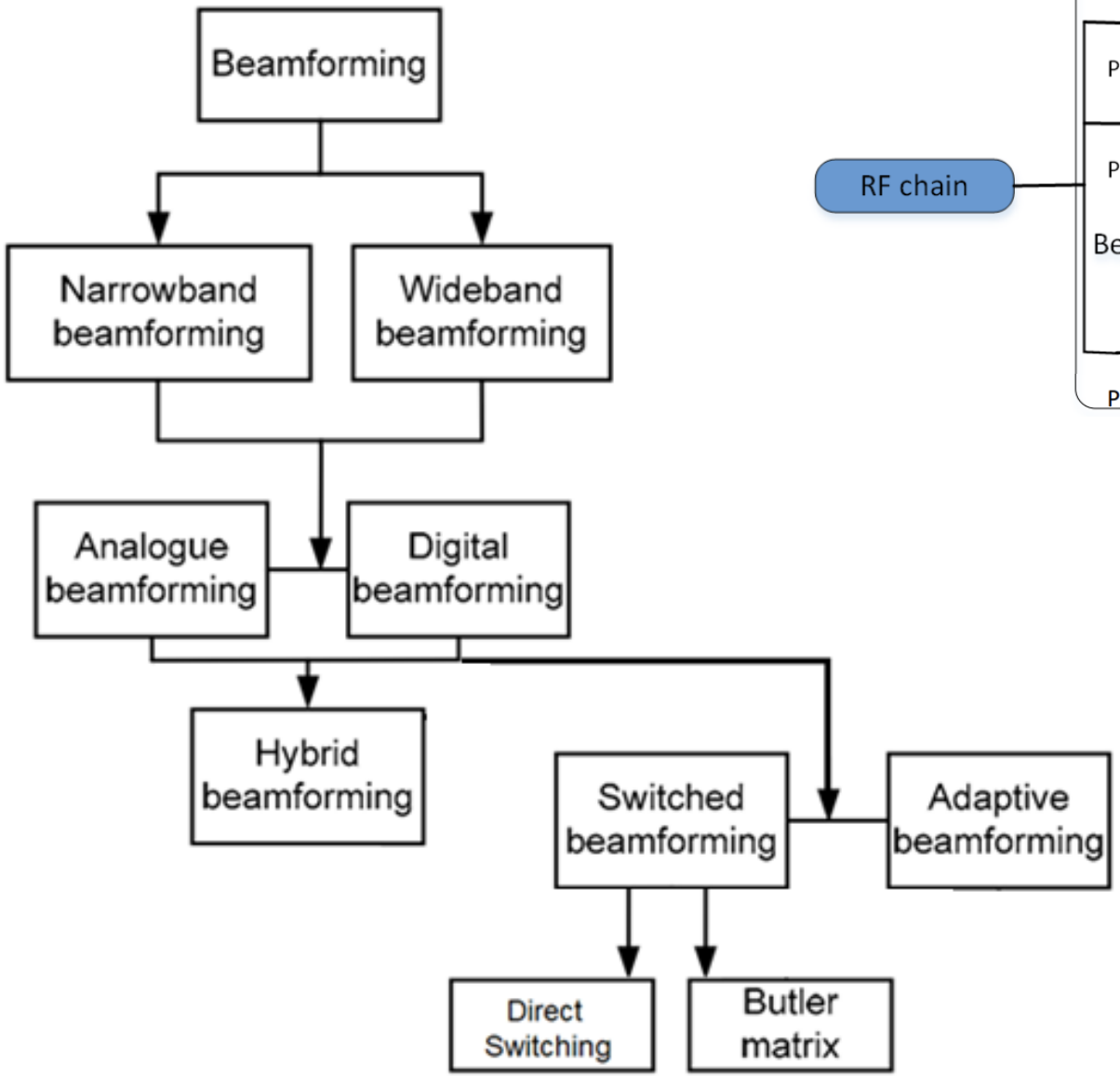
Changing element phase to steer the beam

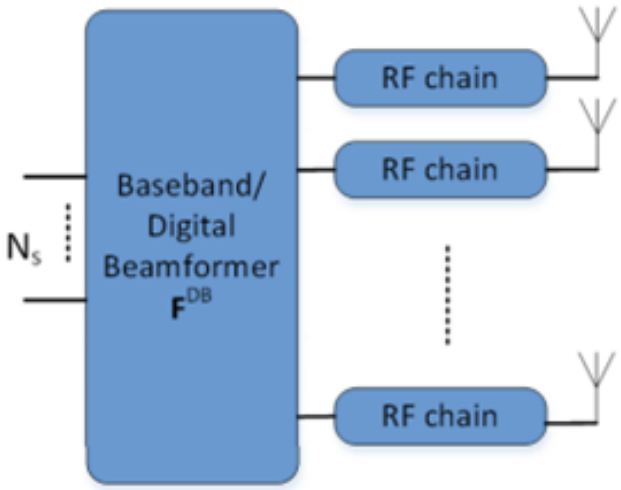


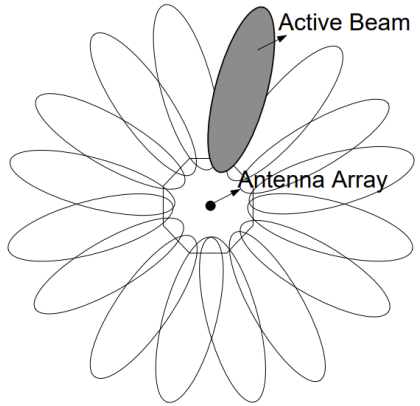
Changing amplitude tapering to form the beam

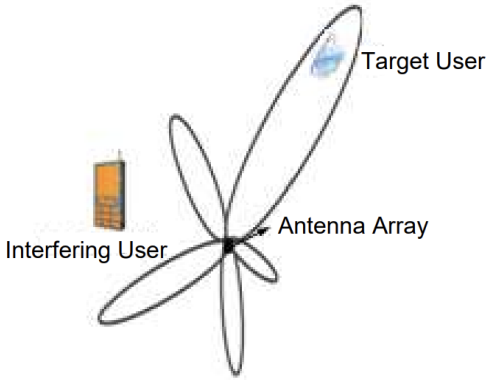
$$S(\theta_0) = \sum_{k=1}^{K} |a_k| e^{\jmath[k_0(k-1)d_x \sin\theta_0 - \psi_k]}$$

Beamforming techniques





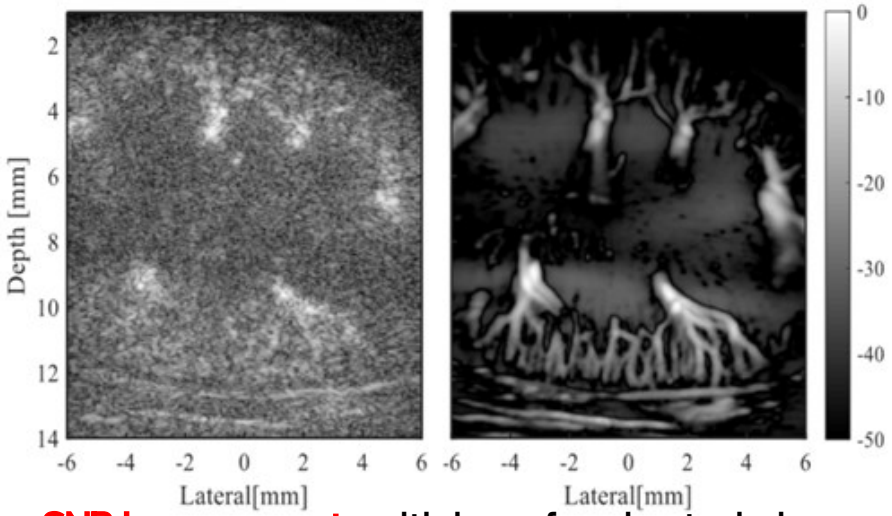




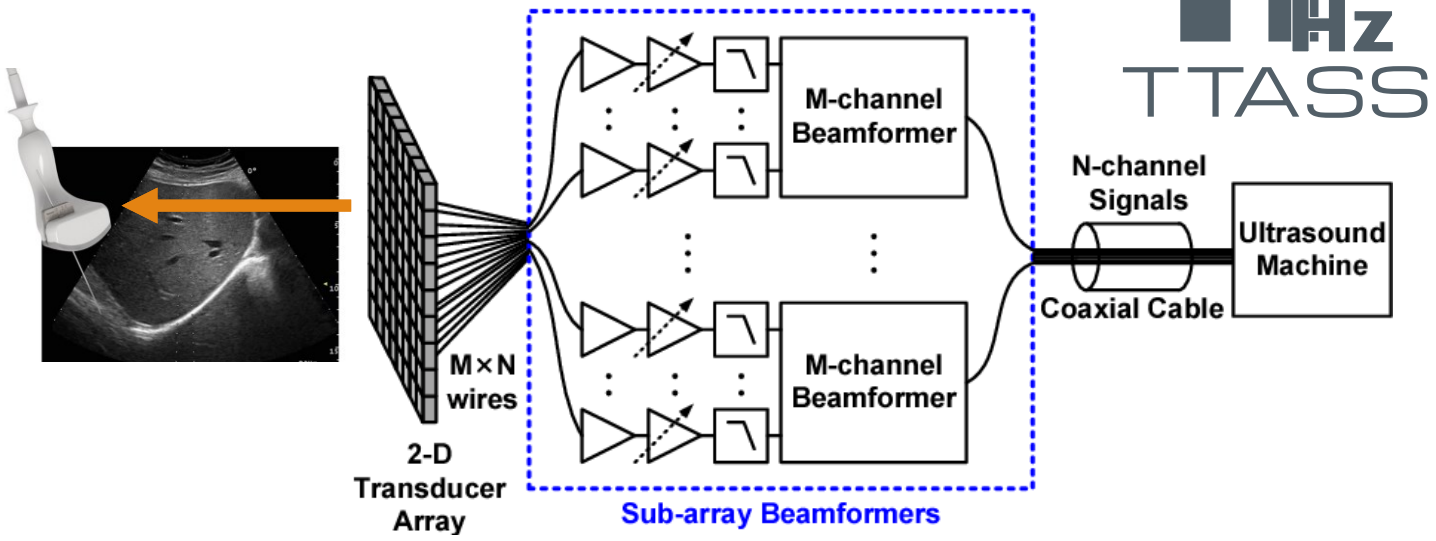
Ahmed, Irfan, et al. "A survey on hybrid beamforming techniques in 5G: Architecture and system model perspectives." IEEE Communications Surveys & Tutorials 20.4 (2018): 3060-3097.

Biomedical applications of beamforming

Improving ecography measurements

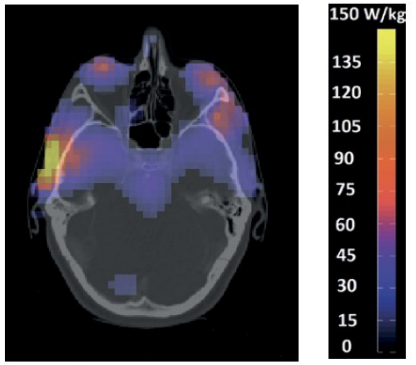


SNR Improvements with beamforming technique

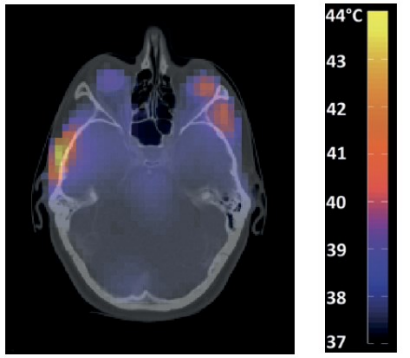


Volume targeting in RF Hyperthermia threatments

Using beamforming it is possible to heat different locations inside the target organ **without changing the applicator**.



SAR

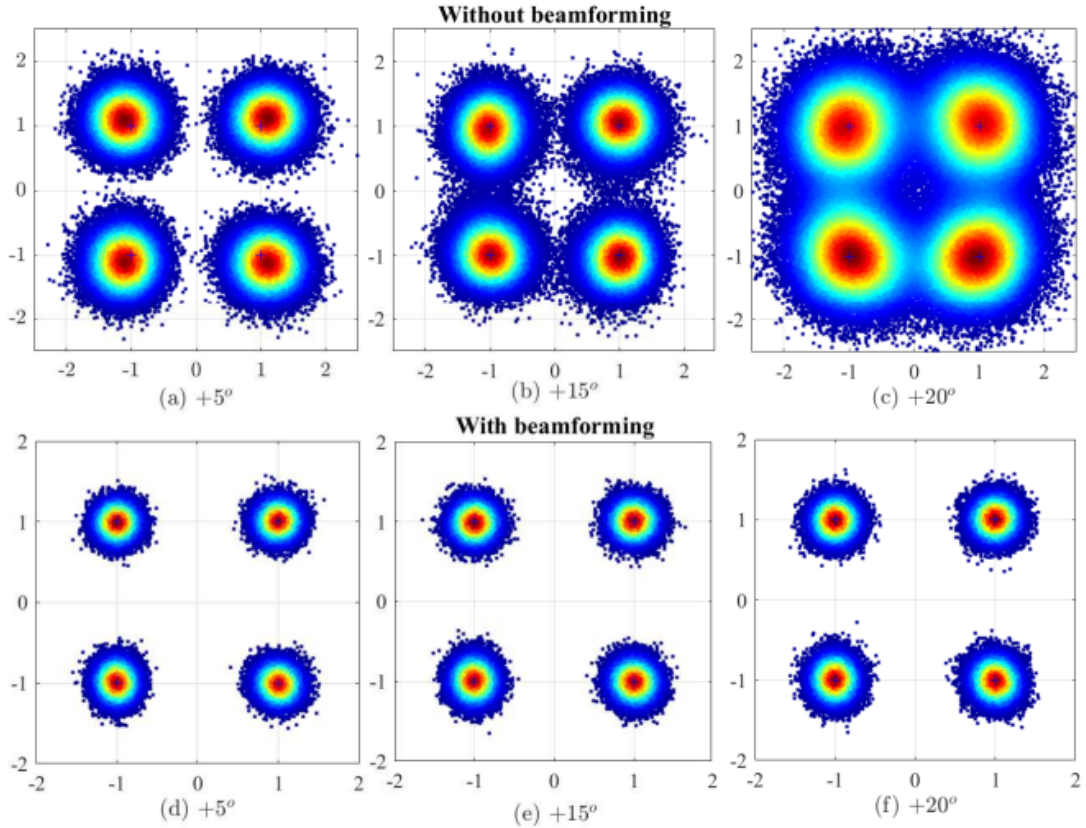


Temperature profile

Main Cons: Complexity, **COSTS**

Communication applications of beamforming

	Without beamforming		With beamforming	
Angle	SNR	corrected BER	SNR	corrected BER
$+5^o$	11 dB	$8 \cdot 10^{-4}$	17.97 dB	$1.52 \cdot 10^{-11}$
$+15^o$	10 dB	$2 \cdot 10^{-3}$	17.4 dB	$9 \cdot 10^{-11}$
$+20^o$	7 dB	$2.6 \cdot 10^{-2}$	17 dB	$2.5 \cdot 10^{-10}$



Received symbols constellation

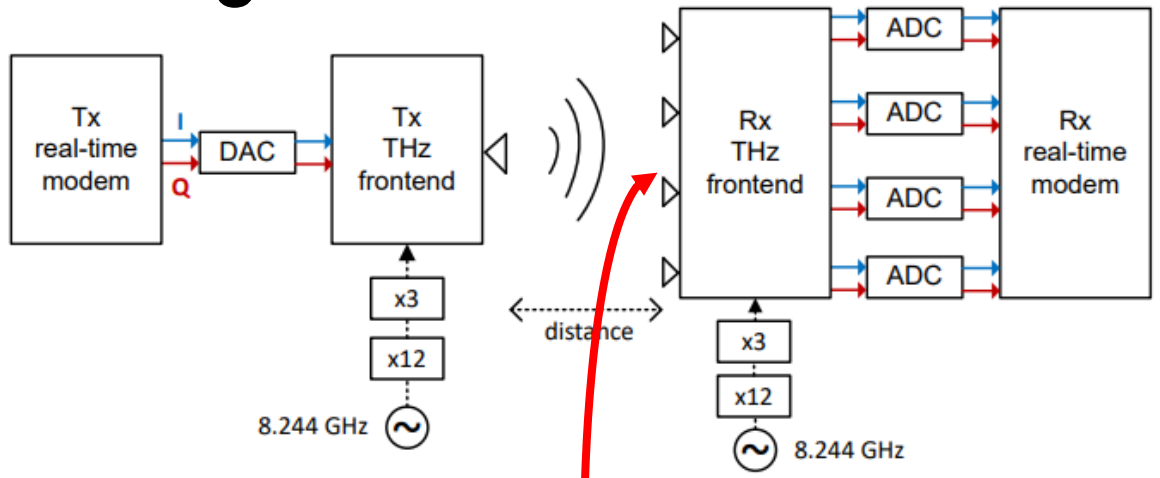


Fig. 1. Rx beamforming scenario

G. D. Ntouni et al., "Real-time Experimental Wireless Testbed with Digital Beamforming at 300 GHz," 2020 European Conference on Networks and Communications (EuCNC), 2020, pp. 271-275.

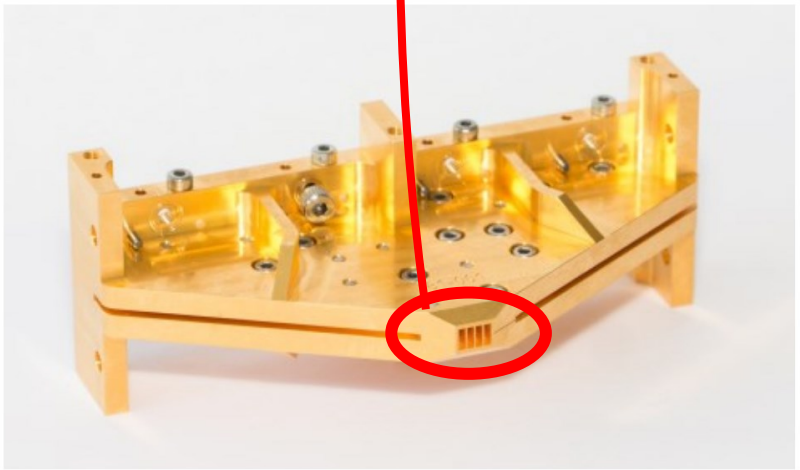


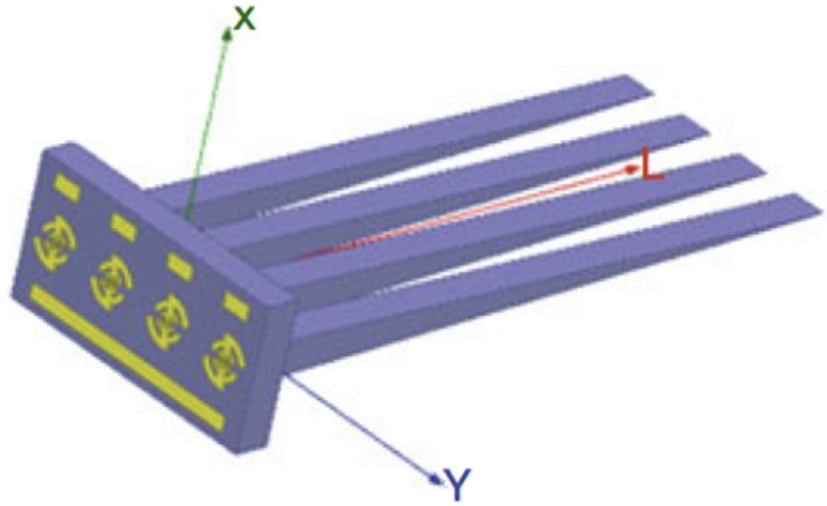
Fig. 2. Antenna module; the WR-3 wave guide flanges are located on the back side.

Beamforming in THz systems: DRW

Can we apply beamforming techniques to THz wireless implementations? **Yes!**

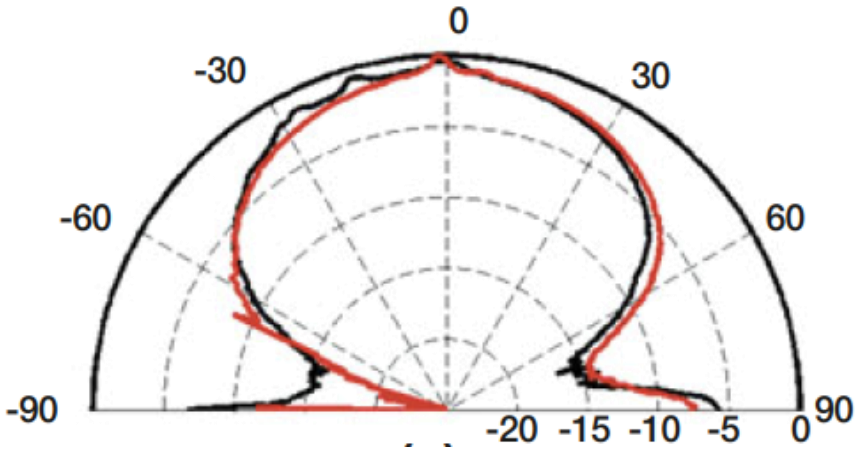
DRW Antenna for 100-200 GHz frequencies.

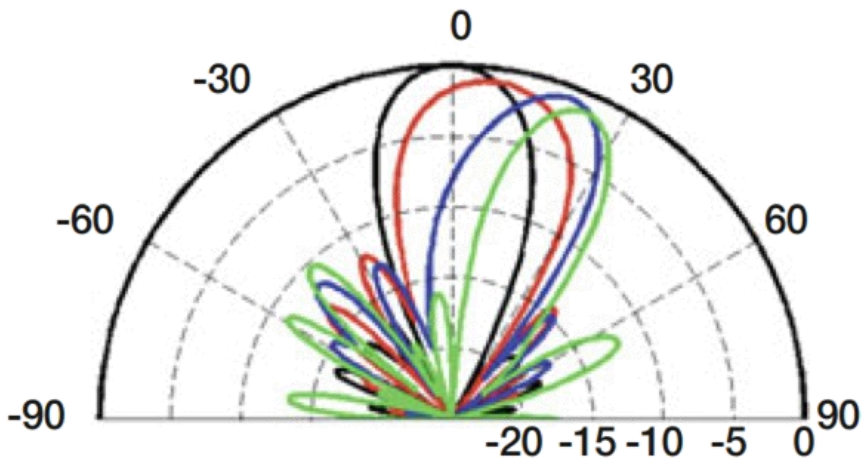
- Affordable
- Low weight
- Compact with respect to Silicon lenses



+ Combine power
+ Increased directionality
+ Can be steered

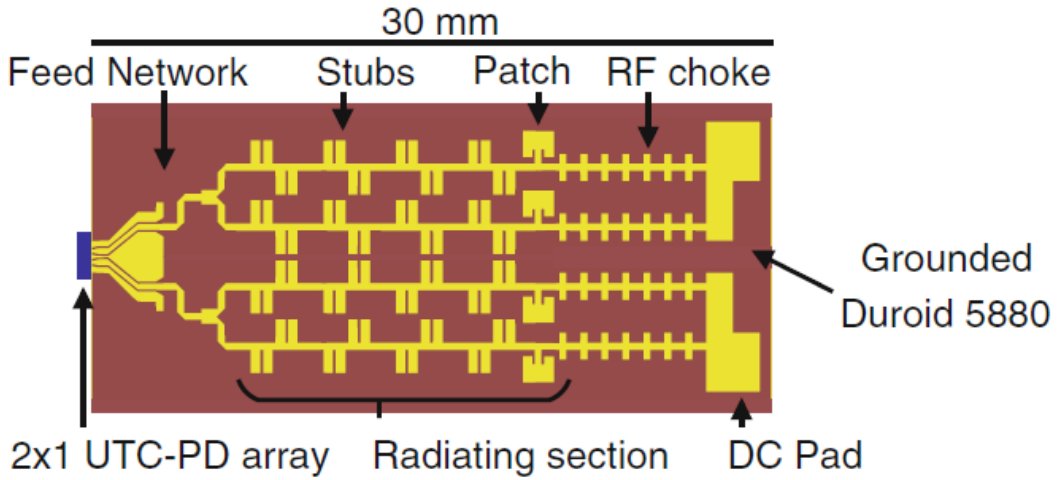
- Increased complexity
- Reduced SLSR





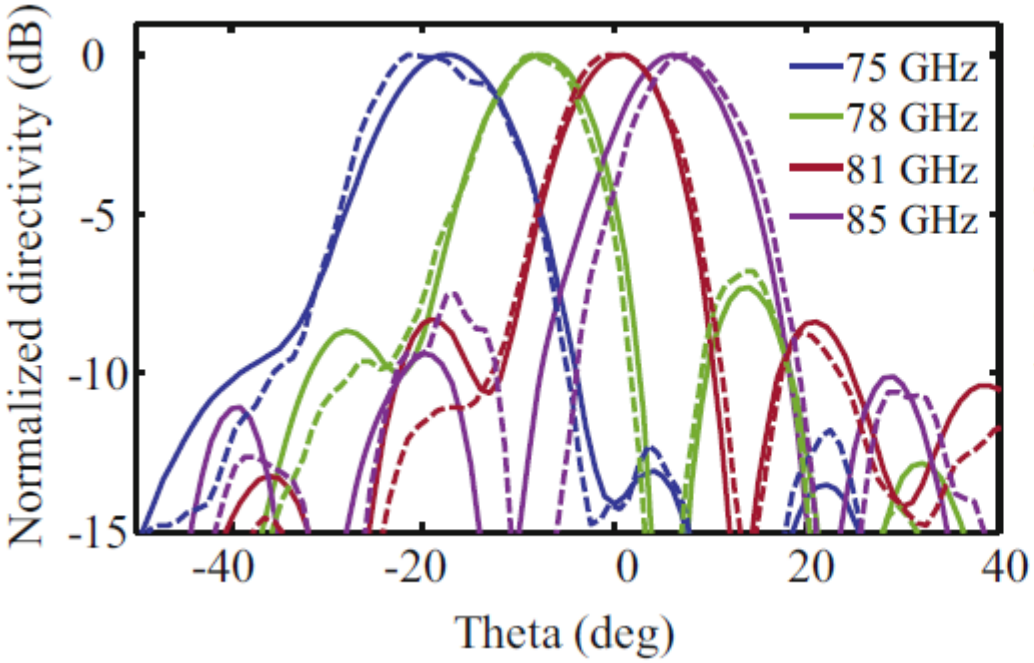
Antenna Arrays for Beamforming, Muhsin Ali et. Al., Springer Series in Optical Sciences Volume 234.

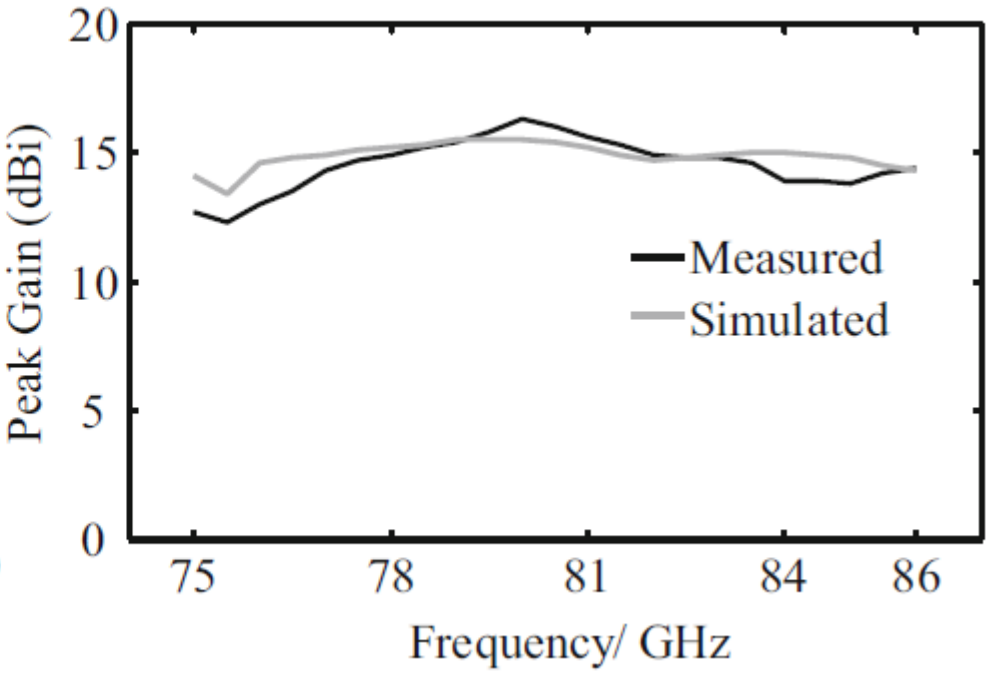
Beamforming in THz systems: leaky wave antennas



Planar antenna
Multiple (parallel) THz sources can be used
Frequency control for beamsteering
Useful for Radar (automotive)

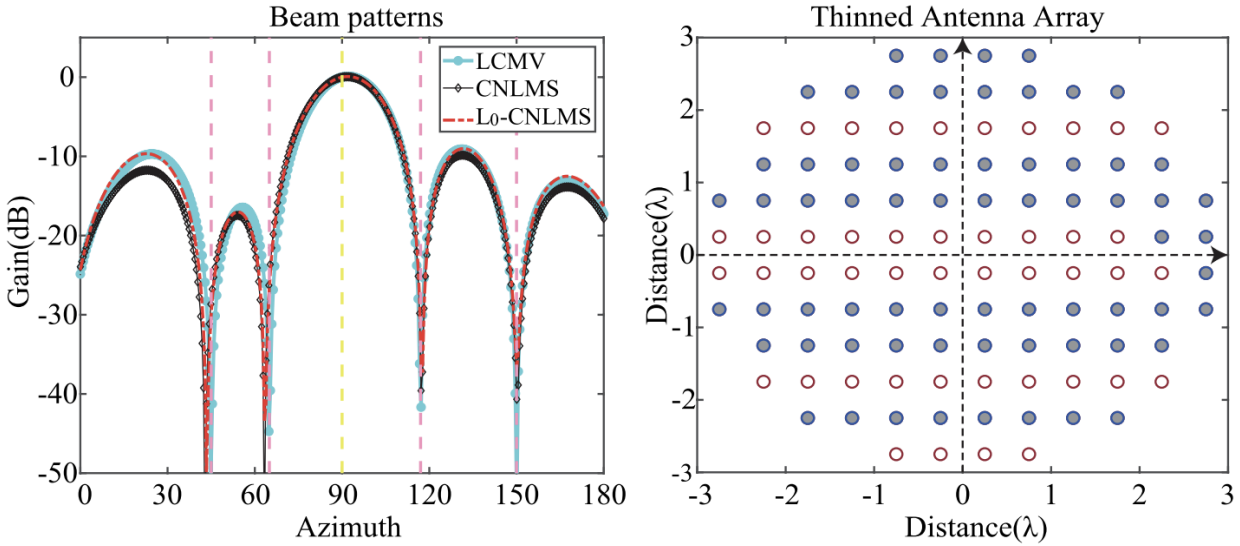
Pascual, A. J., Ali, M., Carpintero, G., Ferrero, F., Brochier, L., Sauleau, R., García-Muñoz, L. E., & González-Ovejero, D. (2020). A photonically-excited leaky-wave antenna array at e-band for 1-D beam steering. Applied Sciences, 10(10), 3474.



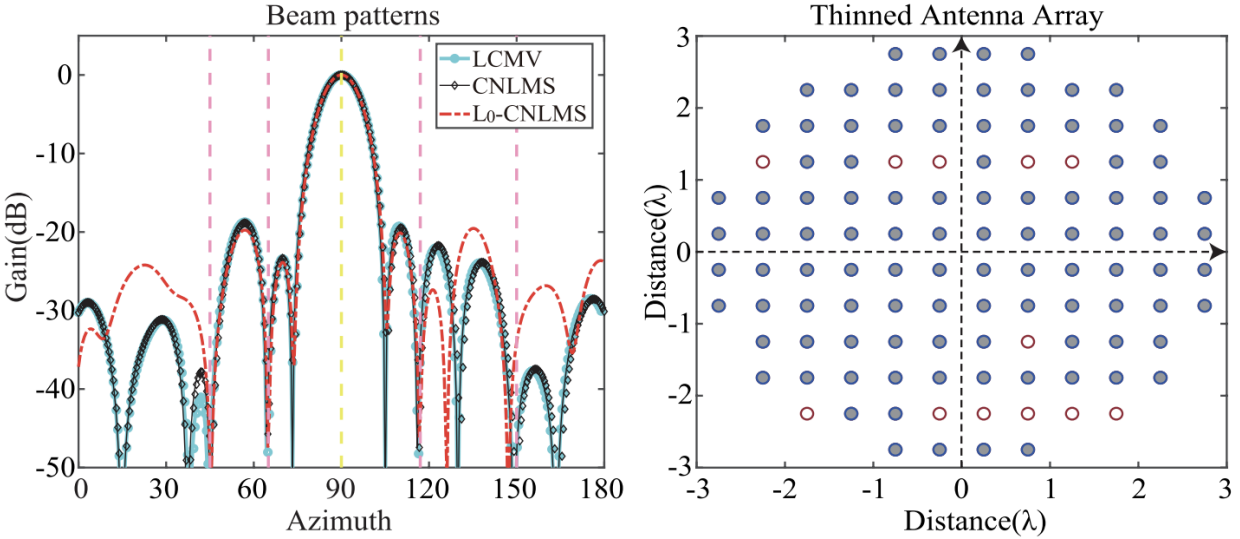


Similar approach demonstrated at 300 GHz

Sparse antenna arrays



I: Array sparsity = 59.8%



II: Array sparsity = 89.2%

Shi, Wanlu, et al. "Controllable sparse antenna array for adaptive beamforming." IEEE Access 7 (2019): 6412-6423.

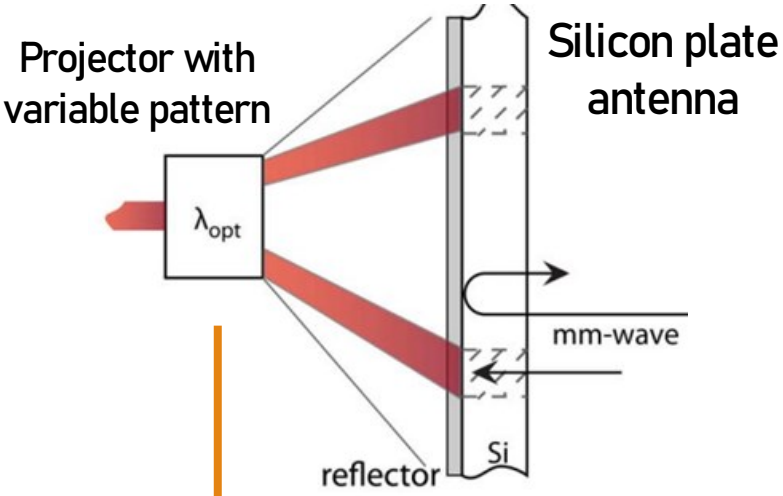
Possibility of different configurations by changing active **elements pattern** and **elements supply** amplitudes and phases.

Can implementation in THz wireless be particularly promising?

Shorter wavelength → smaller base elements → **higher density arrays** !

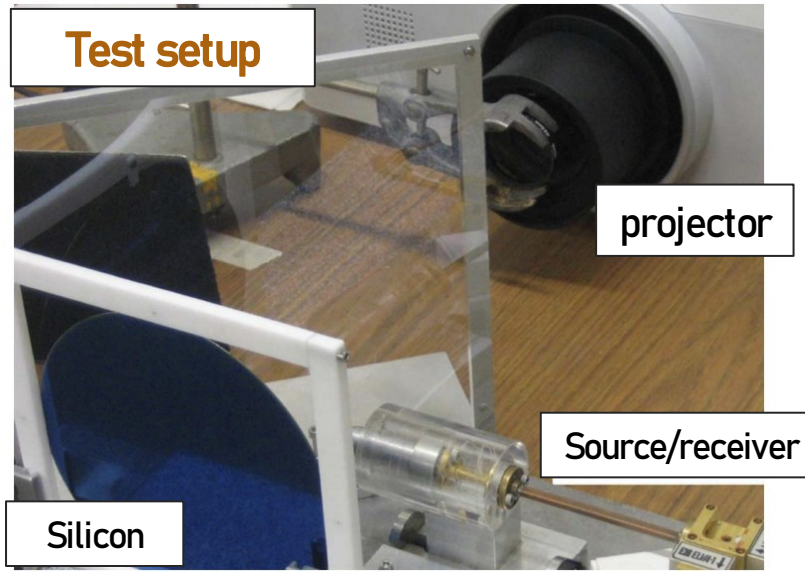
Sparse antenna arrays: an optically operated implementation

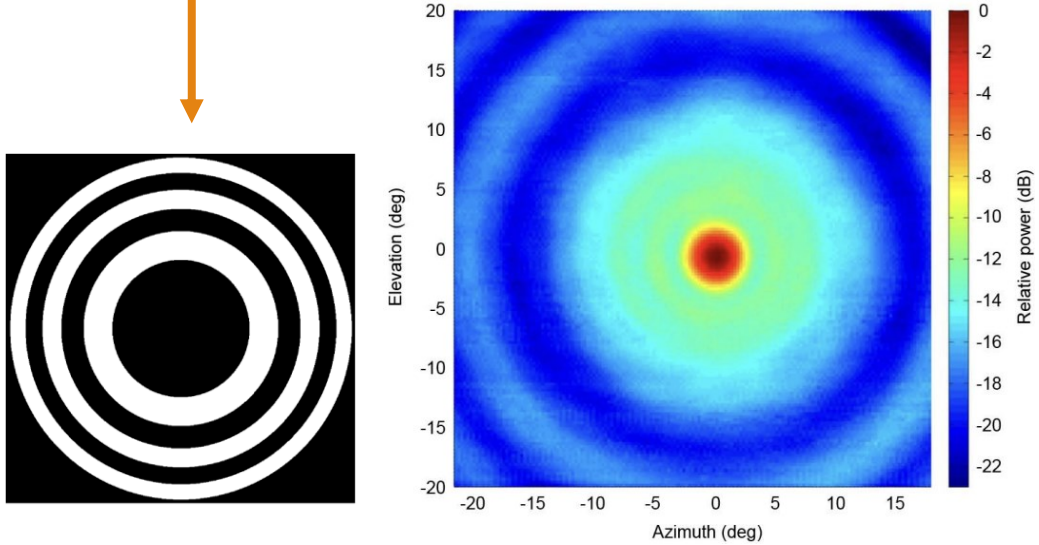
Gallacher, Tom F., et al. "Optical modulation of millimeter-wave beams using a semiconductor substrate." IEEE transactions on microwave theory and techniques 60.7 (2012): 2301-2309.



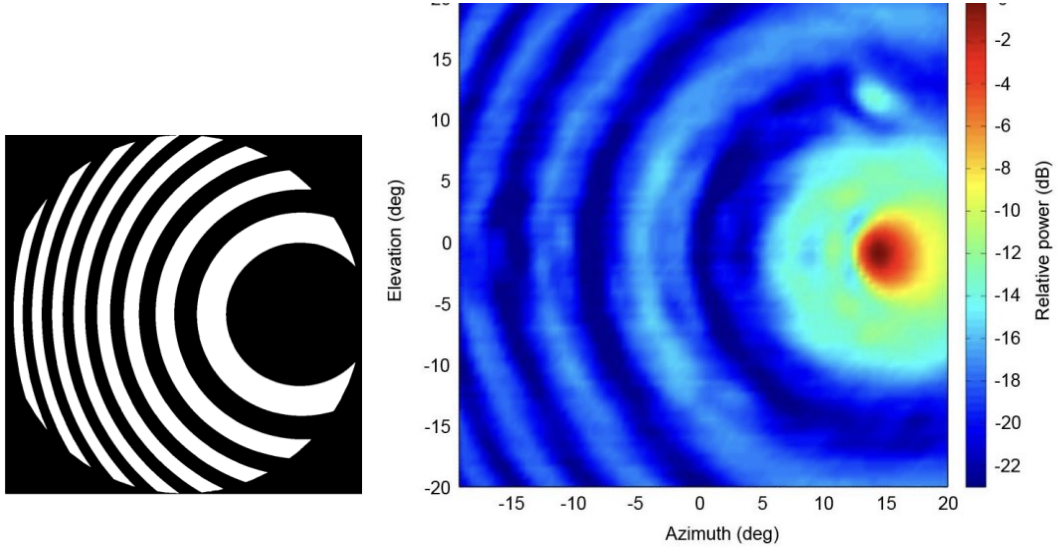
Different illuminations give configurable array factor.

It is possible to implement a Sparse Antenna Array.





Configuration pattern 1: 0° beam steering



Configuration pattern 2: 15° beam steering

Conclusions

Can beamforming make wireless better?

Yes

How?

Form and steer the beam → optimize radiation pattern to achieve better wireless parameters

- Beamforming can be applied to many different applications
- Pros and cons must be always considered in each case scenario
- High degree of freedom beamforming solutions are promising for THz implementations

THANKS FOR YOUR ATTENTION