

# TERA▲6G

## An integrated approach to millimeter-wave multi-MIMO steerable antenna arrays for 6G

**Guillermo Carpintero**

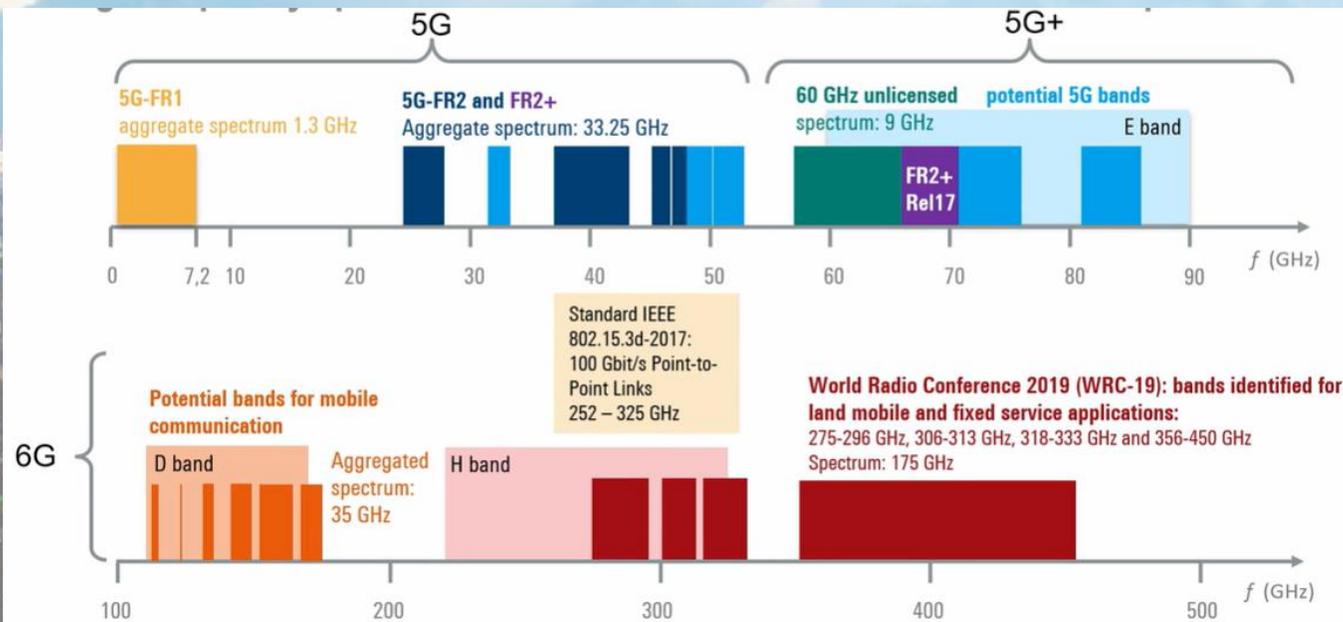
**Universidad Carlos III de Madrid, Spain**

# Towards increasing network capacity

Reaching towards spectrum regions with available bandwidth

Spatial multiplexing technologies

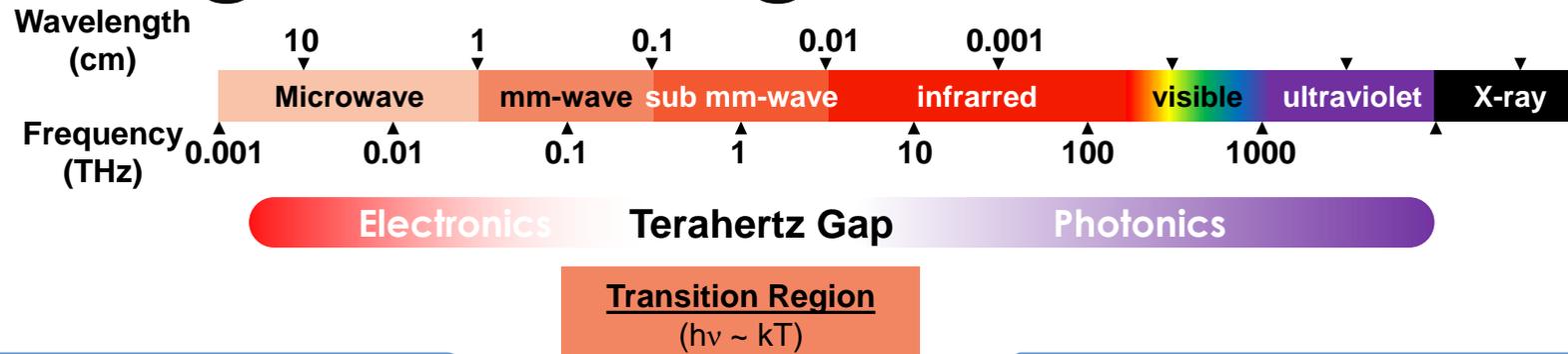
Shannon Theorem  $C(\text{bit/s}) = BW(\text{Hz}) \cdot \log_2(1 + S/N)$



T. Eichler, R. Ziegler, "FUNDAMENTALS OF THZ TECHNOLOGY FOR 6G" Rohde & Schwarz White Paper Version 01.00 (2022)

There is a need for millimeter-wave/Terahertz antenna arrays

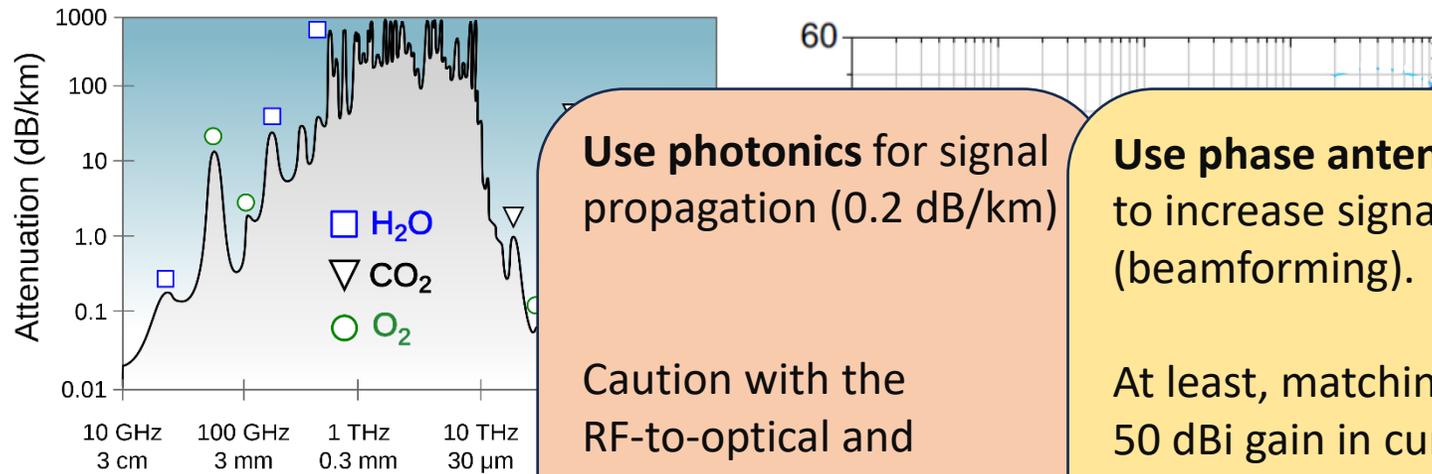
# Terahertz range challenges



## High transmission losses . . .

Microstrip,	1	dB/mm @ 600 GHz
Waveguide,	0.08	dB/mm @ 600 GHz
Atmospheric loss	0.0002	dB/mm @ 600 GHz
	0.02	dB/mm @ 557 GHz

No transistors, semiconductor lasers, isolators, . . . **compact terahertz sources** are hard to build!

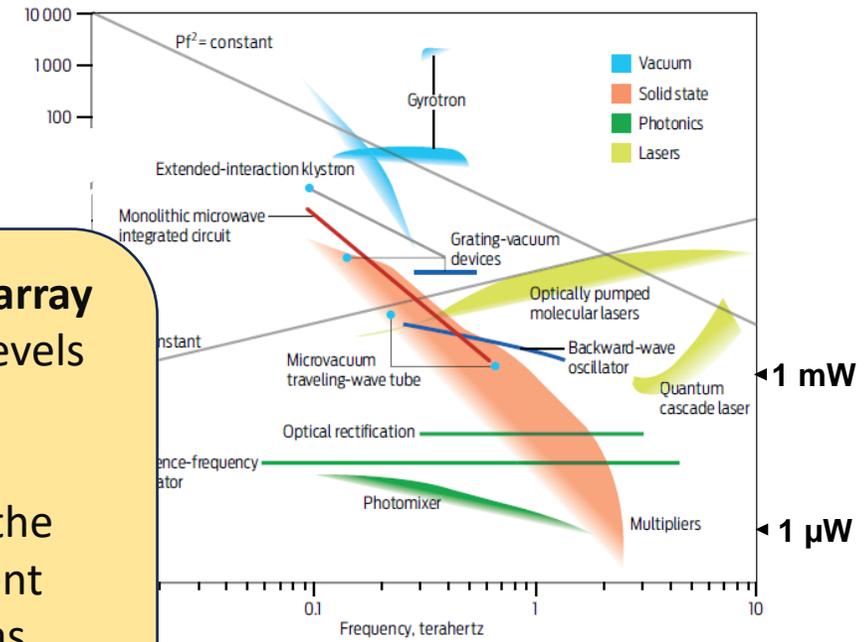


**Use photonics** for signal propagation (0.2 dB/km)

Caution with the RF-to-optical and optical-to-RF Conversion losses.

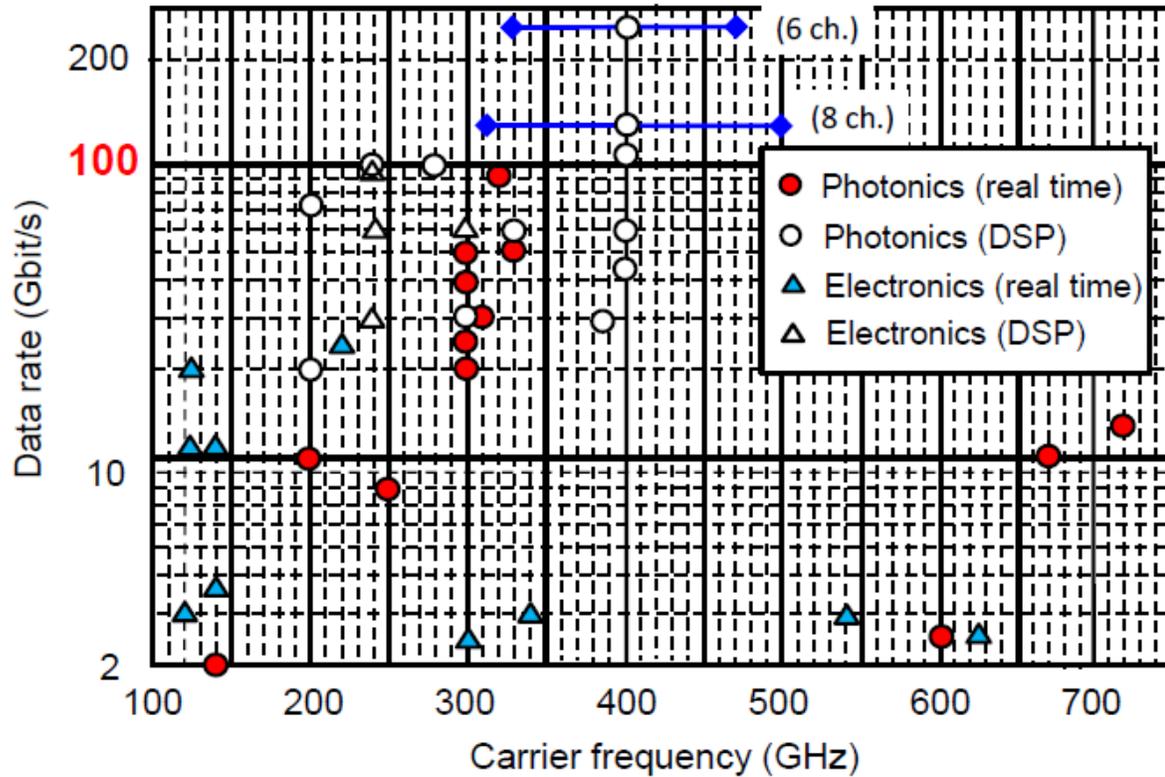
**Use phase antenna array** to increase signal levels (beamforming).

At least, matching the 50 dBi gain in current Cassegrain antennas.



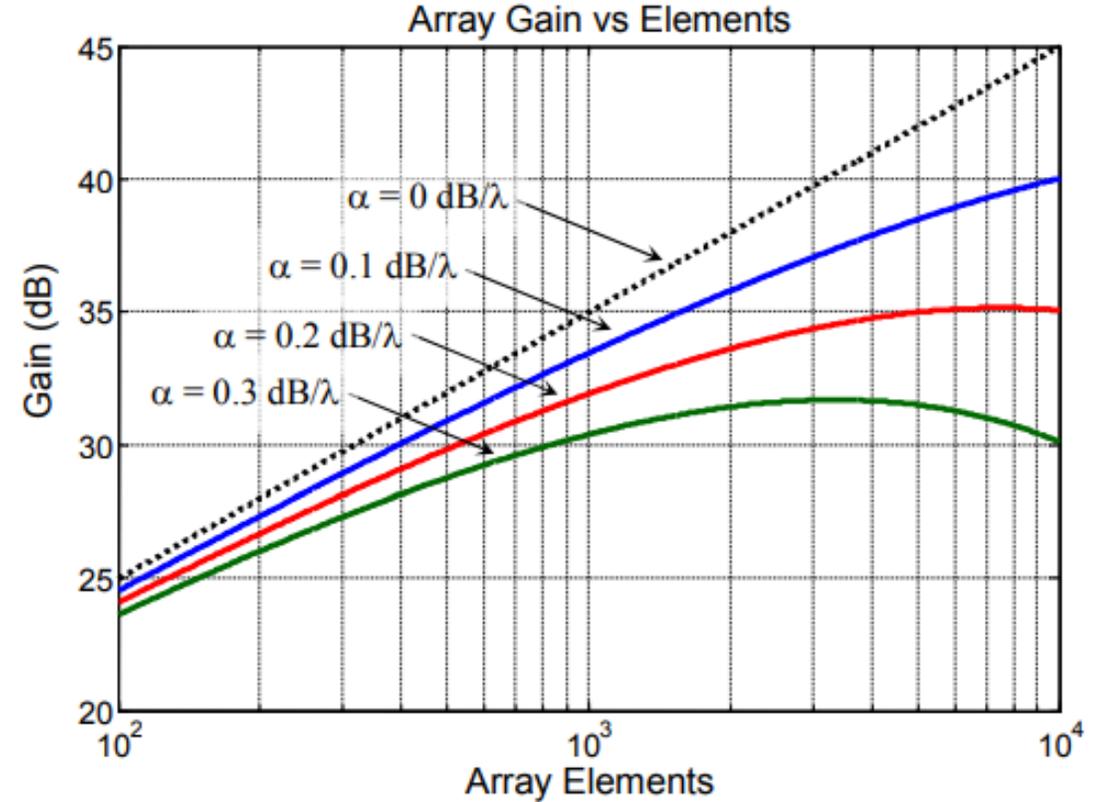
# Photonics, a key enabling technology (I)

Photonics vs Electronics systems performance



T. Nagatsuma, "Advances in Terahertz Communications Accelerated by Photonics Technologies," 24th OptoElectronics and Communications Conference (OECC), Fukuoka, Japan (2019)

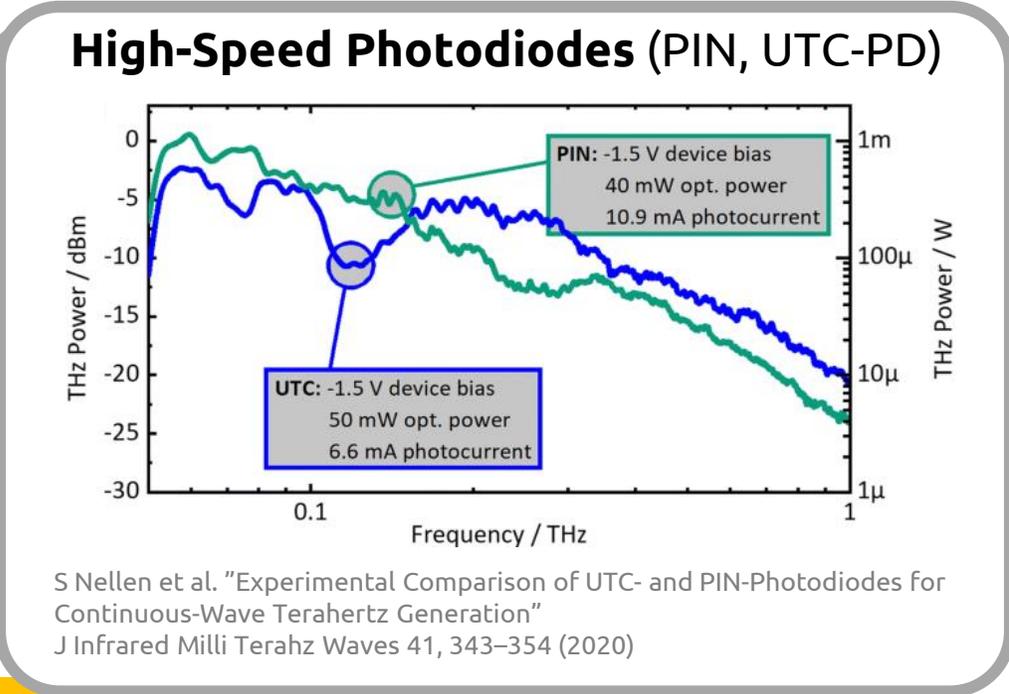
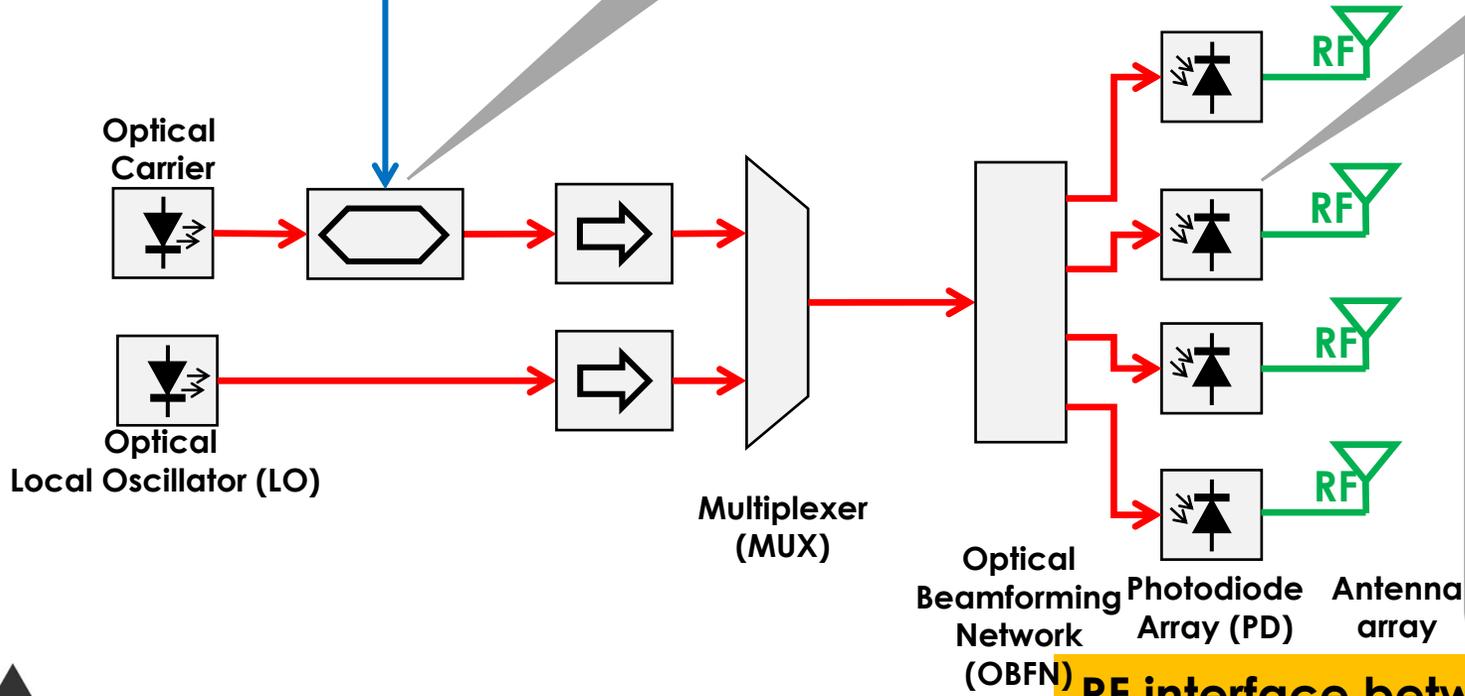
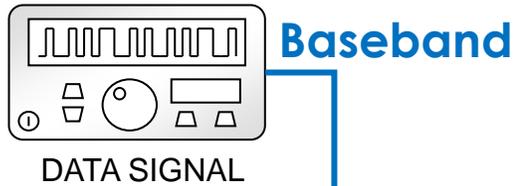
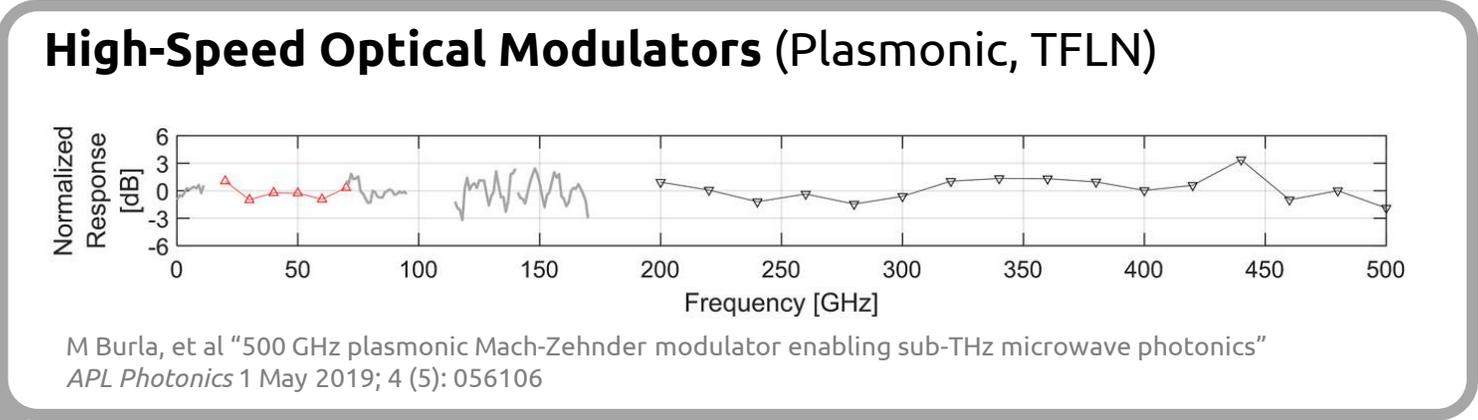
Electrical distribution of signals to antennas



R.V. Gatti et al "Flat-profile active scanning antenna for satellite terminals in Ku-band operating on new fast trains generation" 28th ESA Antenna Workshop on Satellite Antenna Technology ESTEC, Noordwijk, The Netherlands (May 2005)

**RF Photonics are spearheading the access to broadband wireless**

# Photonics, a key enabling technology (II)



**RF interface between PD and antenna?**



# MIND THE GAP, on-chip antennas

- Broadband

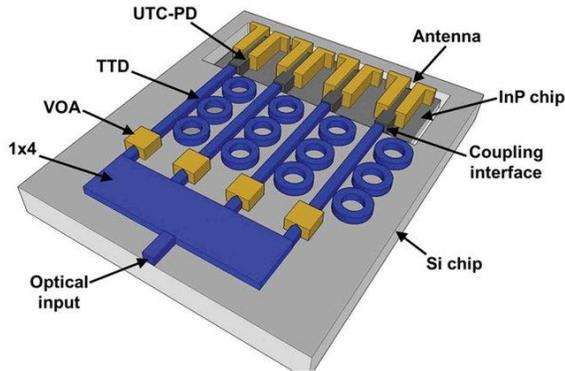
- Allows to integrate active devices (LNA)

- 1D Array only

- Waste of InP area with large metal patterns

- Requires transition at the edge to maintain radiation efficiency

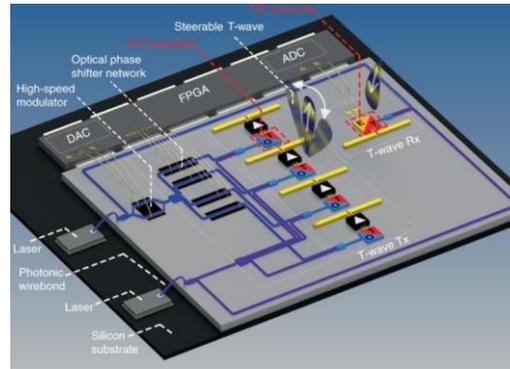
## End-fire antenna



- 😊 Beamforming
- 😊 Beam steering
- 😞 Edge emission (1D)

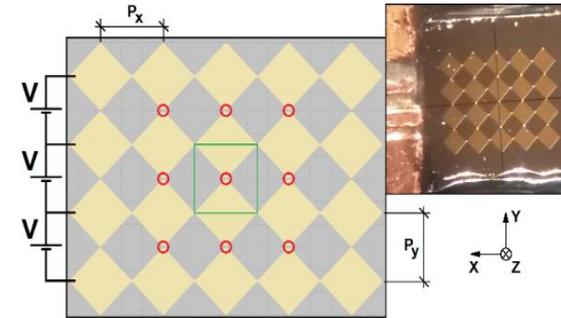
J.A. Nanzer, et al "Millimeter-Wave Photonics for Communications and Phased Arrays" Fiber and Integrated Optics (2015)

## Planar antenna



- 😊 Beamforming
- 😊 Beam steering
- 😞 Out-of-plane emission?

T. Harter et al. "Silicon-plasmonic integrated circuits for terahertz signal generation and coherent detection" Nat. Photon (2018).



- 😊 Beamforming
- 😞 Beam steering
- 😞 Optical access

E García-Muñoz et al "Photonic-based integrated sources and antenna arrays for broadband wireless links in terahertz communications" IOP Semiconductor Science and Technology (2019)

- Broadband

- Avoid wire bond

- Low radiation efficiency (Needs Si lens)

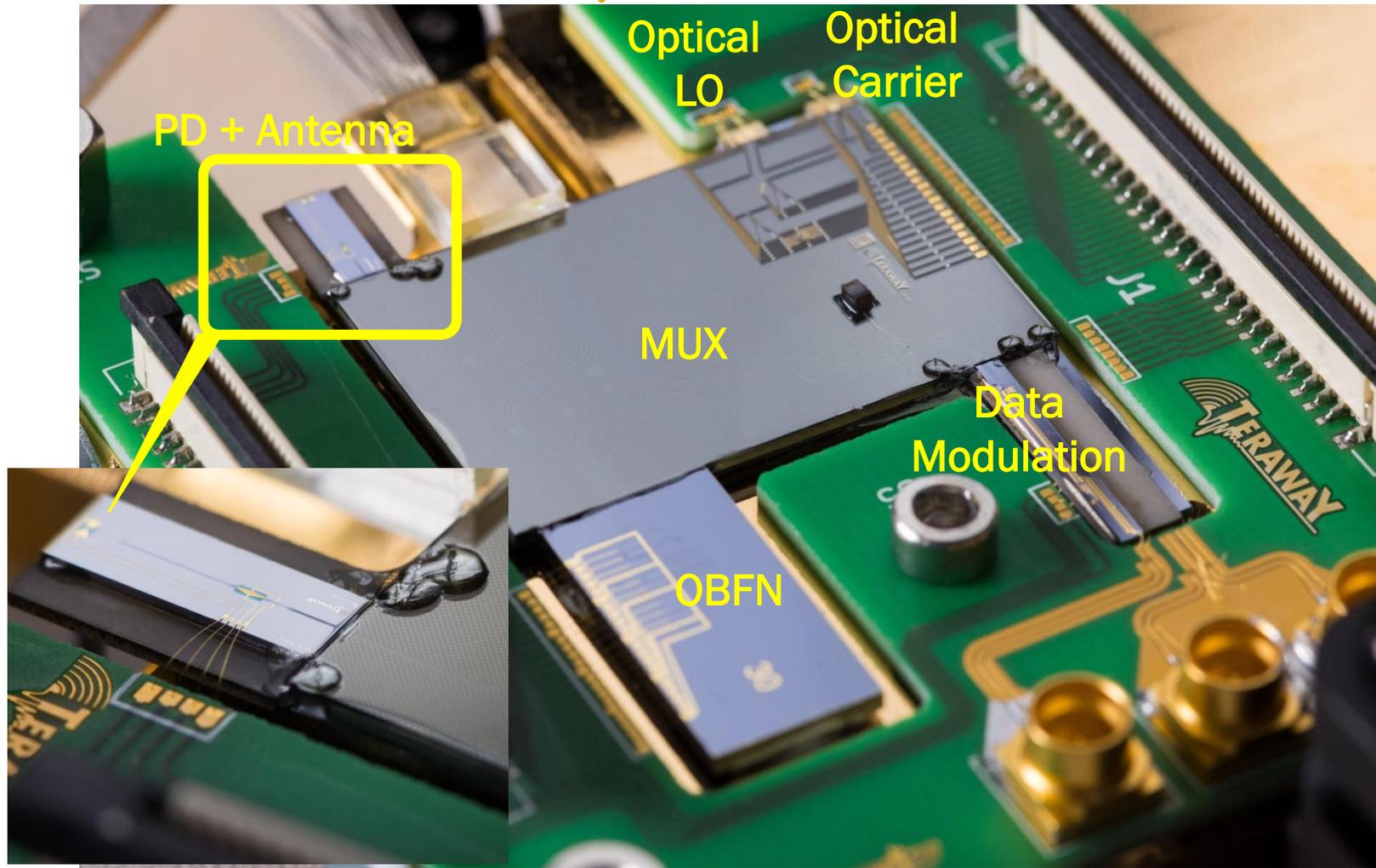
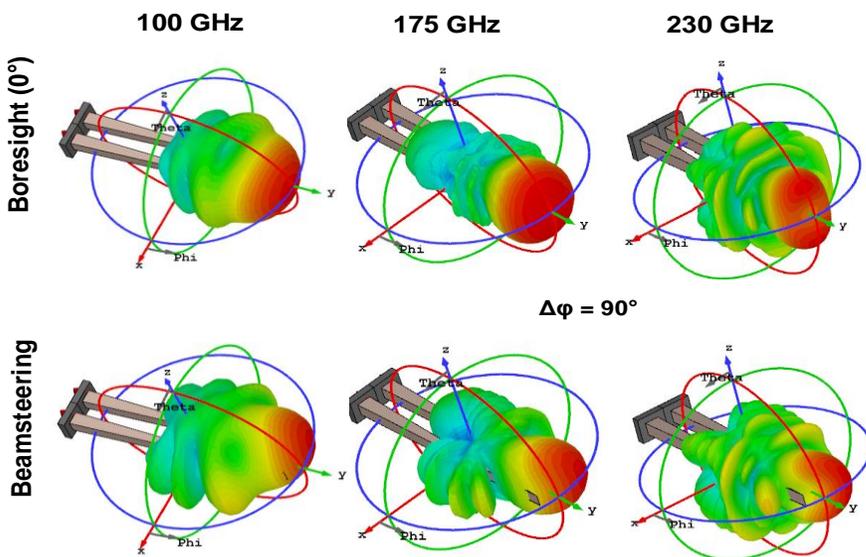
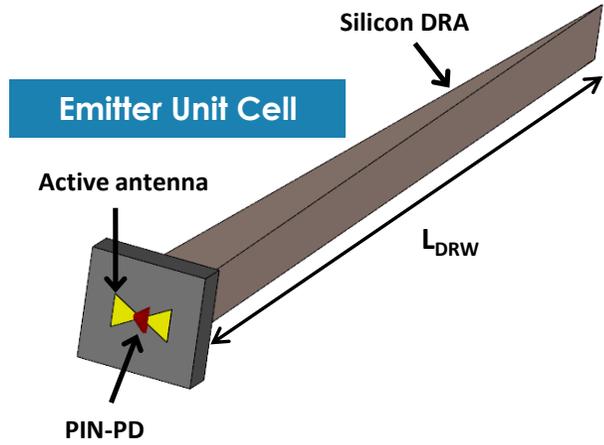
- Challenging impedance matching

- Hard to integrate other devices (LNA)

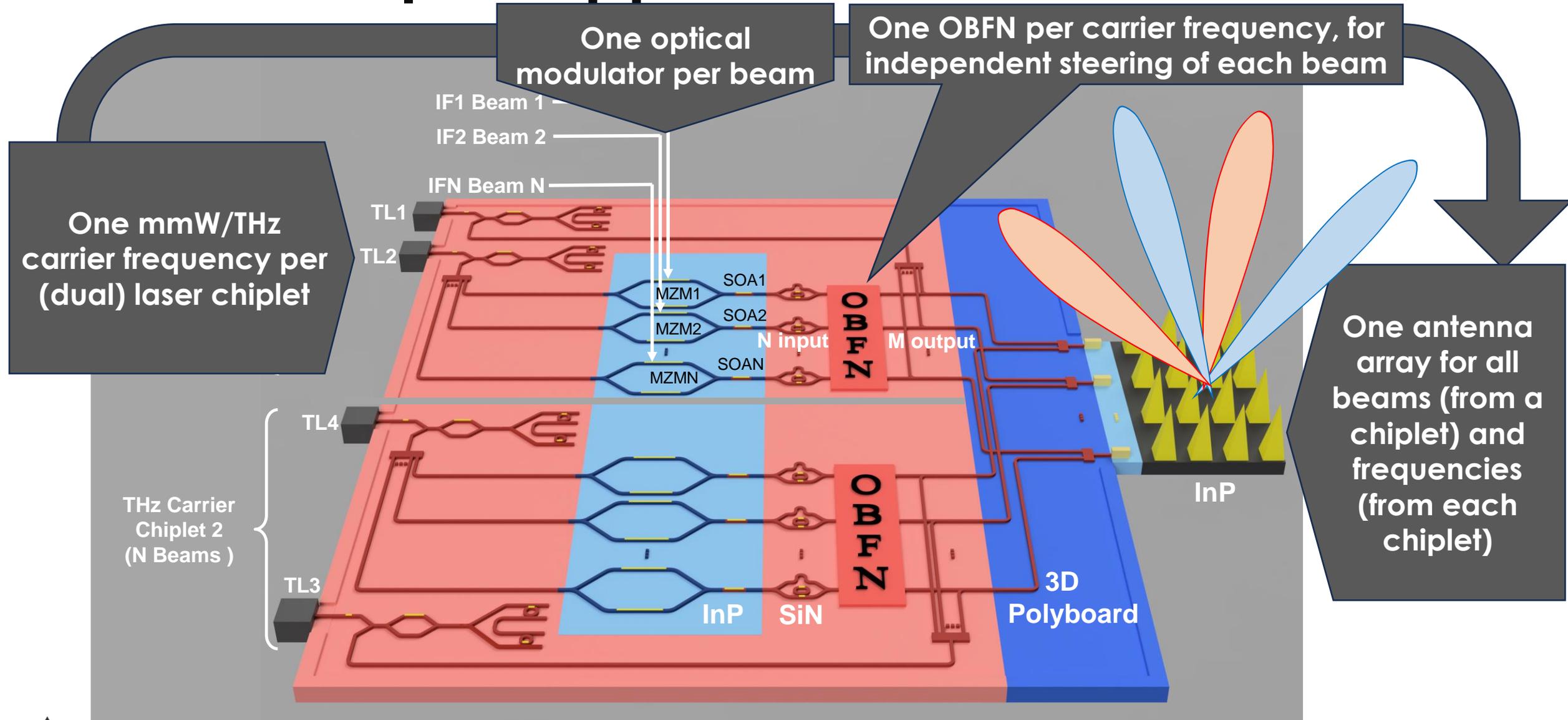
- Waste of InP area with large metal patterns

1D array ... or ... just beamforming

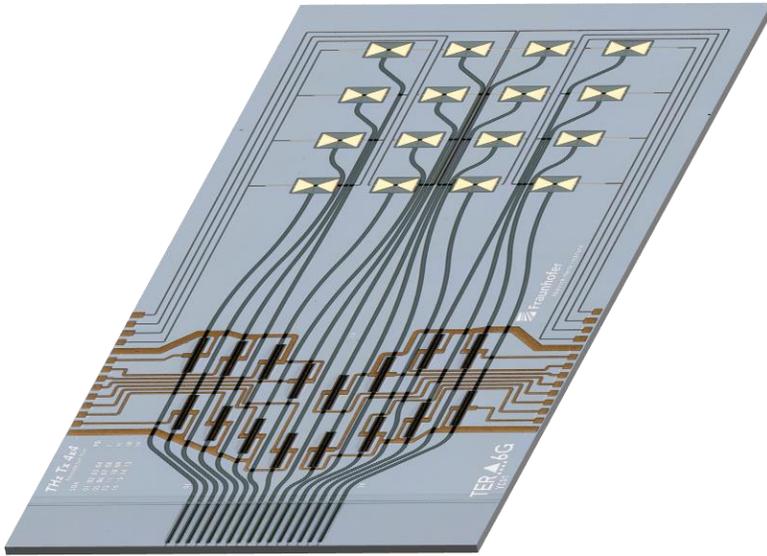
# TERAWAY experience



# TERA6G chiplet approach

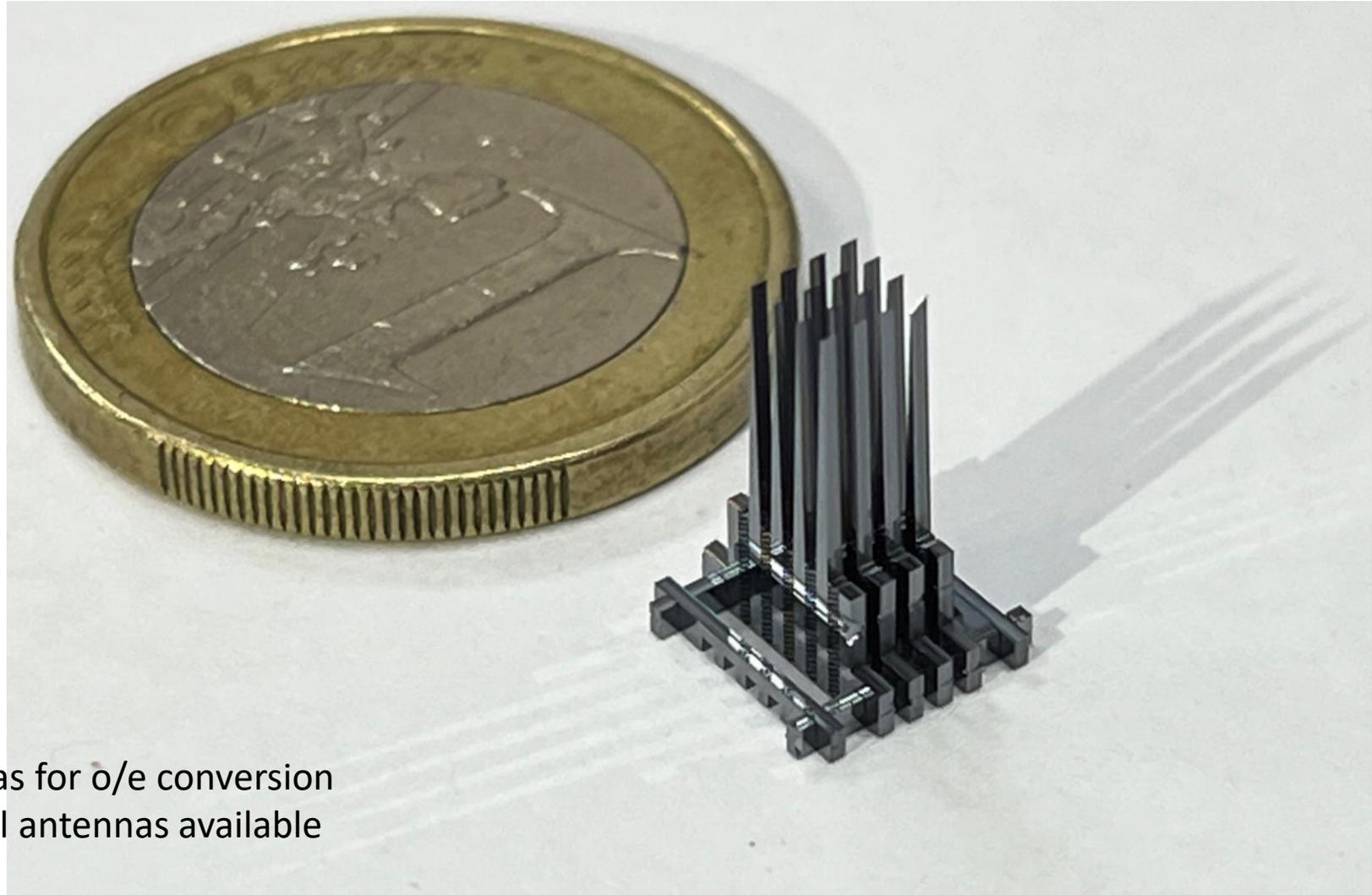


# TERA6G, towards a 2D mmW/THz array



## 4x4 antenna array for 2D beam steering

- 16 individual optical inputs
- SOAs to boost the optical power
- PDs in the feeding point of the antennas for o/e conversion
- Broadband antennas: bowtie and spiral antennas available



# Integrated Photonic Systems Roadmap

## 2023 IPSR-I Integrated Photonic Systems Roadmap

2023\_IPSR-I\_Roadmap\_Chapters\_3D Sensing - LiDAR - IPSR-I 2024

2024 IPSR-I Silicon Photonics\_Updated V2

3D Sensing - LiDAR - IPSR-I 2024

Aerospace Application guide - IPSR-I 2024

AgriFood Application guide - IPSR-I 2024 final

Biomedical Application guide - IPSR-I 2024

Datacenter & Telecom Application guide IPSR-I 2024

Electronic Photonic Design Automation - IPSR-I 2024

INP AND III-V COMPOUNDS - IPSR-I 2024

Interconnects & transceivers IPSR-I 2024

Polymer IPSR-I 2024

RF Photonics - IPSR-I 2024

Spectroscopy and Refractive Index Sensing IPSR-I 2024

Testing IPSR-I 2024



**DOWNLOAD @** [https://www.photonicsmanufacturing.org/2023\\_ipsr-i\\_roadmap\\_chapters](https://www.photonicsmanufacturing.org/2023_ipsr-i_roadmap_chapters)

**CONTRIBUTE, contact** [guiller@ing.uc3m.es](mailto:guiller@ing.uc3m.es)



Project contact email [tera6g@uc3m.es](mailto:tera6g@uc3m.es)  
Project website: [uc3m.es/research/tera6g](http://uc3m.es/research/tera6g)  
Instagram: [tera6g\\_eu\\_6gsns](https://www.instagram.com/tera6g_eu_6gsns)  
LinkedIn TERA6G Project

**Thank you!**

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**TER▲6G**

# TERA6G Consortium

	Beneficiary	Beneficiary Short name
1.	Universidad Carlos III de Madrid   ES	UC3M
2.	Institute of Communications & Computer Systems   EL	ICCS
3.	Fraunhofer Heinrich-Hertz Institute   DE	FhG-HHI
4.	LioniX International BV   NL	LXI
5.	PHIX BV   NL	PHIX
6.	University of Piraeus Research Center   EL	UPRC
7.	Oulun Yliopisto   FI	UOULU
8.	Cumucore OY   FI	CMC
9.	Intracom Telecom Solutions   EL	ICOM
10.	Telefónica Investigación y Desarrollo   ES	TID



Builds upon previous experience from H2020 projects

 <p>Grant agreement ID: 871668 From 11/2019 to 10/2022</p> <ul style="list-style-type: none"> <li>Hybrid integrated photonics-based THz generation.</li> <li>Hybrid integrated photonics-based THz detection</li> <li>High-speed photodiode-based mmW/THz transmitter</li> <li>2D transmitter antenna arrays</li> <li>Waveguide-integrated photoconductive-based mmW/THz receiver</li> </ul>	 <p>Grant agreement ID: 871464 From 11/2019 to 10/2022</p> <ul style="list-style-type: none"> <li>D-band propagation and channel modelling</li> <li>Beamforming and tracking</li> <li>Reconfigurable Intelligent Surfaces and beamforming</li> <li>Blockage and misalignment in D band BF</li> <li>Baseband processing</li> </ul>	 <p>Grant agreement ID: 761794 From 06/2017 to 03/2020</p> <ul style="list-style-type: none"> <li>300 GHz regime propagation and channel modelling</li> <li>Pencil Beamforming algorithms and impairments</li> <li>Pencil beamforming MAC and multiple access schemes</li> <li>BF codebook design</li> </ul>	 <p>Grant agreement ID: 871668 From 09/2020 to 02/2023</p> <ul style="list-style-type: none"> <li>5G Core with network slice manager</li> <li>3GPP Service based architecture with 5GLAN and TSN modules</li> <li>SDN controller integrated to network slice manager</li> </ul>
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# TERA6G Goals

## TERA6G GOALS

- Develops a 6G millimetre/terahertz wave transmitter module based on Blass matrix optical beamforming network and 3D optical distribution network.
- Creates a scalable multi-beam receiver module for 6G millimetre/terahertz wave transmissions using hybrid photonic integration technology.
- Assembles and demonstrate the developed transmitter and receiver modules with functionalities such as terabit-per-second wireless data links, channel sounding, and radar ranging.
- Designs network functions and interfaces to manage multi-beam THz wireless systems resources and integrate them into existing end-to-end orchestrated communication networks, following 3GPP standards.
- Develops methods and algorithms to maximise the energy efficiency of THz wireless multi-beam nodes in dynamic networks using a Data Analytics Function (DAF).

