

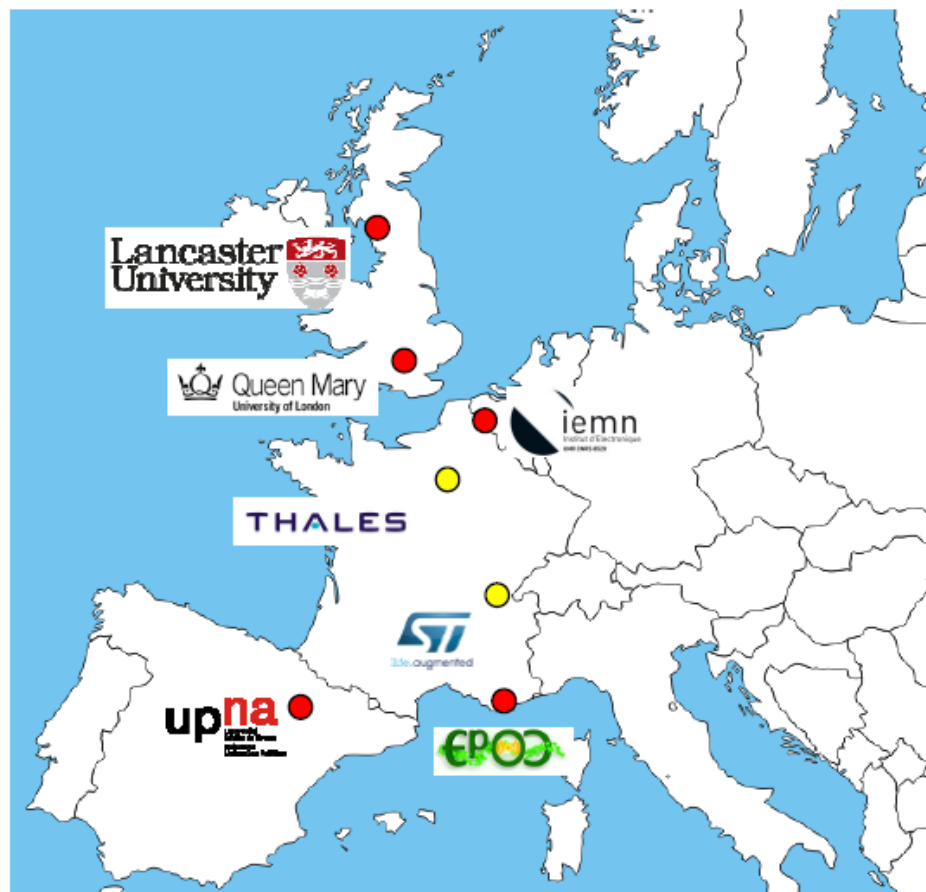
TMCS 2015

Terahertz Band for Next-Generation Mobile Communication Systems (TMCS)

Partner ●

Industrial
support ●

UC Davis/DMRC:
(USA)



TMCS 2015

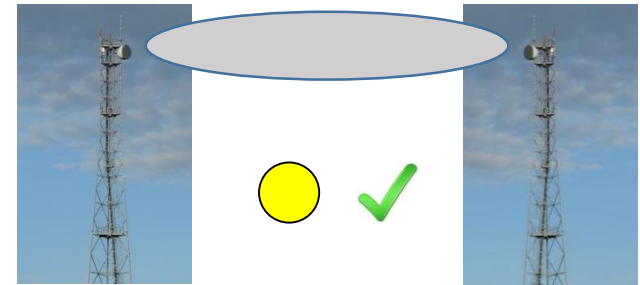
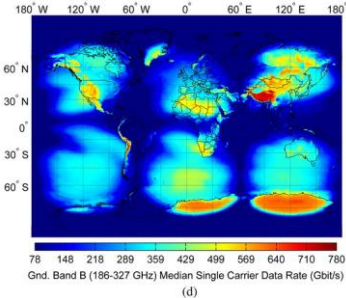
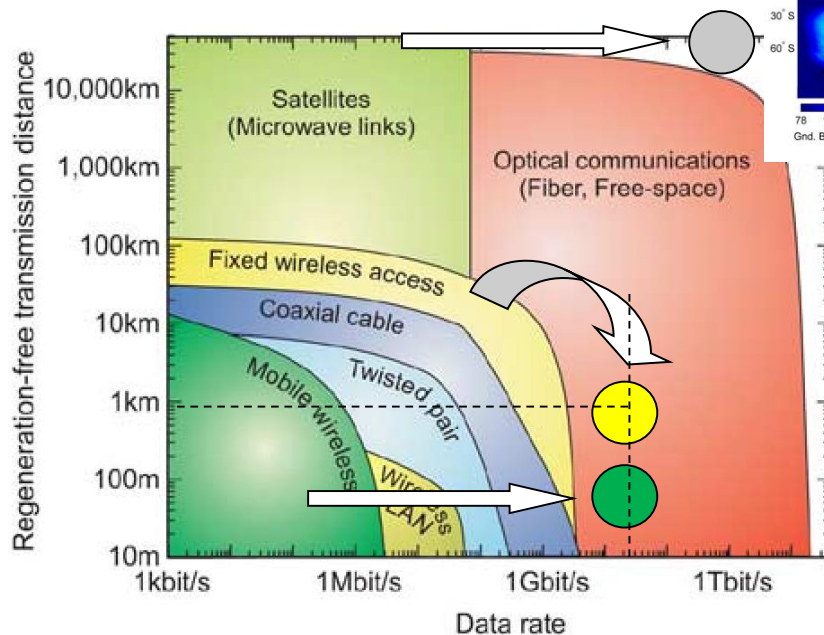
Terahertz Band for Next-Generation Mobile Communication Systems (TMCS)

Outline

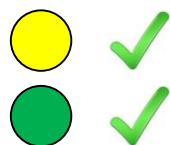
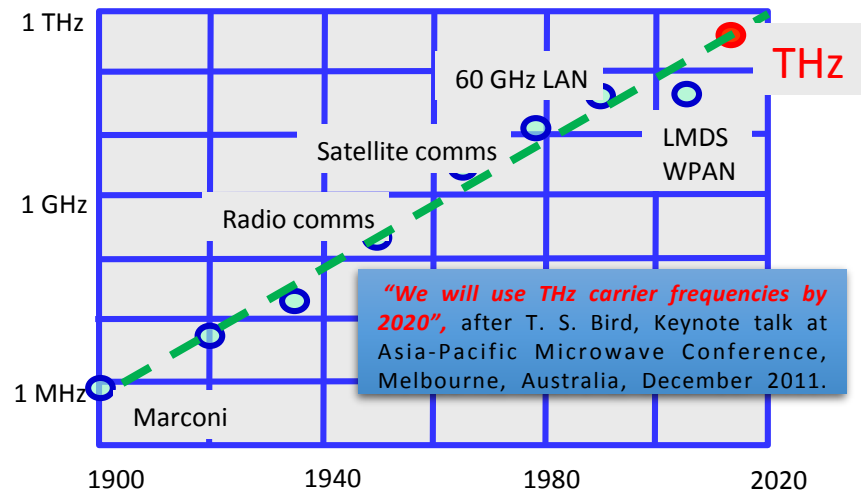
- Scientific background
- Key challenges and potential impact of the project
- Presentation of each partner of the consortium with their specificity and added value
- Main scientific results, dissemination and other output
- Sustainability/Valorisation

- **Scientific background: why THz frequencies?**

- Context: **Possible interest for THz?**



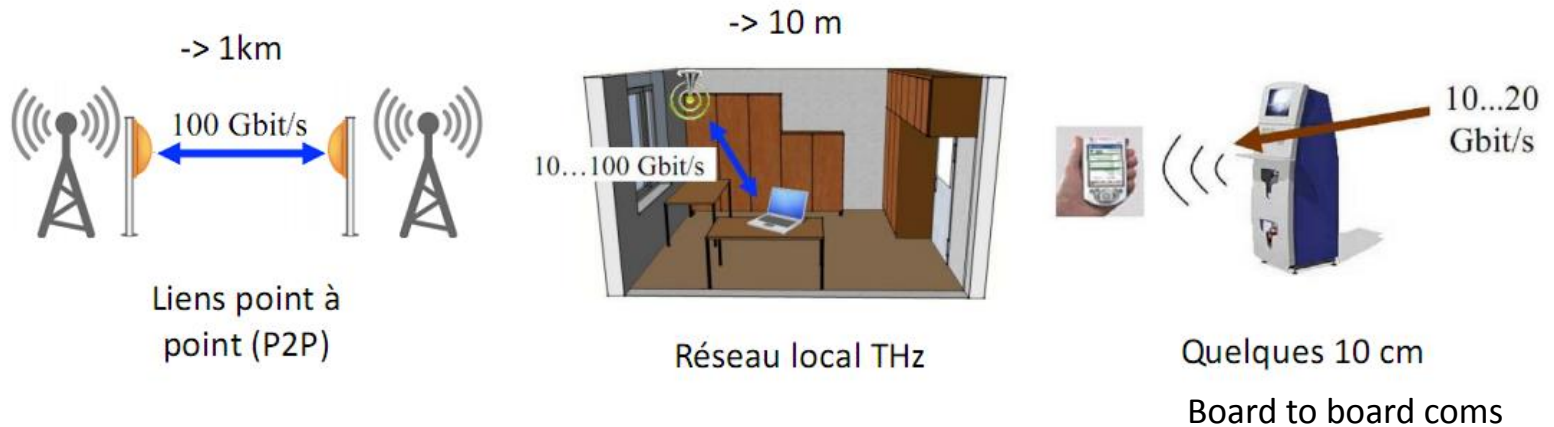
- Line of sight, Point to point



Future P2P links

Future mobile wireless links

- **Scientific background: why THz frequencies?**



Fiber-optic compatible (1.55 μm).

Alternatives

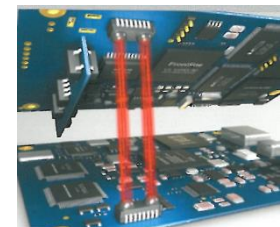


« FSO »
(Free Space optics,
0.4 / 0.78 μm)
(ex: Intellimax) ~ Gbit/s

Backhaul Q & E-band

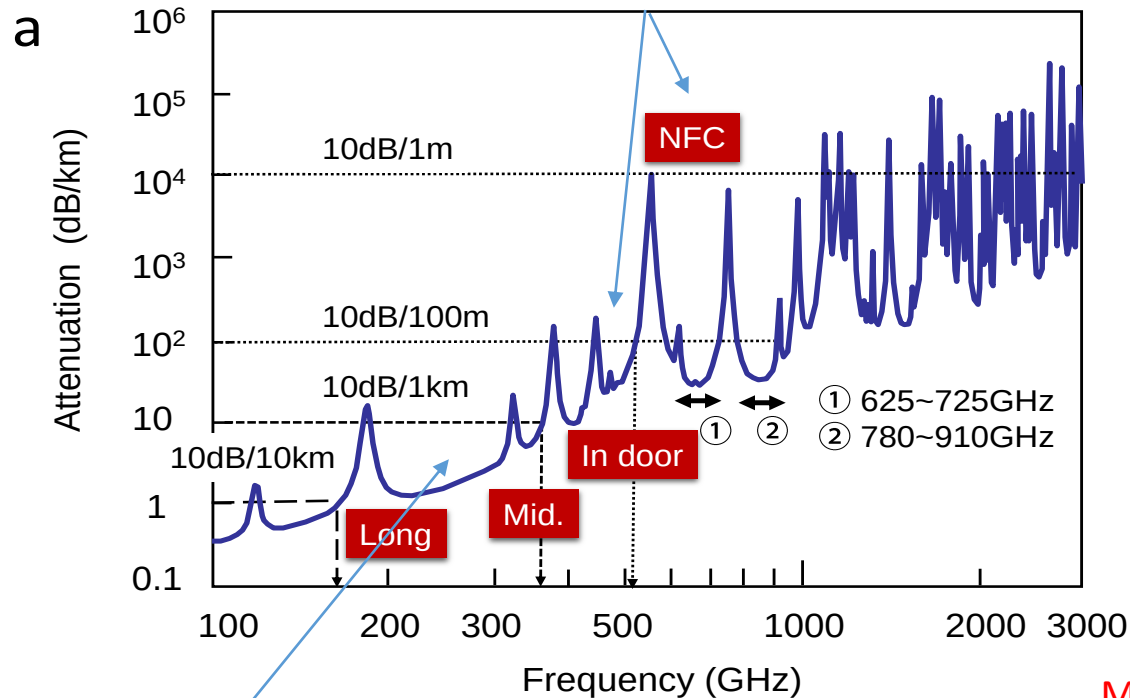
ELVA: 10 Gbps / 10
km (clear sky)

Compete with:



Indoor THz : small cells, frequency re-use.

- **Scientific background: why THz frequencies?**



Point to point

T. Nagatsuma, G. Ducournau, C.C. Renaud

Nature Photonics 10, 371–379 (2016)
doi:10.1038/nphoton.2016.65

Major interest in 300 GHz-band:

- Technologies start to be available
- Link budget is ok for km-range links
- Frequencies not allocated > 275 GHz

- ***A new paradigm at THz frequencies?***

THz frequencies: one (big) difference with usual radio waves:

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

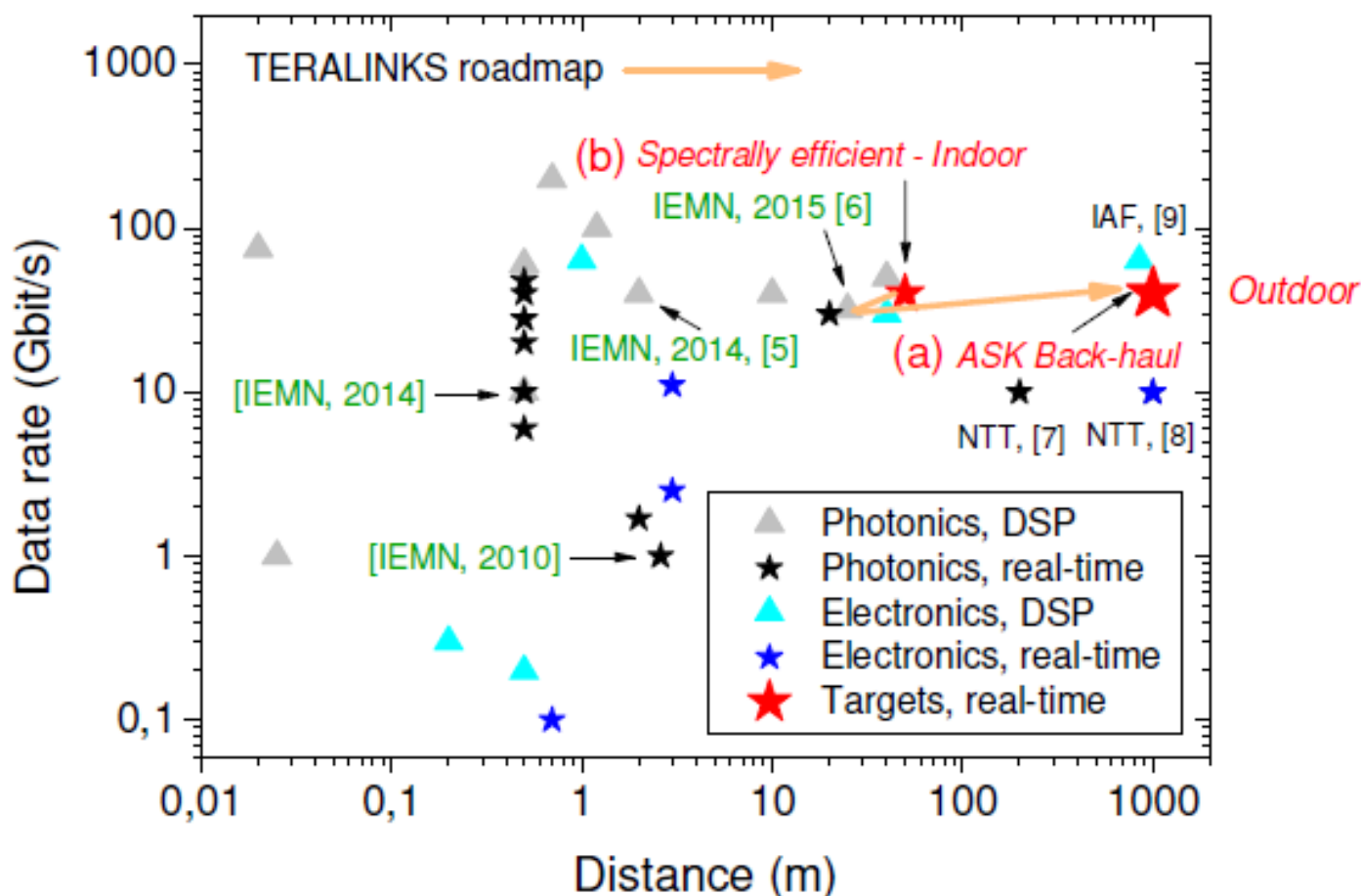
From Shannon theorem: B bandwidth, S/N = signal to noise ratio, C = channel capacity

RADIO: Small B, thus high S/N required/complex modulations

THz: Huge B, thus more margin on S/N (in theory)...
However THz power is often limited
=> **Importance** of amplifiers, as SSPA, Tube, LNAs...)

	RADIO	THz
B		
$\frac{S}{N}$		

- **Potential impact of the project: where we want to go within TERALINKS?**



- ***Potential impact of the project: strong interest for THz datacoms, as a new IEEE standard has been released***

IEEE Standard for High Data Rate
Wireless Multi-Media Networks

Amendment 2: 100 Gb/s Wireless
Switched Point-to-Point Physical
Layer

300 GHz coms... are on the way

Window = 250-320 GHz

=> IEEE 802.15.3d

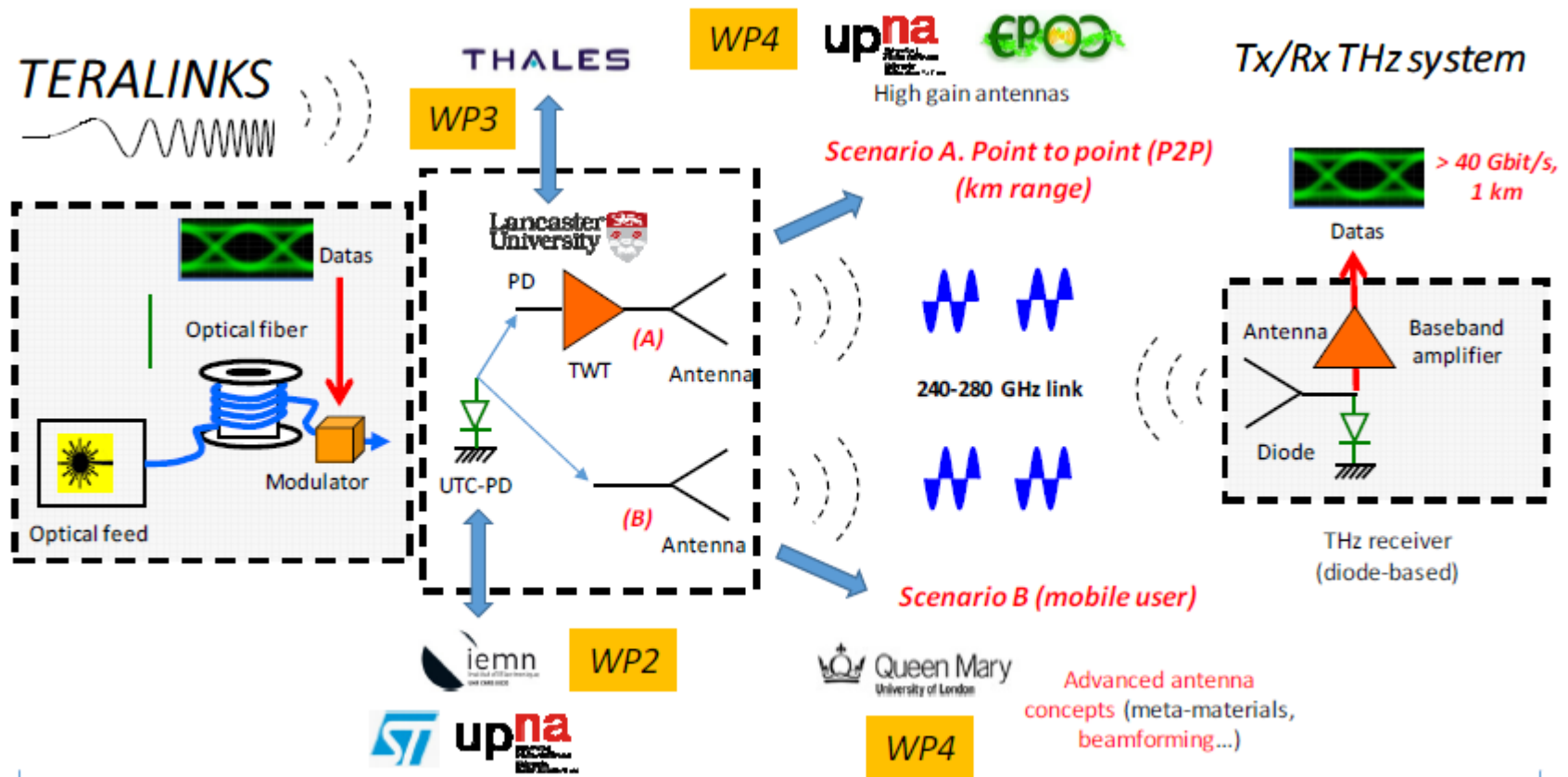
F.A.Q. (Frequently asked questions)

Do we really need this?

5G: 10 Gbps per mobile user (expected)

*100 users in a cell => 1 Tbit/s to be aggregated...
So we need THz bands*

- **Presentation of each partner of the consortium with their specificity and added value: system-view of teralinks project**



- **TERALINKS Tx/Rx in a nutshell**

Frequency	220-260 GHz
THz source	up to 1 mW / packaged
TWT power amplifier	Gain > 30 dB Power: 3-4 W
Antenna	50 dBi (high gain) > 20 dBi, beam-steering capable (indoor)
Receiver (direct)	Zero bias detector Schottky ~ 1 kV/W
Rx bandwidth (GHz)	40 GHz, including baseband amplifier
Modulation	ASK (real-time) 40 Gbit/s
Link budget (outdoor)	140 dB (1 km) 40 dB with 50 dBi antennas



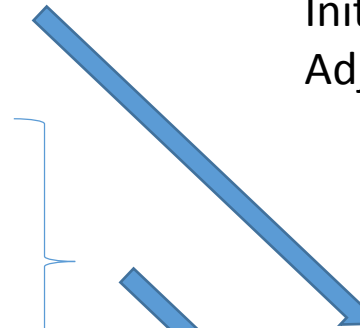
Photonics-based



Associated to photodiode (waveguide)

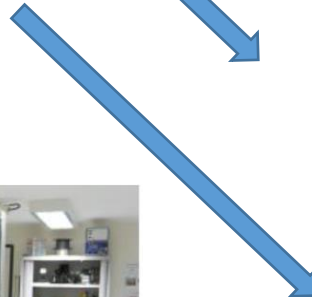
Initial BW: center 240 GHz

Adjusted to 230 GHz



Indoor & outdoor antennas

Indoor: different topologies + beam-adjusting antennas

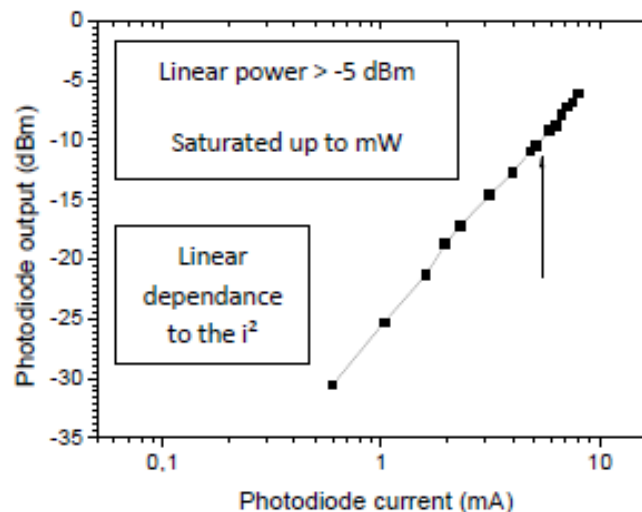
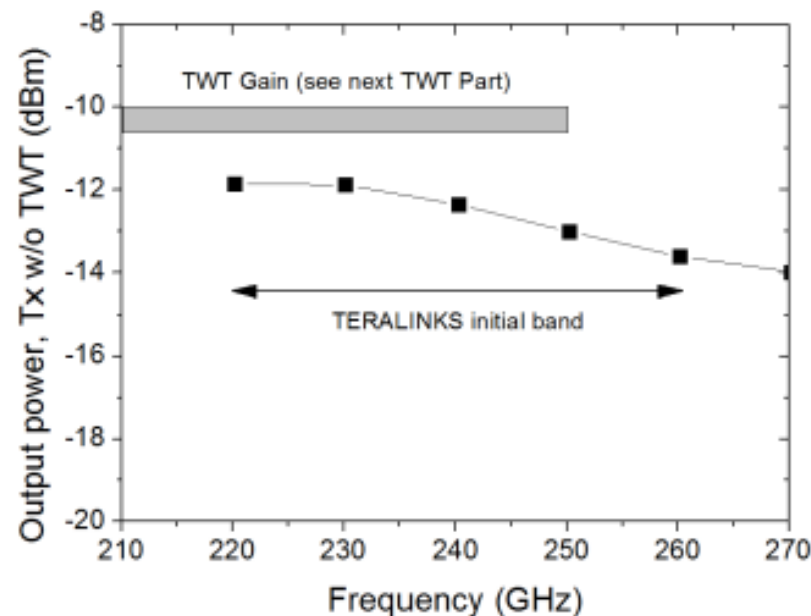


Under final validation (May, 2019)
At IEMN, on the TERALINKS testbed



- **TERALINKS Tx/Rx: progresses in year #2**

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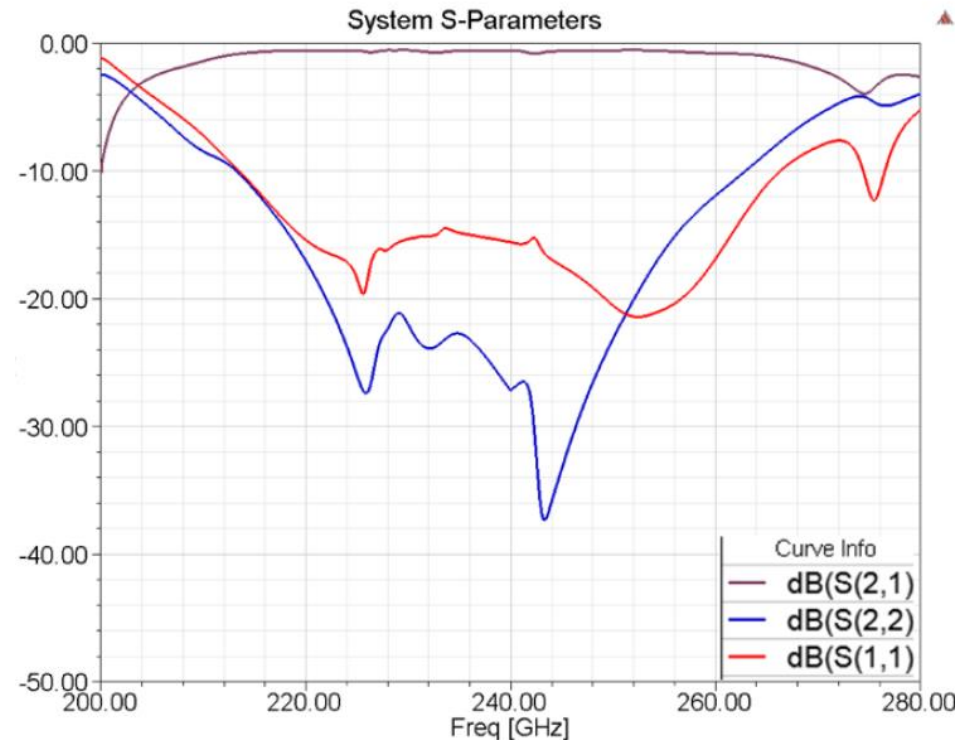
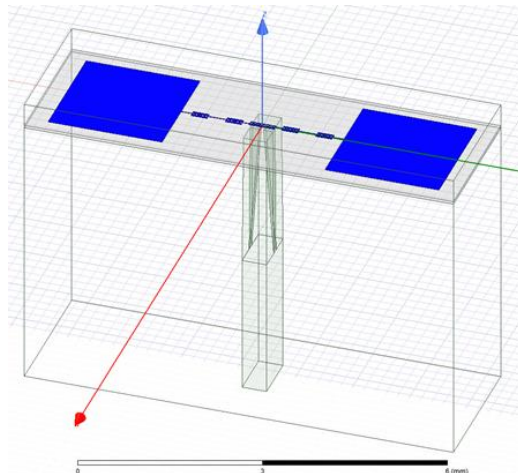
Photodiode linearity

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Photodiode integration: final structure to be chosen according to the device final electrical performances



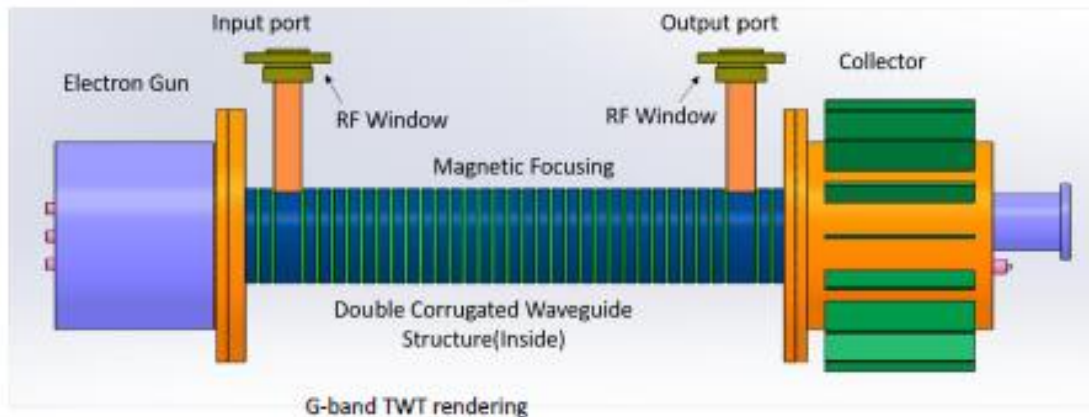
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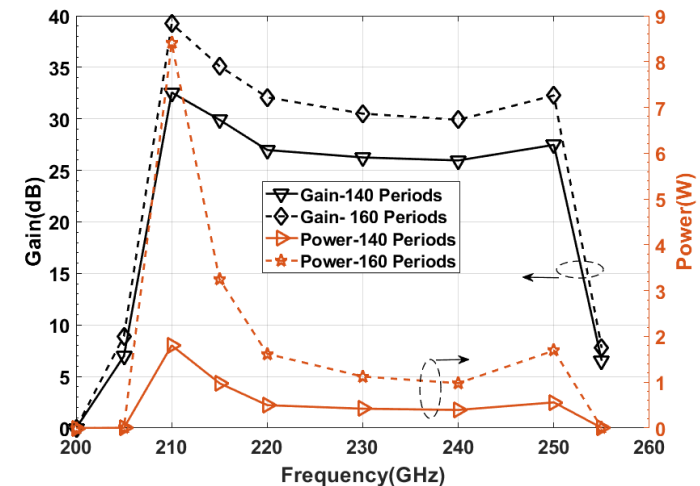
TWT



- State-of-the art TWT targeted for TERALINKS
- Design completed (Band adjusted 220-260 => 210-250 GHz) (Still 40 GHz bandwidth, in accordance to targeted data-rate)
- Fab is on-going, slow-wave structure ok, electron-gun
- Risk mitigation: single section of SWS/high gain

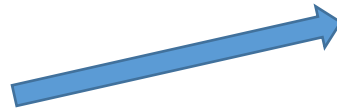


G-band TWT rendering



- **TERALINKS Tx/Rx in a nutshell**

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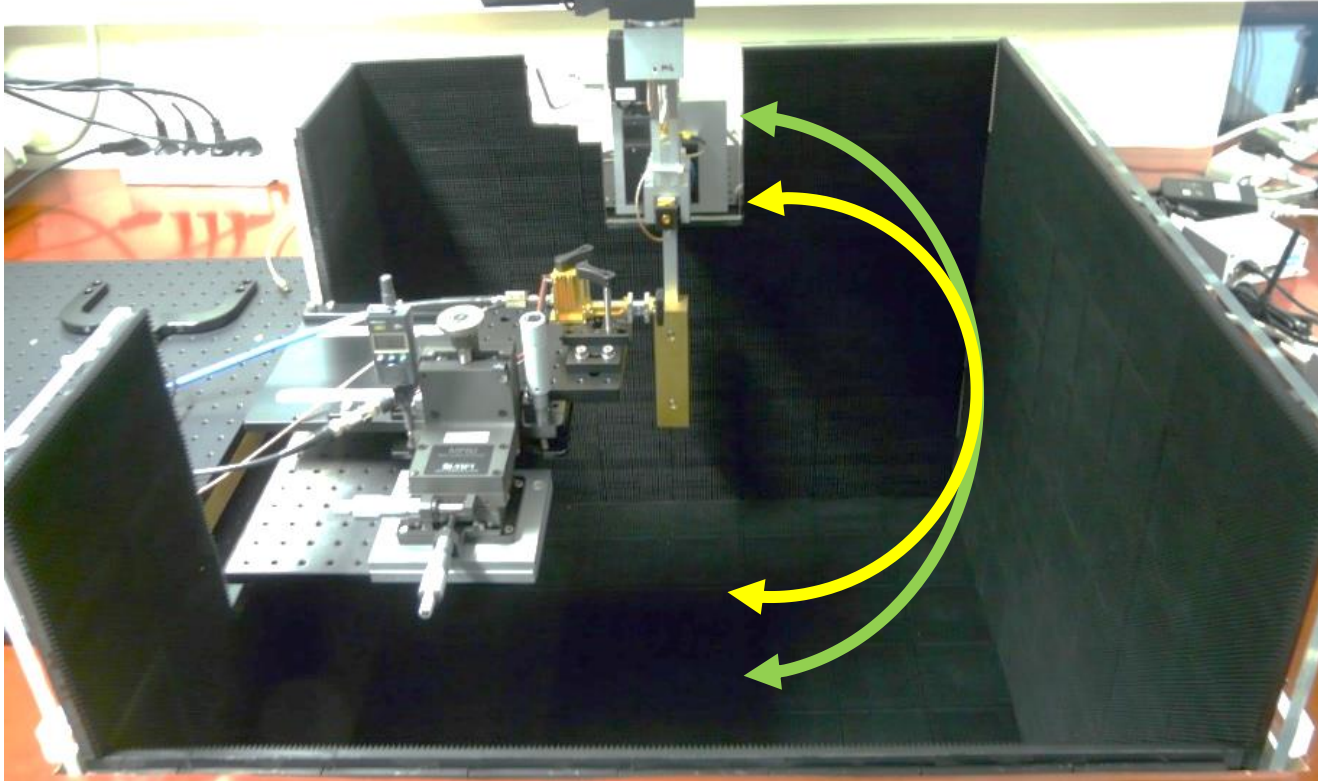
Indoor & outdoor antennas

Indoor: different topologies + beam-adjusting antennas

+ Radiation pattern setup (Full 3D) developed during TERALINKS

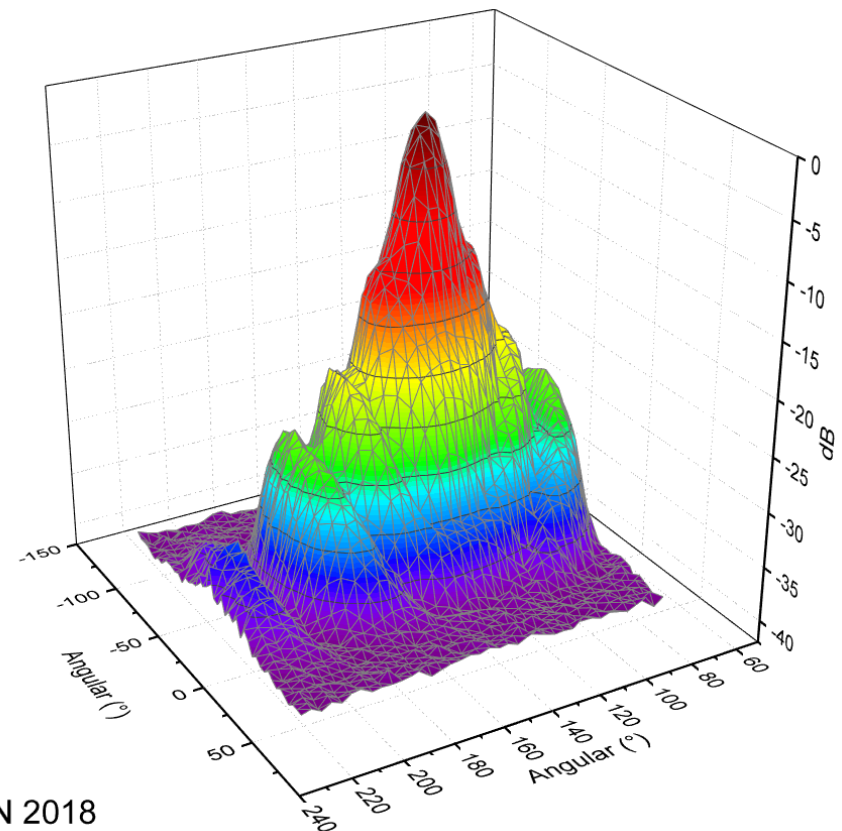
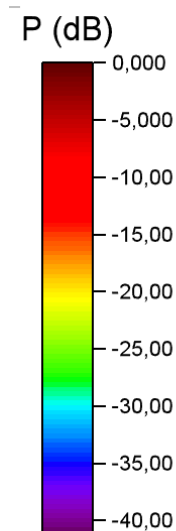
- ***TERALINKS 3D radiation pattern setup***

Operation: 220-350 GHz
50 dB dynamic with 2x25 dBi



- **TERALINKS 3D radiation pattern setup**

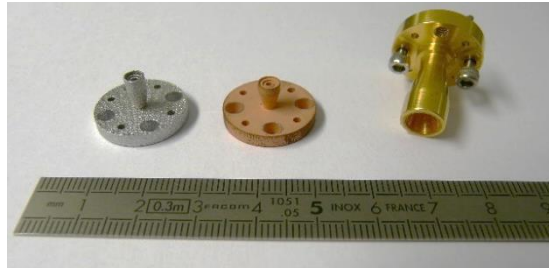
Example of measurement of
25 dBi antenna (for indoor links)



280 GHz, IEMN 2018

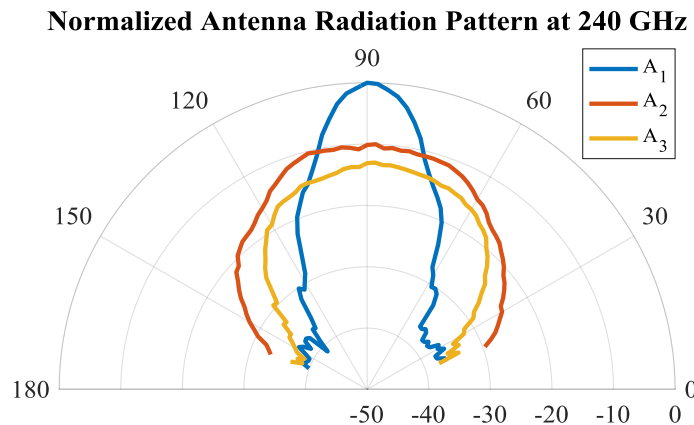
- **Main scientific results, dissemination and other output**

Antennas;



Year #1:

240 GHz horns, characterized in 2D
for THz links



Year #2:

Risk mitigation we pursued two ways:

“**Risk limited designs**” to secure links

“Advanced design” to make proof of concepts

Low risk designs

- High gain structures (lens structures)
- Large mirror for long distance link

Advanced structures

- Luneburg lenses fed by near-field probe: enabling beam adjustment

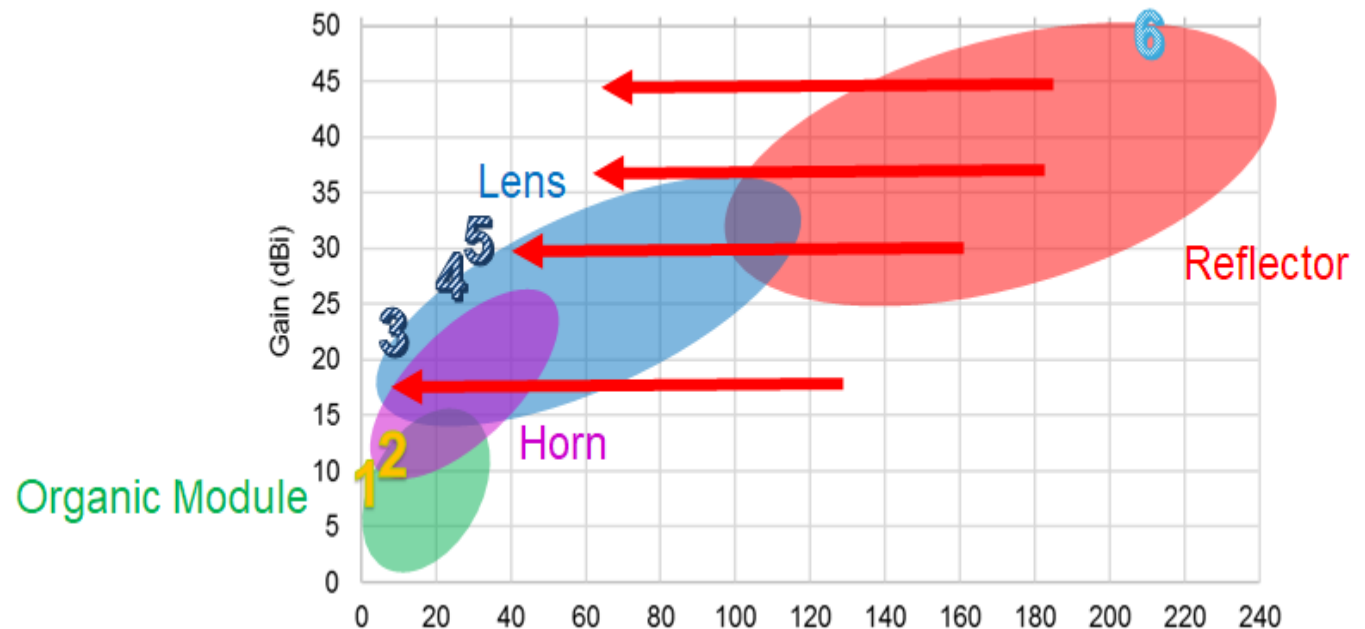
- **Main scientific results, dissemination and other output**

Antennas;

Year #2:

Low risk designs (final required gain will depend on TWT power)

- Achievable gains



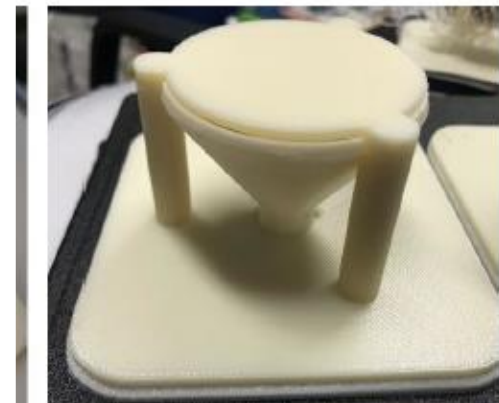
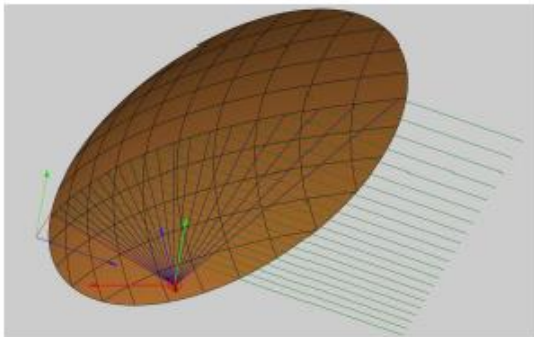
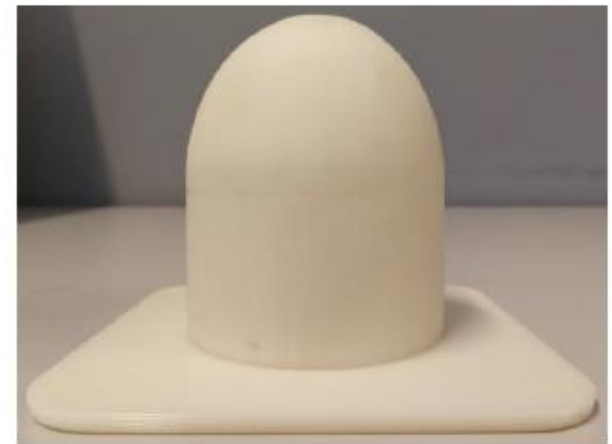
- **Main scientific results, dissemination and other output**

Antennas;

Year #2:

Low risk designs (final required gain will depend on TWT power)

- High gain structures (lens structures or Cassegrain)
> 35 dBi
- Large mirror for long distance link (> 50 dBi)



- **Main scientific results, dissemination and other output**

Antennas;

Year #2:

Advanced structures

- Luneburg lenses fed by near-field probe:
enabling beam adjustment

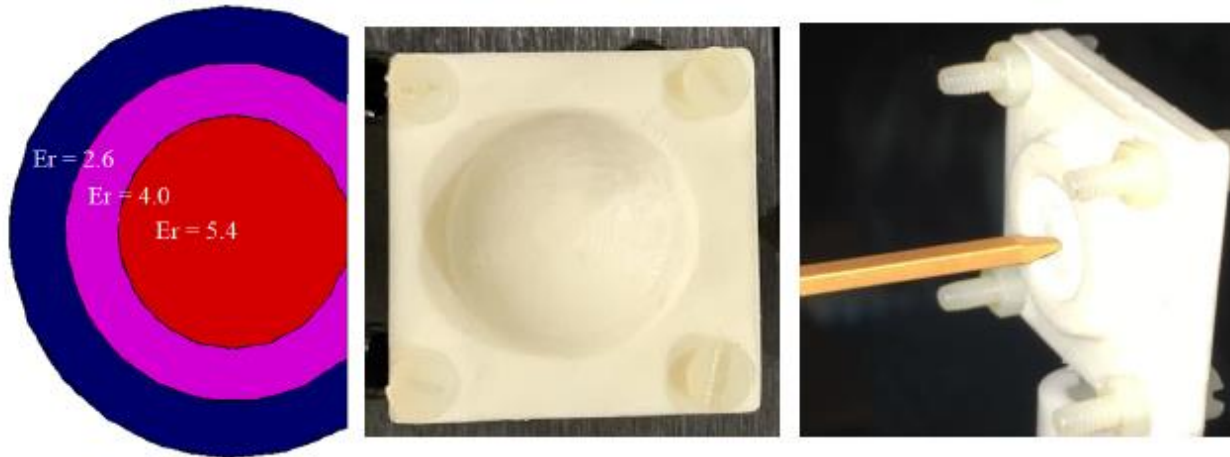


Figure: The design and the fabricated prototype of the 3-layered 3D-printed Luneburg Lens. The lens is fed using a WR-03 waveguide probe.

- **Main scientific results, dissemination and other output**

Antennas;

Year #2:

Advanced structures

- Luneburg lenses fed by near-field probe: enabling beam adjustment

Join work IEMN/QMUL (UK)

To be submitted to journal paper

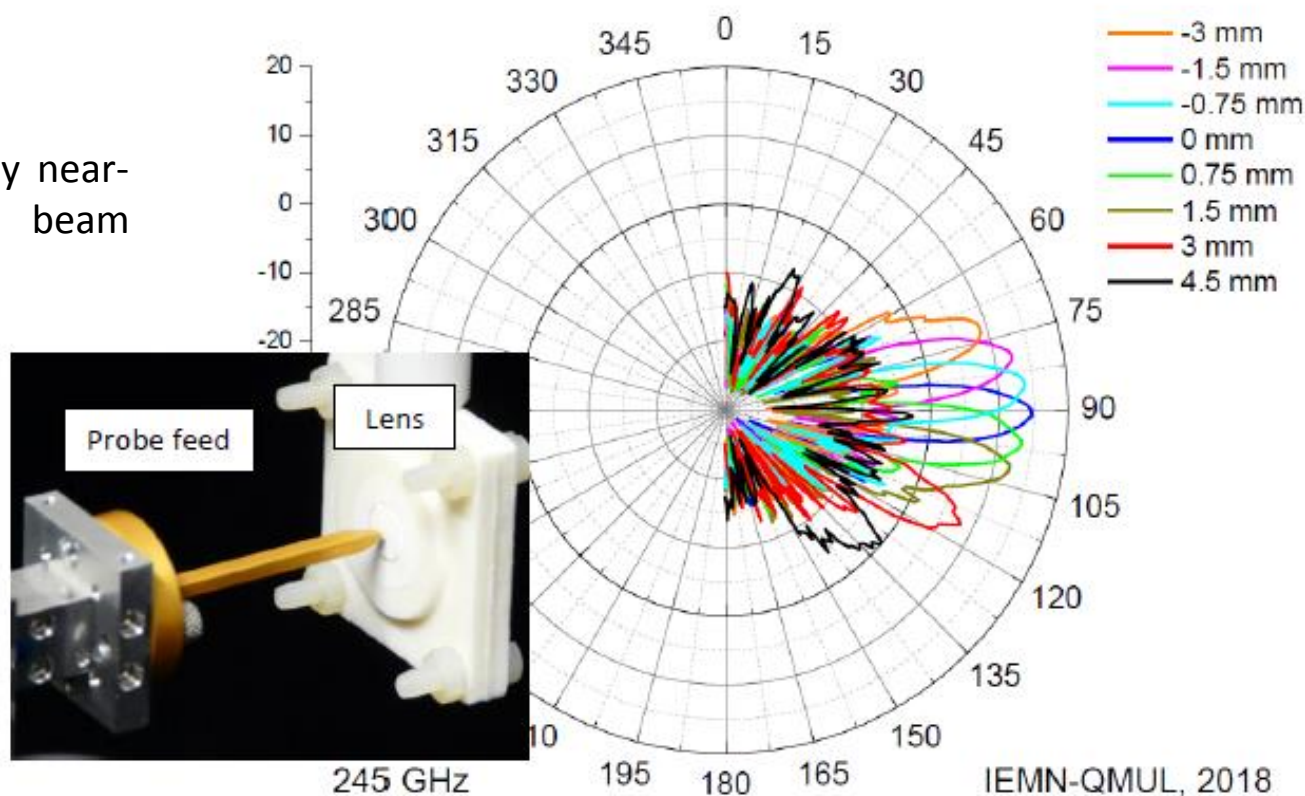


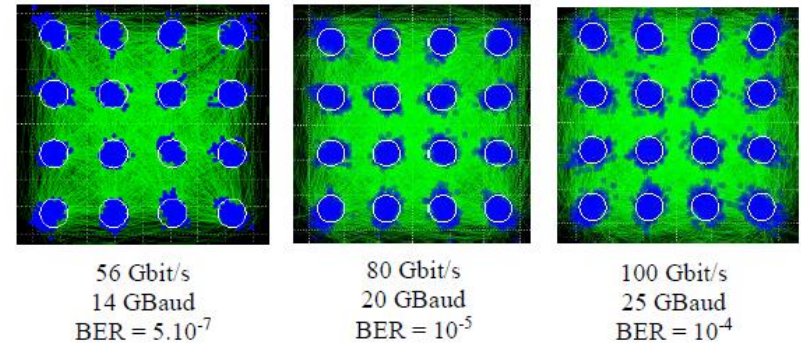
Figure. Beam-steering demonstration at 245 GHz

- **Main scientific results, dissemination and other output**

Examples of dissemination

-> 2018, Q2 (April 2018)

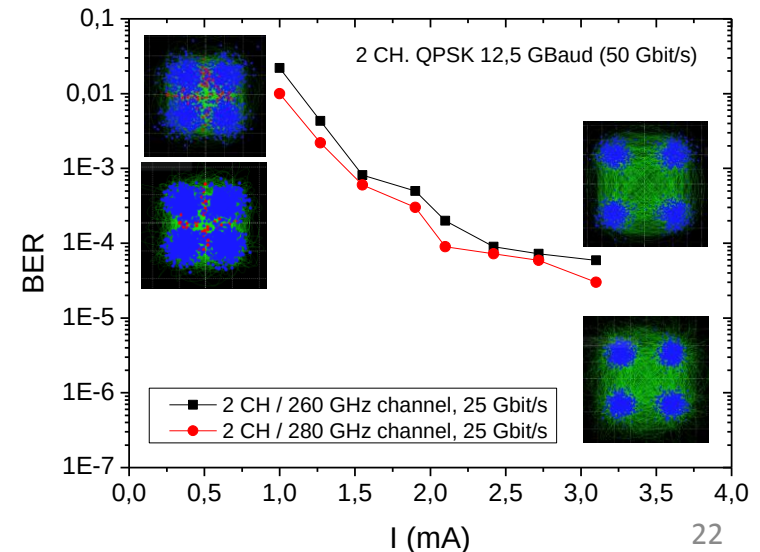
Single channel 100 Gbit/s transmission
using III-V UTC-PD photodiodes for future
IEEE 802.15.3d wireless links in the 300
GHz band



-> 2019 (submitted to IRMMW conference)

First achievement of 50 Gbit/s 300 GHz link
using silicon photonics!

(Technology from IAB partner ST Micro, joint
work IEMN/Univ Nice)



Several collaborations

THz source: Collaboration IEMN-UPNA On the THz source, IEMN and UPNA

Tube amplifier: Collaboration with USA (TERALINKS AISG)

Prof. Luhmann, University of California, Davis, supports the project with his research group and state of the art facilities.

Collaboration IEMN-LU

On the use of a TWT amplifier towards THz communications, almost no data is actually available on the literature. In TERALINKS, we will get the opportunity to combine the THz modulated signals with the TWT, for the first time, thus we expect strong outcome of the transnational collaboration.

Collaboration IEMN-Univ Nice-UPNA-QMUL

In TERALINKS we have collaboratively established a full 3D antenna measurement system, and already used it for first antenna prototypes, at 240 GHz.

Overall Collaboration of all partners

The final goal of TERALINKS is to achieve, for the first time, a real-time transmission system combining all technologies delivered by partners. We again consider that this is a strong added value as all sub-system and partner expertise is required for the whole system demonstration.

- **Sustainability/Valorisation, EU Projects enabled by CHISTERA activity**

Within TERALINKS consortium, new connections are currently ongoing for European-level research projects for THz communication developments, all of these enabled projects falls in the H2020 EU program.



We can also mention that a **join ANR-DFG project, "TERASONIC"**, which investigates the combination of photonics emitters and solid-state receivers has been granted by IEMN partner in 2018.

EU THOR PROJECT (ICT 2018, H2020) 2018-2021 (IEMN Partner)

Join initiative between Europe and Japan will enable real implementation of THz communication systems towards future 5G and beyond new network architectures.

EU ULTRAWAVE PROJECT (ICT 2017, H2020) 2017-2020 (LU PI)

The ULTRAWAVE project (LU partner involved) is aimed at developing a high capacity backhaul that enables 5G cell densification by exploiting bands beyond 100 GHz.

- ***Dissemination list (8 papers (journal), 15 international conferences)***

International publications on scientific journals:

1. X. Li, X. Huang, S. Mathisen, R. Letizia and C. Paoloni, "71-76 GHz Double Corrugated Waveguide Traveling Wave Tube for Satellite Downlink", accepted IEEE Trans. on Electron Devices, Special issue, June 2018
2. R. Waring, C. Paoloni, "Lagrangian Simulator for Millimetre Wave TWT based on Non-Rotationally Symmetric Slow-Wave Structure", in Journal of Electromagnetic Waves and Applications, 31, 17, p. 1902-1913 12 p. September 2017.
3. J Ma, NJ Karl, S Bretin, G Ducournau, DM Mittleman, "Frequency-division multiplexer and demultiplexer for terahertz wireless links", Nature communications 8 (1), 729.
4. E.LACOMBE, C. BELEM-GONCALVES, C.LUXEY, F. GIANESELLO, C. DURAND, D. GLORIA, G. DUCOURNAU, "10 Gbps indoor THz communications using Industrial Si Photonics Technology", IEEE Microwave and Wireless Components Letters, vol. 28, April 2018, pp. 362-364.
5. Basu, Rupa, Laxma R. Billa, Rosa Letizia, and Claudio Paoloni. "Design of sub-THz traveling wave tubes for high data rate long range wireless links." Semiconductor Science and Technology 33, no. 12 (2018): 124009.
6. VK Chinni, P Latzel, M Zégaoui, C Coinon, X Wallart, E Peytavit, JF Lampin, K Engenhardt, P Szriftgiser, M Zaknoune, G Ducournau, Single-channel 100 Gbit/s transmission using III–V UTC-PDs for future IEEE 802.15. 3d wireless links in the 300 GHz band, Electronics Letters 54 (10), 638-640.
7. G Ducournau, Silicon photonics targets terahertz region, Nature Photonics, Vol. 12, pages 574–575 (2018).
8. J. Gao, C. Wang, K. Zhang, Y. Hao, and Q. Wu, "Beam steering performance of compressed Luneburg lens based on transformation optics," Results in Physics, vol. 9, pp. 570-575, Jun 2018.

- ***Last part of the project (-> 2019 Sept.)***

The TERALINKS project is working towards the demonstrator of the THz links (in & outdoor)!

Outdoor:

- Use of the TWT
- Use of the photodiode to feed the TWT
- Using large antennas (reflectors), we forecast large transmission distance according to the TWT power design. (**never demonstrated yet in the community**)

Indoor:

- Use of the « advanced » antennas in data com link (**never demonstrated yet in the community**)

In a nutshell: many challenges!

THANK YOU