Terahertz communications using photonics based emitters for 300 GHz band

From mmWave to terahertz communications for beyond 5G

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IEMN is a French CNRS/University institute
Located north of France, close to (5 km!) Belgium

1h10 min by fast train from CDG
30 min from Brussels midi

Outline

THz communications: context

Photomixing for optical to radio conversion, towards high-level schemes

Links using photonics

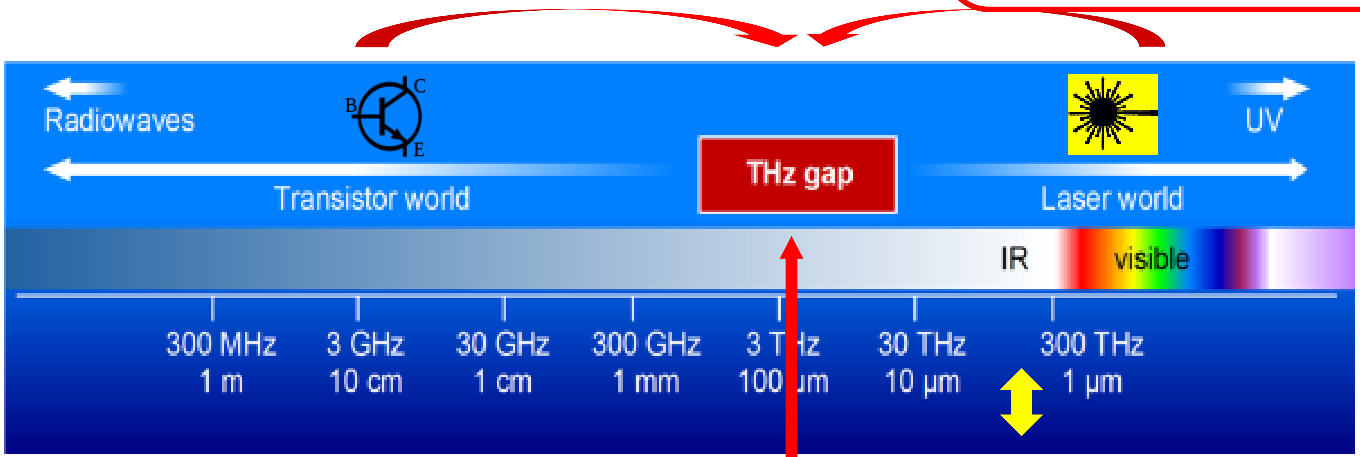
Conclusion / Challenges

A little bit of Terahertz

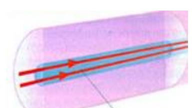
• **Sources**

➢ Electronic sources:
- Multiplication chains, RTD, transistors, diodes …
(compact, room temp., but bandwidth limited / efficiency)

➢ Opto-electronics:
- Photodiodes, photoconductors
(tunable, room temp., but power limited, efficiency)



1 THz ⇔ 1 ps ⇔ 300 µm ⇔ 4,1 meV ⇔ 49 K



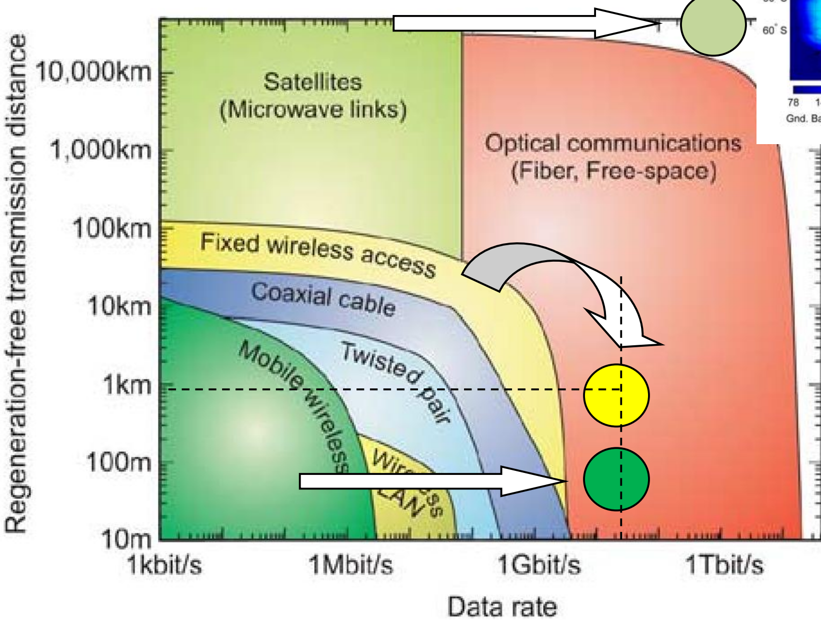
Optical fibers (1.55 µm)

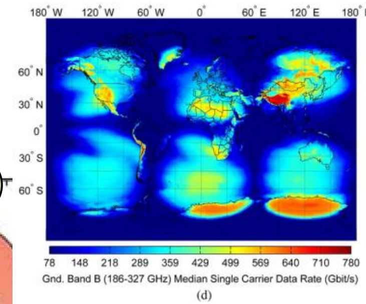
➢ Direct generation
- QCL, non-linear optics, molecular lasers
(power = ok , but efficiency, bulky, sometime cryogenic, …)

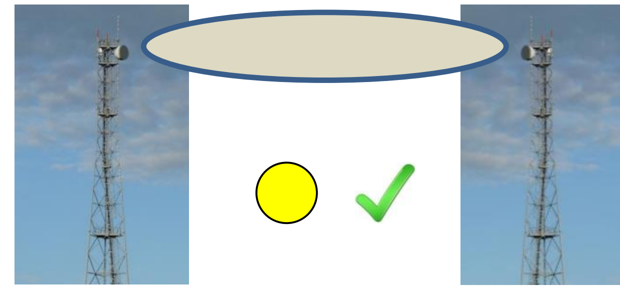
1. Context

Exponential Growth on IP traffic / Fastest growth on wireless channel

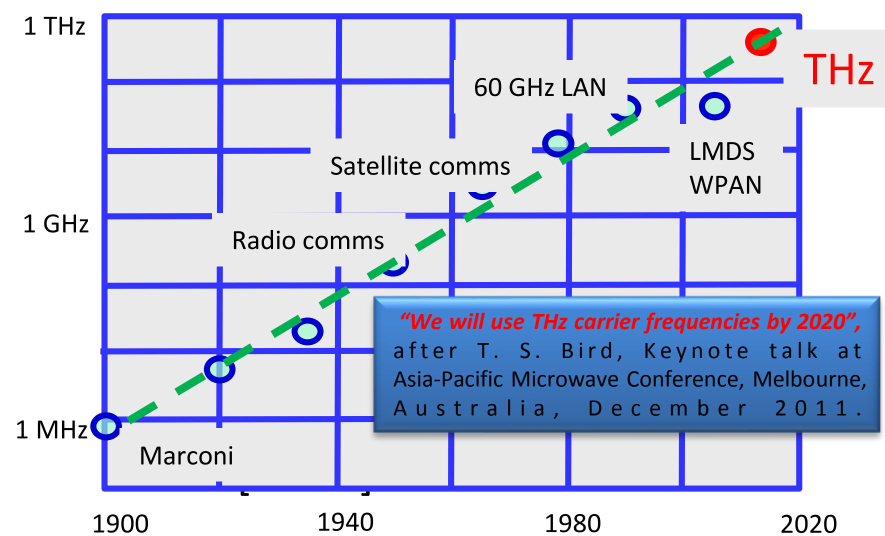
- Context: **Possible interest for THz**?







- Line of sight, Point to point



"We will use THz carrier frequencies by 2020", after T. S. Bird, Keynote talk at Asia-Pacific Microwave Conference, Melbourne, Australia, December 2011.

Future P2P links

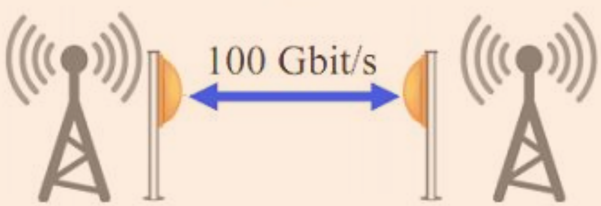
Future mobile wireless links

Adapté de [P.J. Winzer; IEEE Proceedings]

Context

P2P applications: first enabler of THz coms?

-> 1km



Liens point à point (P2P)

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…)

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

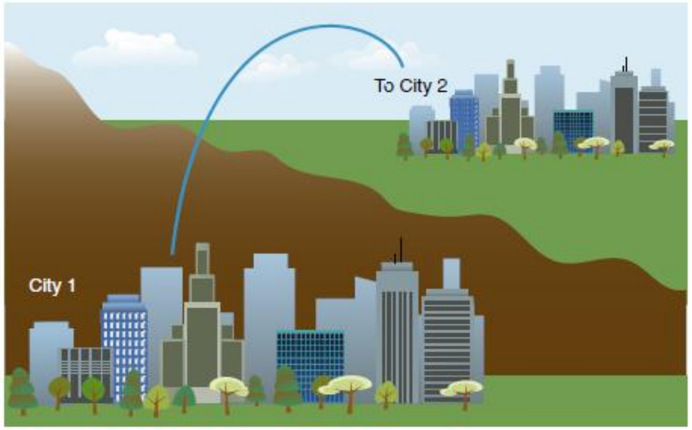
Alternatives

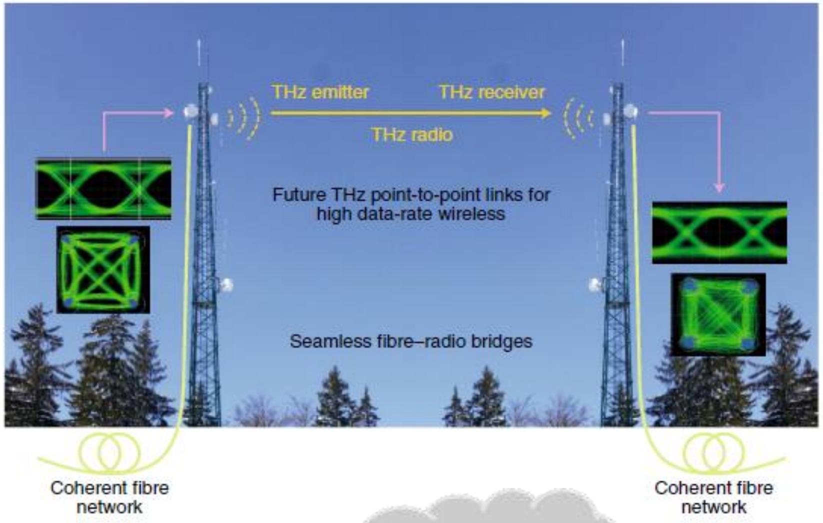
« FSO »
(Free Space optics,
0.4 / 0.78 µm)
(ex: Intellimax) ~ Gbit/s

Backhaul Q & E-band

ELVA: 10 Gbps /
10 km (clear sky)

Context → *P2P scenario examples*



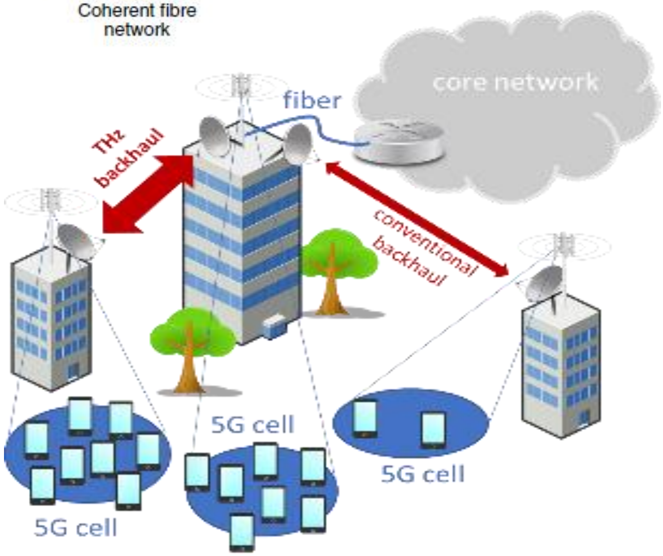


Inter-city

In the city [THOR Project, thorproject .eu]

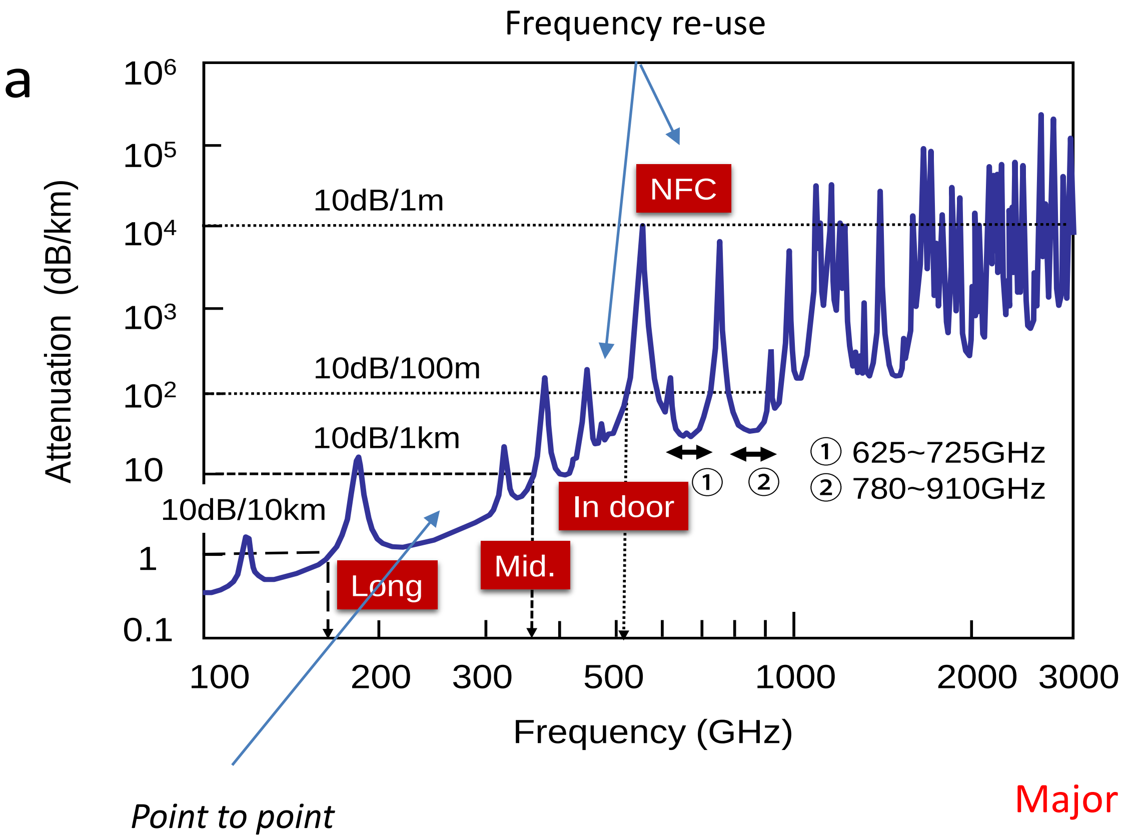
THOR

2018-2021



Outdoor demo of THz links combining photonic-based LO, Solid-state active devices + TWT @ 300 GHz

Which frequencies?



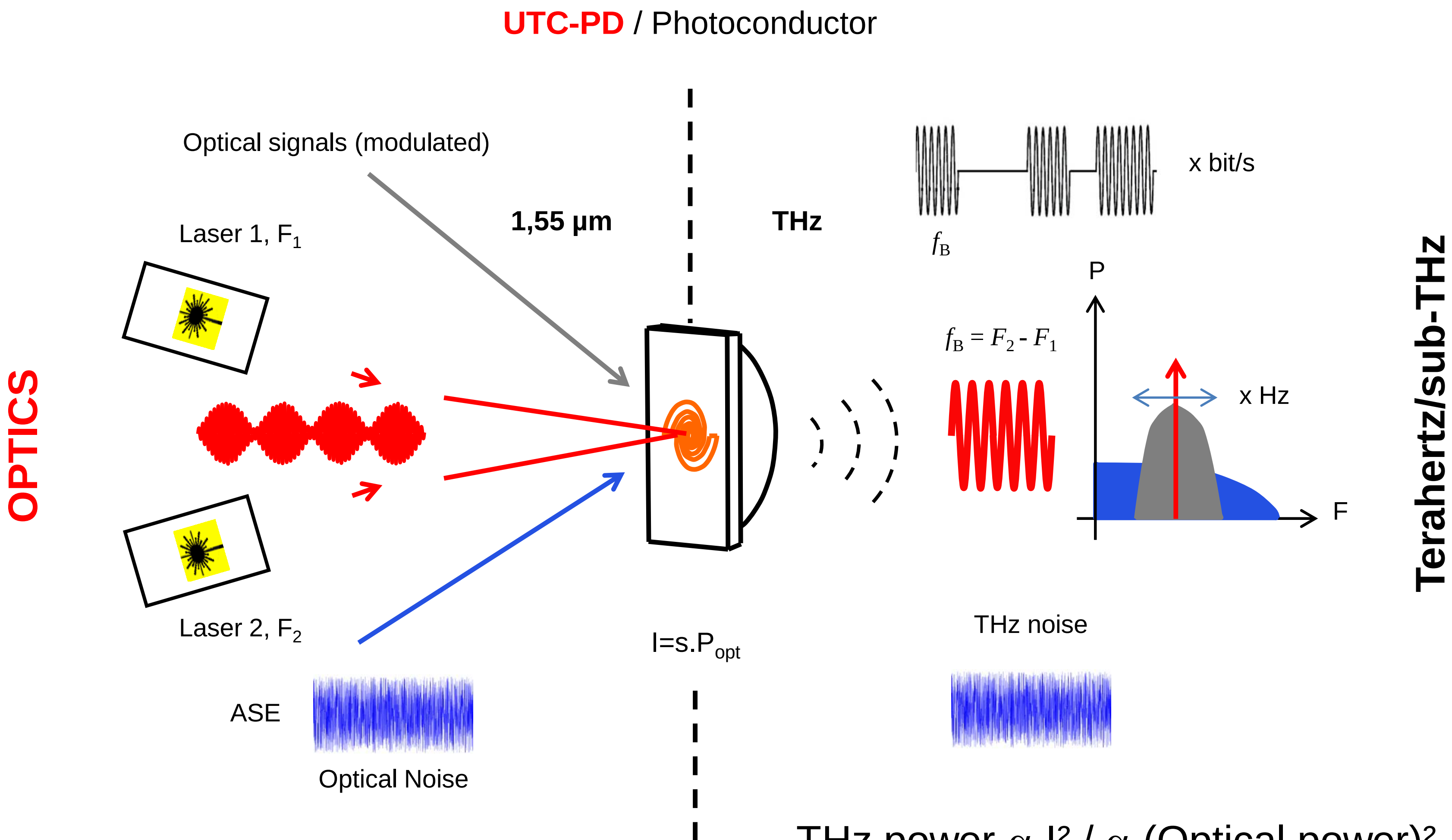
T. Nagatsuma, G. Ducournau, C.C. Renaud

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

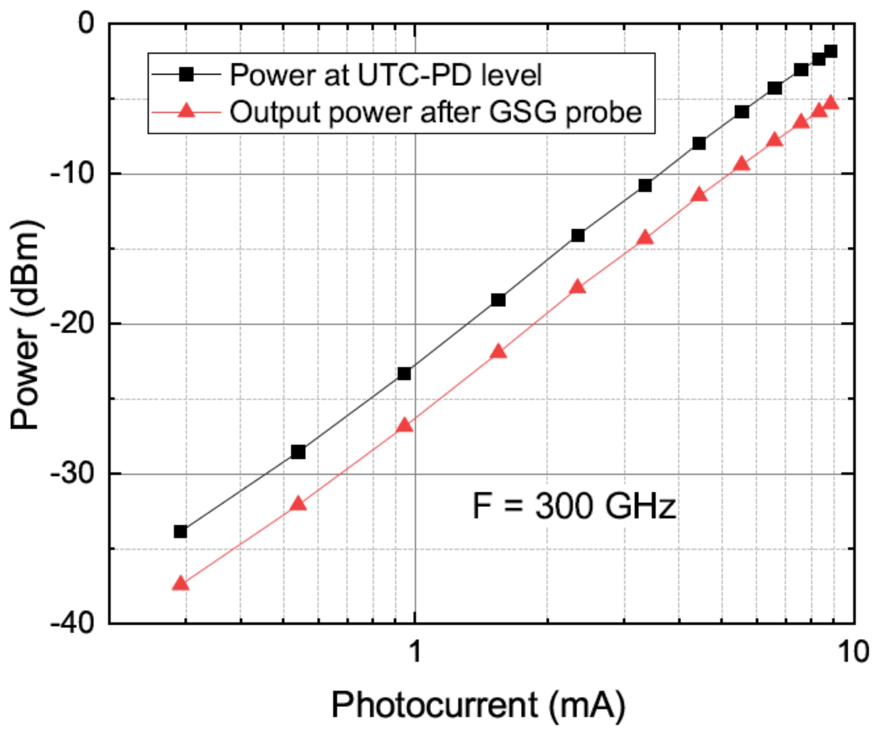
Photomixer: from optical to THz



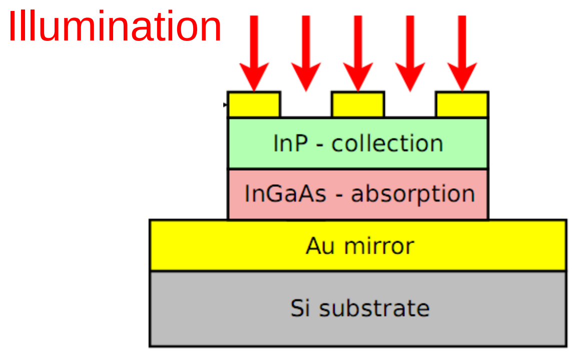
THz power α I² / α (Optical power)²

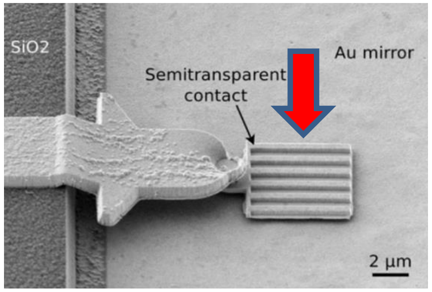
Photomixer: from optical to THz

UTC-PD : en cavité résonnante



RCE-UTC: resonant cavity enhanced UTC-PD

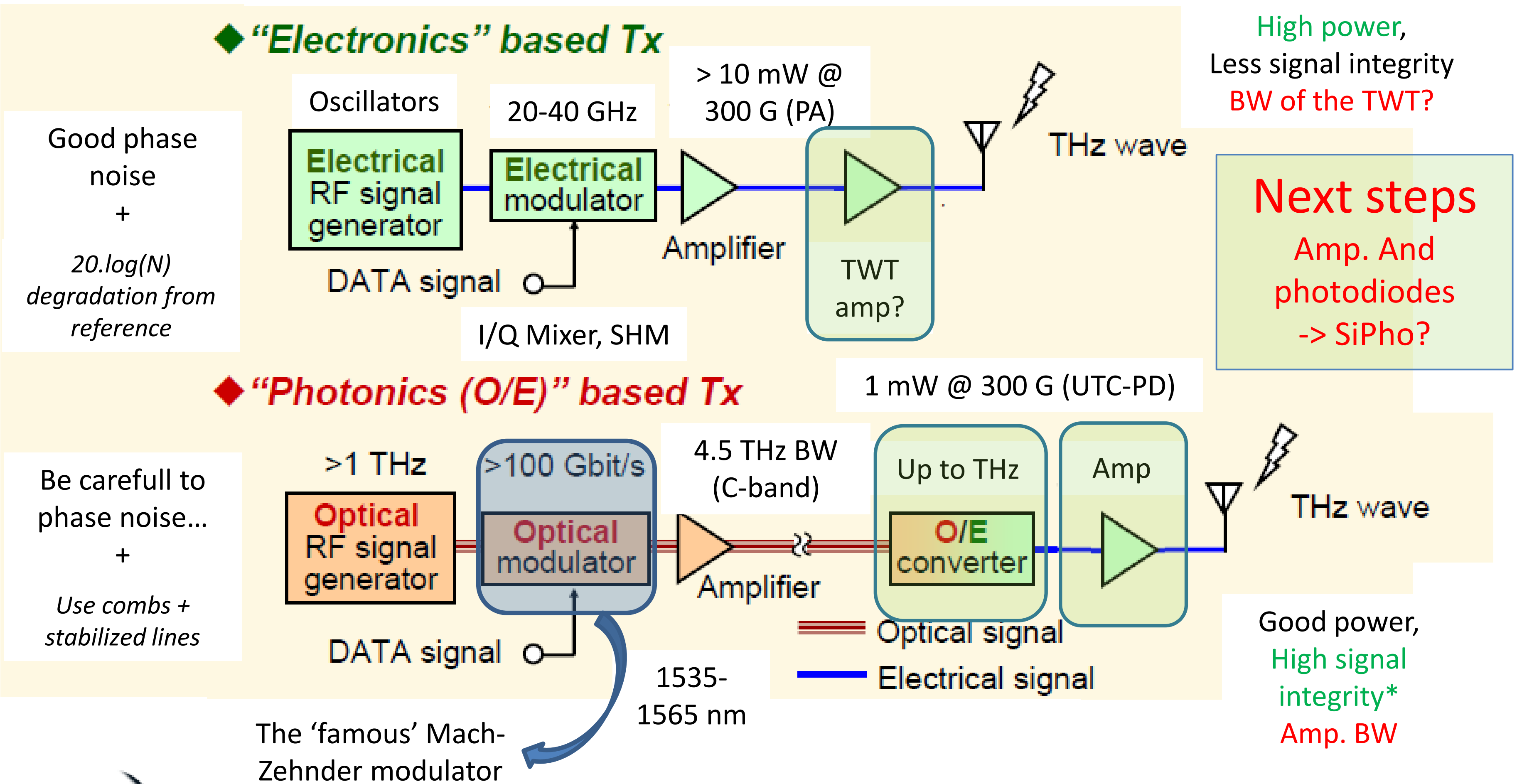




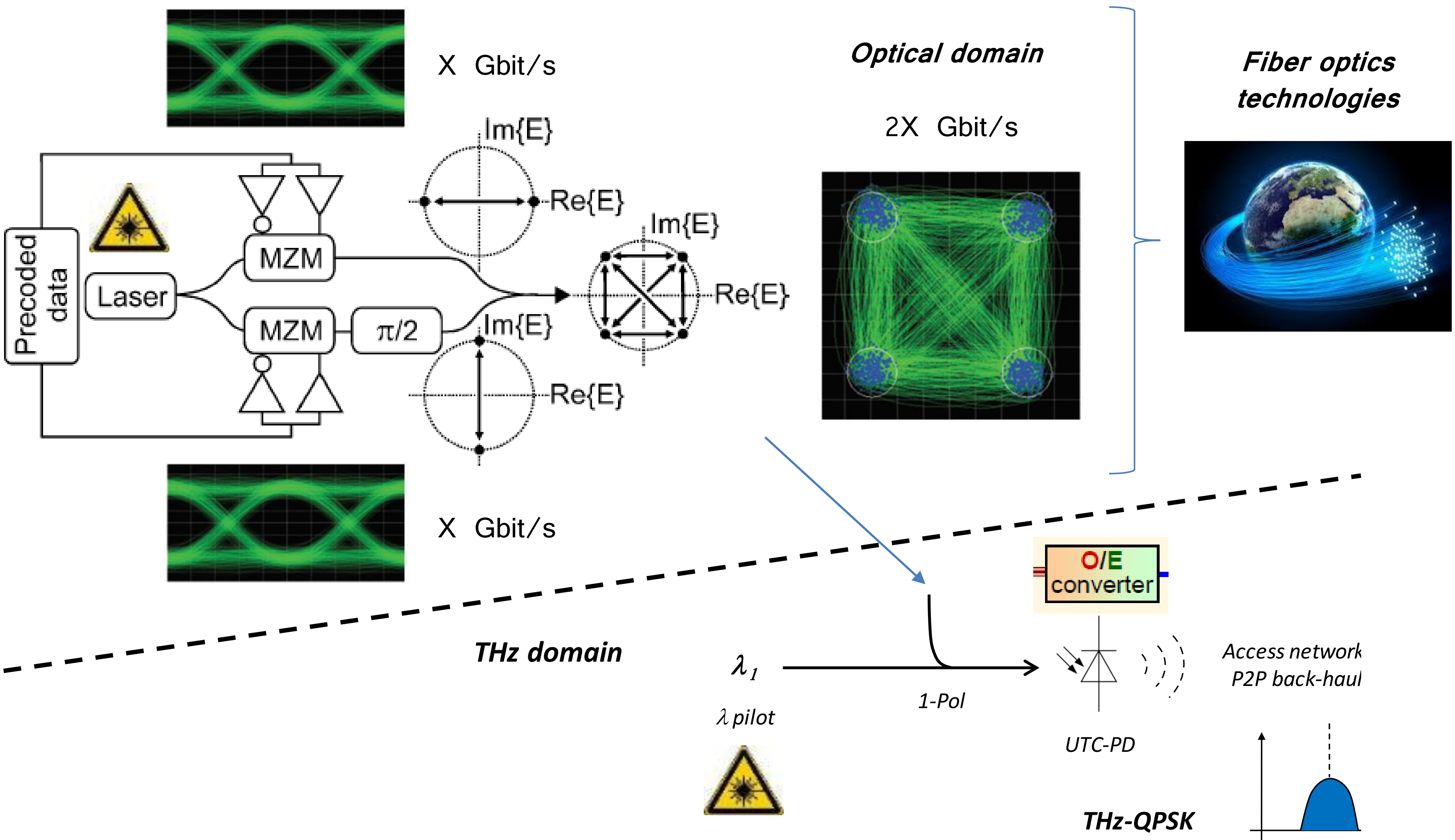
(c)

Tx architecture comparison (electronic/photonic)

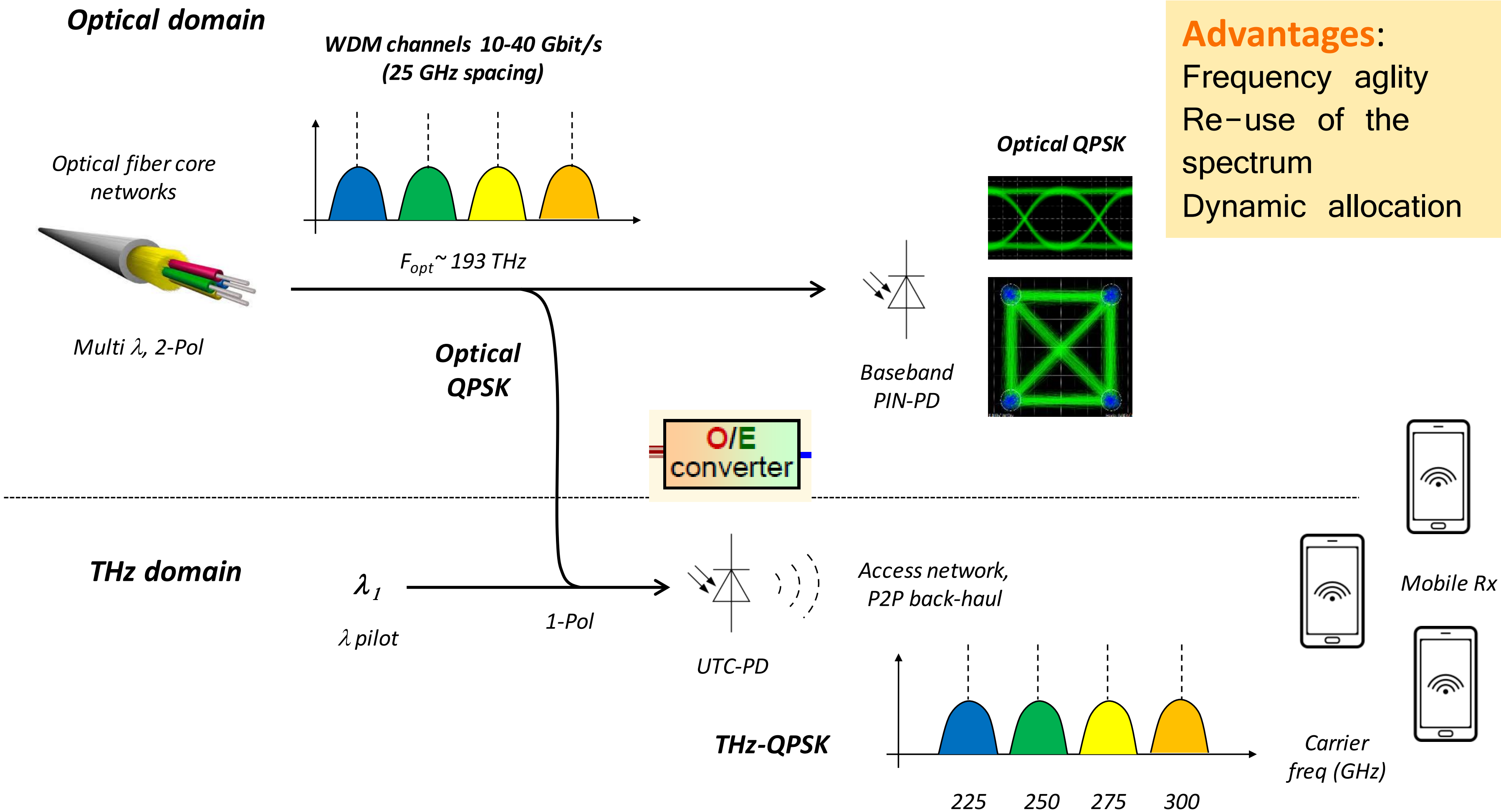
➢ Modified from IG THz study Group (15-10-0149-01)



Dual structure in I/Q at optical level enable QPSK



At the end… what optics can do for THz spectra…



Advantages:
Frequency aglity
Re-use of the spectrum
Dynamic allocation

Link to the new IEEE 802.15.3d

Need to find THz technologies compliant to the new std

We have to consider this towards future system developments

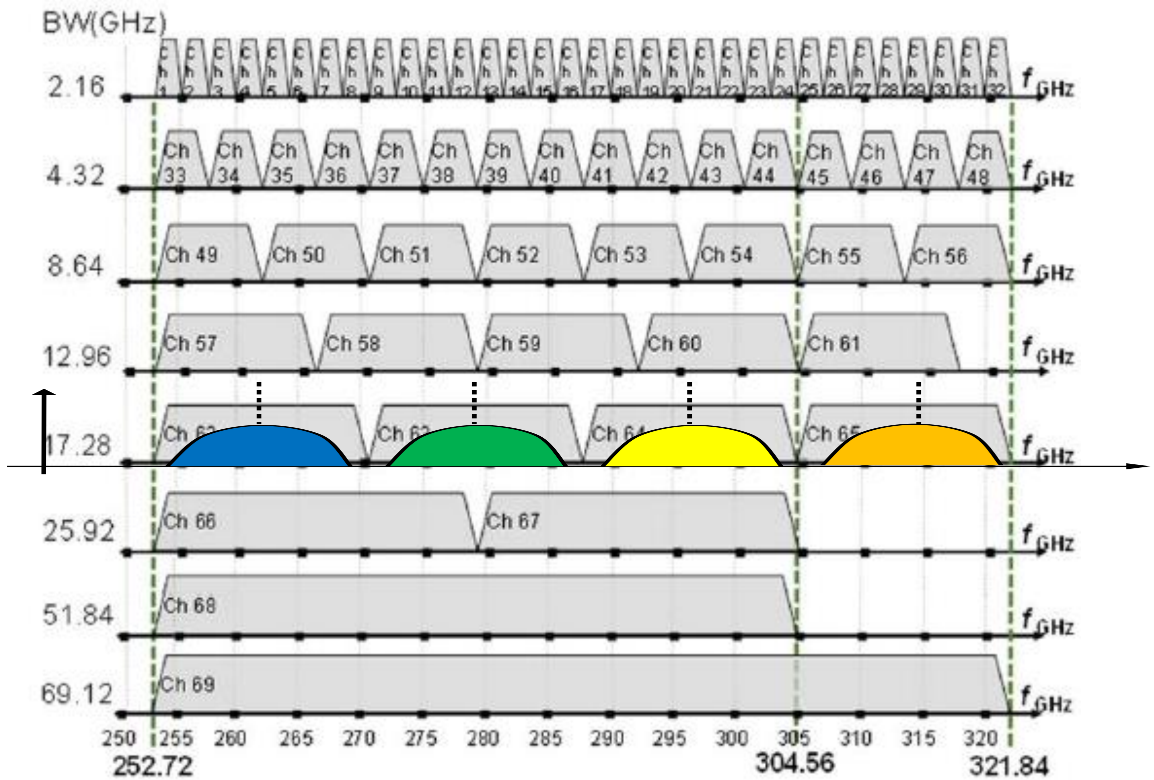
Carriers: from 252 to 321 GHz
BW: 2.16 GHz to 69.12 GHz
Formats: ASK, PSK… up to 64-QAM

Table 6-17i—OOK Supported FEC field format

Bit	Description
0	LDPC (1440,1344)
1	LDPC (1440,1056)

Table 6-17h—SC Supported Modulations field format

Bit	Description
0	π/2 8-PSK
1	π/2 8-APSK
2	16-QAM
3	64-QAM



Photonics is an enabler of multi-frequency THz com systems

Link examples using photonics Tx

Usually, initial THz links have been enabled by photonics-based transmitters, coupled to waveguide-based systems.

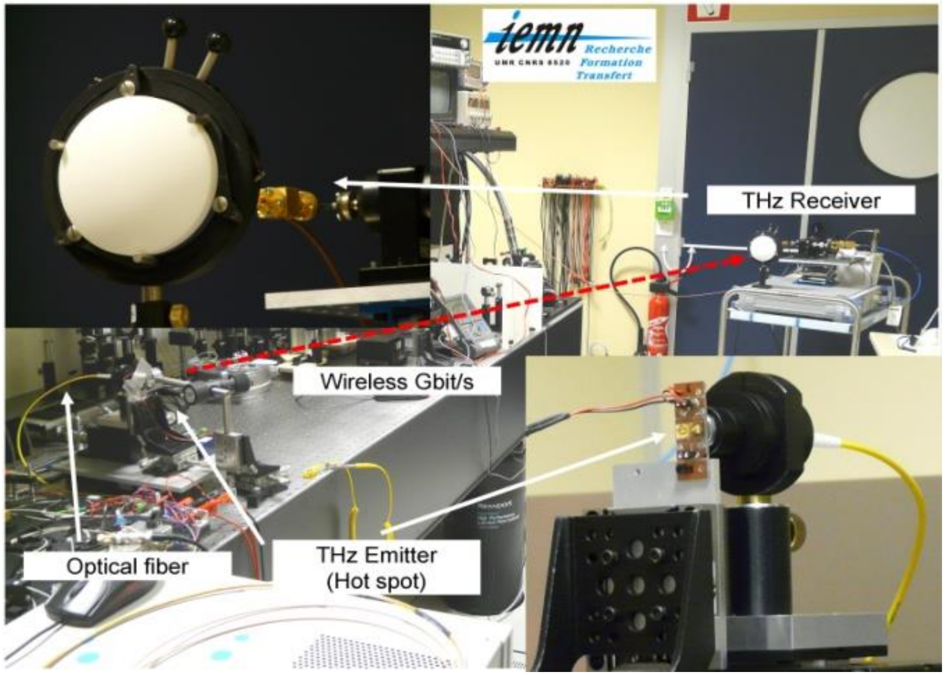
Now, integrated Rx are also used in combination to Photonic-Tx.

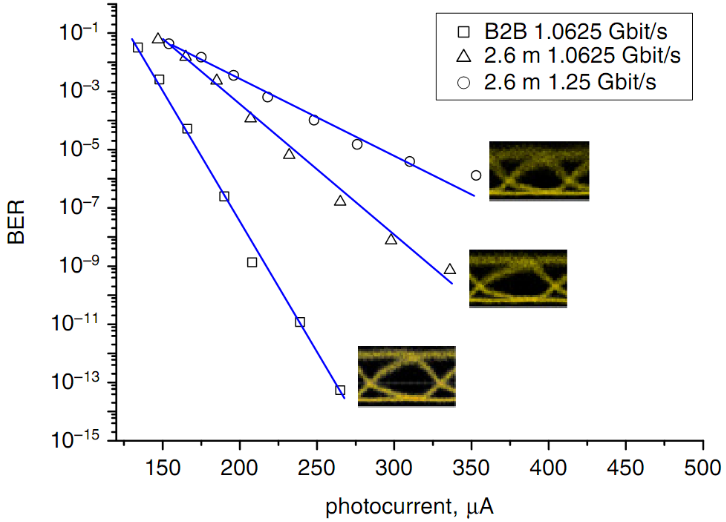
Tx-Rx fully based on photonics is generally a little bit more difficult due to conversion losses of optically-pumped mixers.

THz passive hot-spot: from fiber to radio THz: almost 10 years ago

- Simple ASK
- 200 G carrier / Passive hot-spot (just fed by a fiber, no bi `

G. Ducournau, et al. Electronics Letters, 46(19) :pp. 1349–1351, 2010.



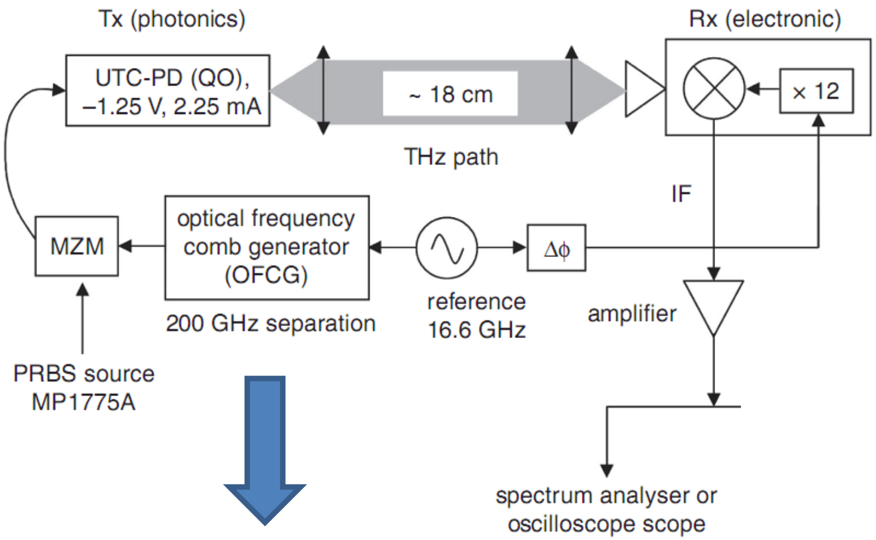


- BER « Error-free » 10^{-11}

IET Premium award 2011

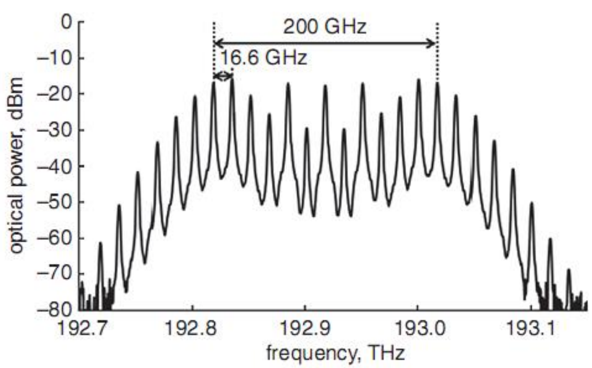
10 Gbit/s (Real-time) using UTC-PD (Tx) + Schottky mixer (Rx)

G. Ducournau / T. Nagatsuma, 2014



Use an optical comb, phase-locked on a micro-wave reference + electronic receiver =>

- Bandwidth: ✓
- Sensitivity: ✓



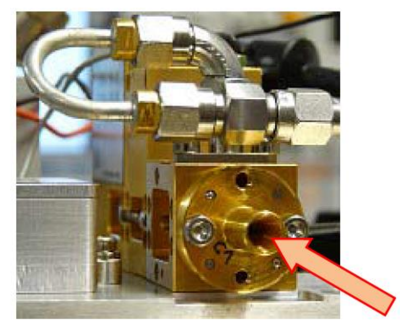
10 Gbps @
-28 dBm in Rx

UTC-PD

200 GHz emission

a

Schottky-based

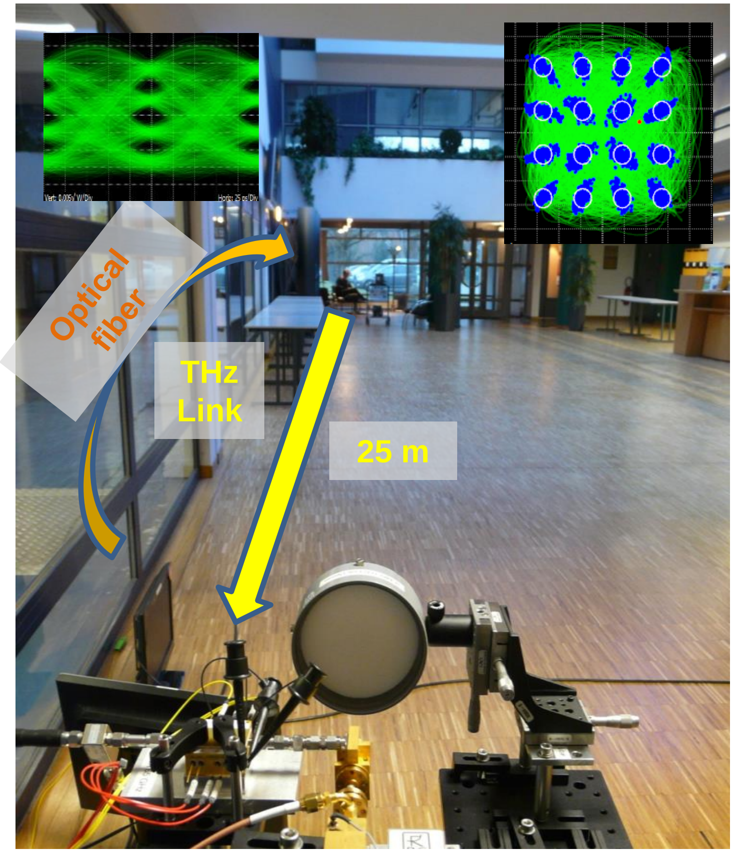


200 GHz reception

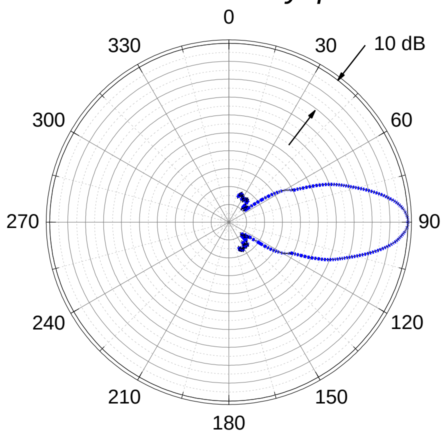
b

Link examples using photonics Tx – 25m 32 Gbit/s

[6] T. Nagatsuma, G. Ducournau, C.C. Renaud. *Advances in terahertz communications accelerated by photonics*. Nature Photonics, vol. 10, no 6, p. 371-379, 2016.



Antenna + lenses: 38 dBi



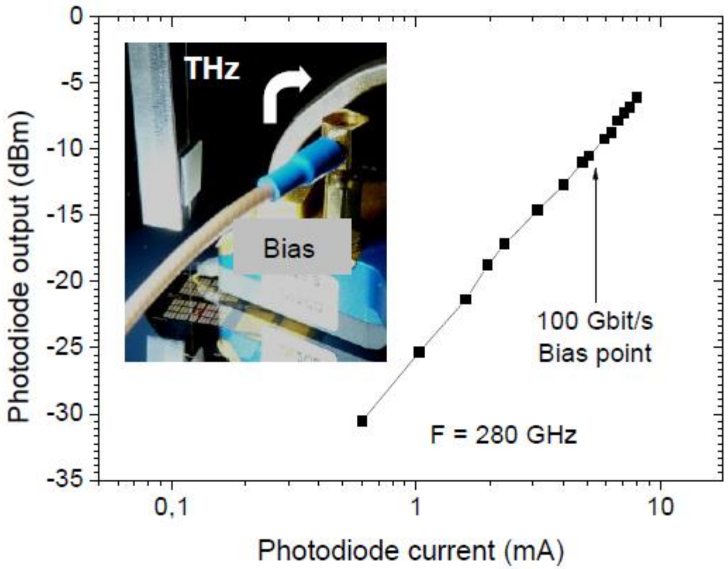
Parameter	Lab demo
Path loss	110 dB
Tx ant. Gain (dBi)	38
Rx ant. Gain (dBi)	38
Bandwidth (GHz)	10
Format	QAM-16
SNR, dB	20
NF receiver, dB	10
Margin, dB	-
Data rate (Gbit/s)	32

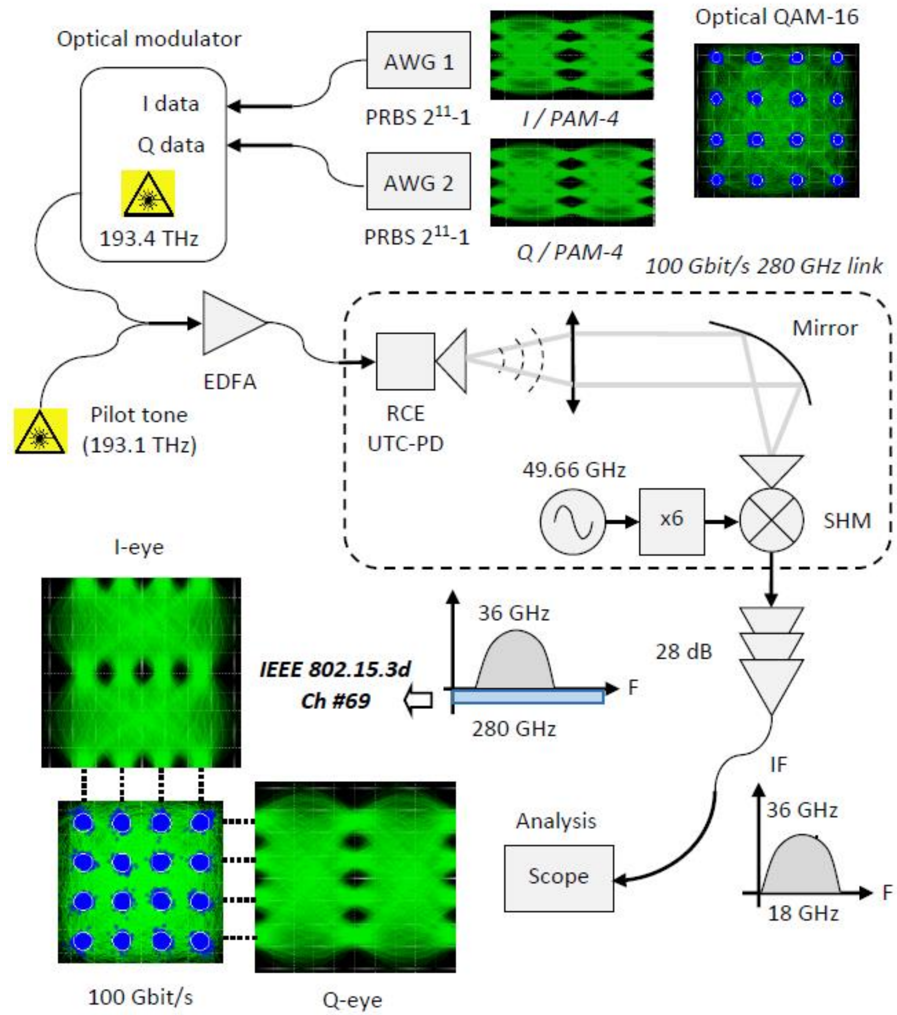
Tx output ~ 50-100 µW

100 Gbit/s single carrier and single Rx…

300 GHz band

Linear photomixer (UTC photodiode)





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

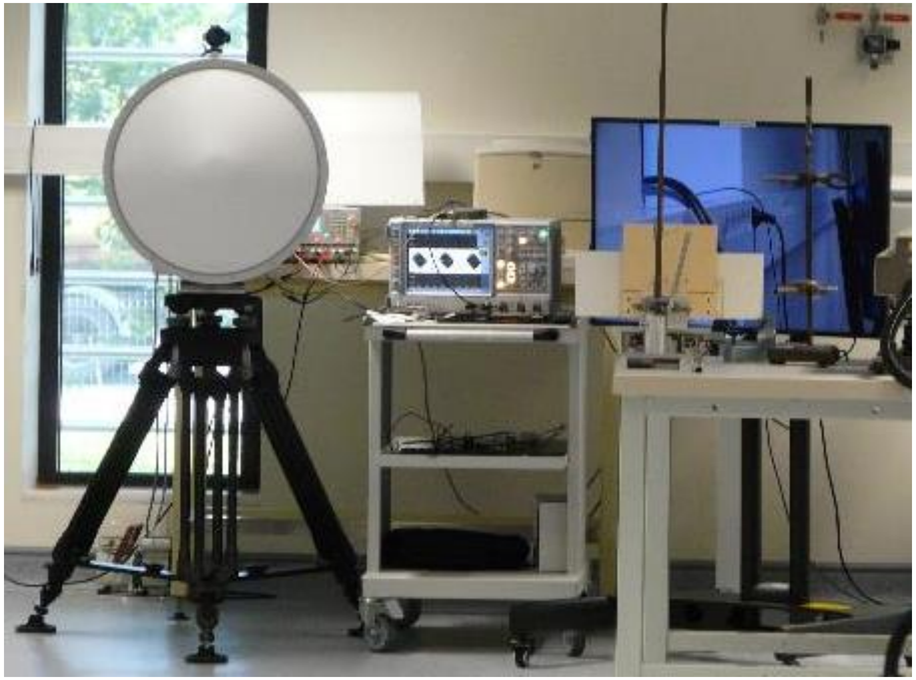
G. Ducournau 2018

Going out of the lab

Testing « real-life » scenario for THz transmissions…

In the-lab…

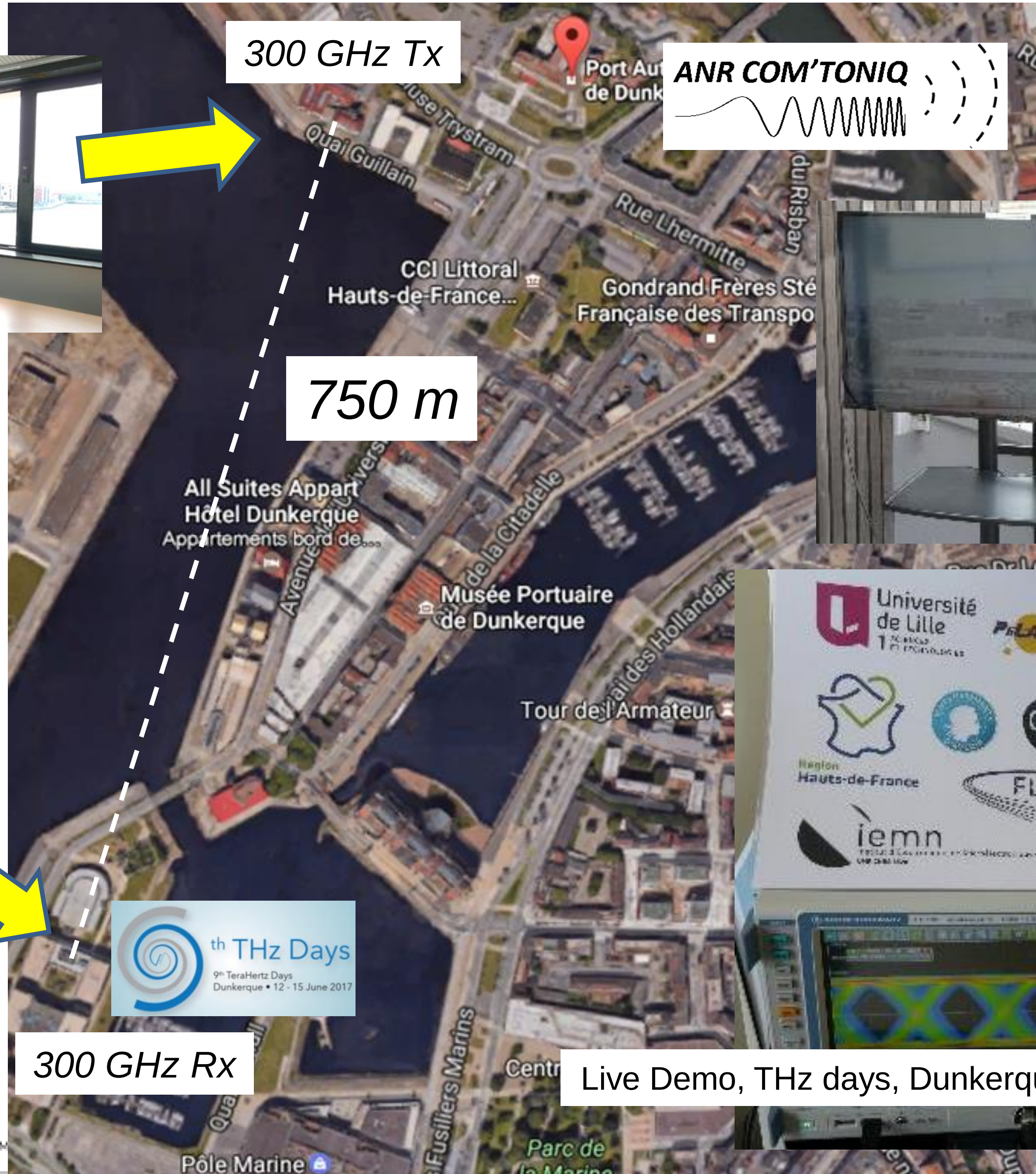
Exemple of HD-TV link



Going out-of-the-lab… link with 750 m

Real-time HD-TV

G. Ducournau
2017



300 GHz Tx

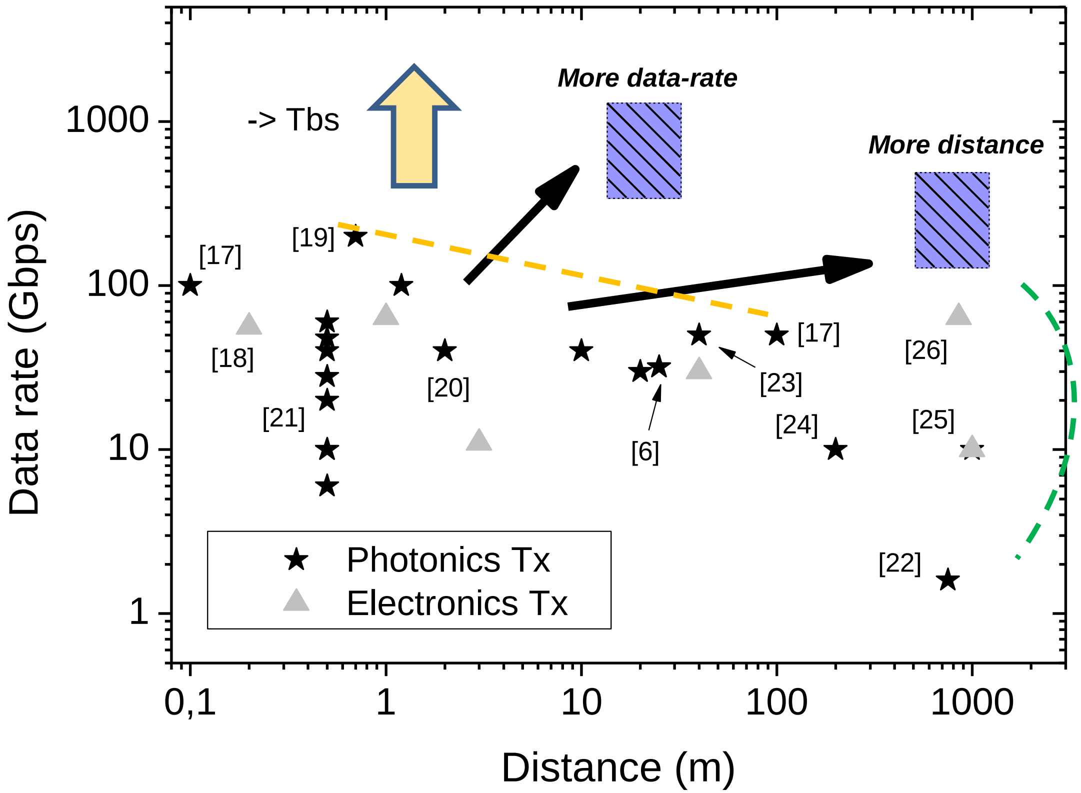
750 m

300 GHz Rx

Live Demo, THz days, Dunkerque, June 2017

In a nutshell

Photonics is pushing the data-rate



More compact systems for future…

So far, the compactness is not scaling for decrease of wavelenght…

Mastering simple schemes for Tx/Rx locking

Electronics is pulling the distance

With moderately-sized antennas (ie not > 50 dBi);

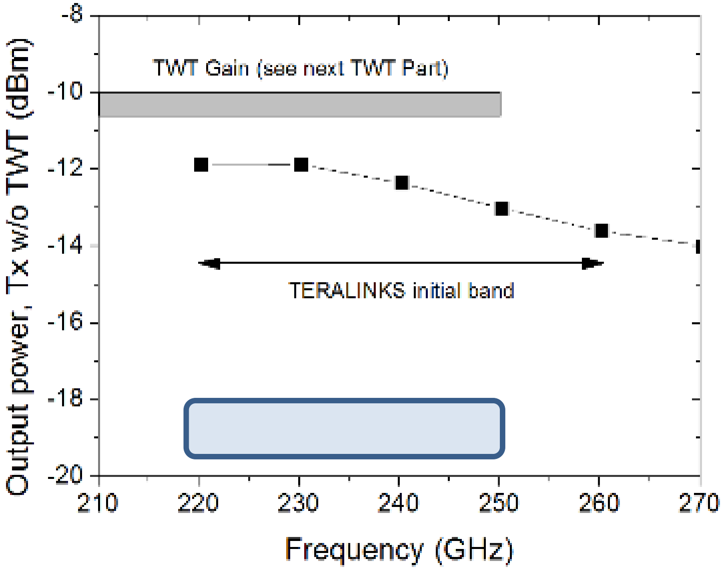
Highest schemes/complexity of mod. scheme: <u>photonic-based Tx usually</u>

TERALINKS

Increase the range of THz links: combination of photonic approaches and TWTA (Collab with Lancaster, Prof. Paoloni)

Frequency	*220-260 GHz*
THz source	*up to1 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



30 GHz of BW combining power and efficient modulation (thanks to optically driven sources)

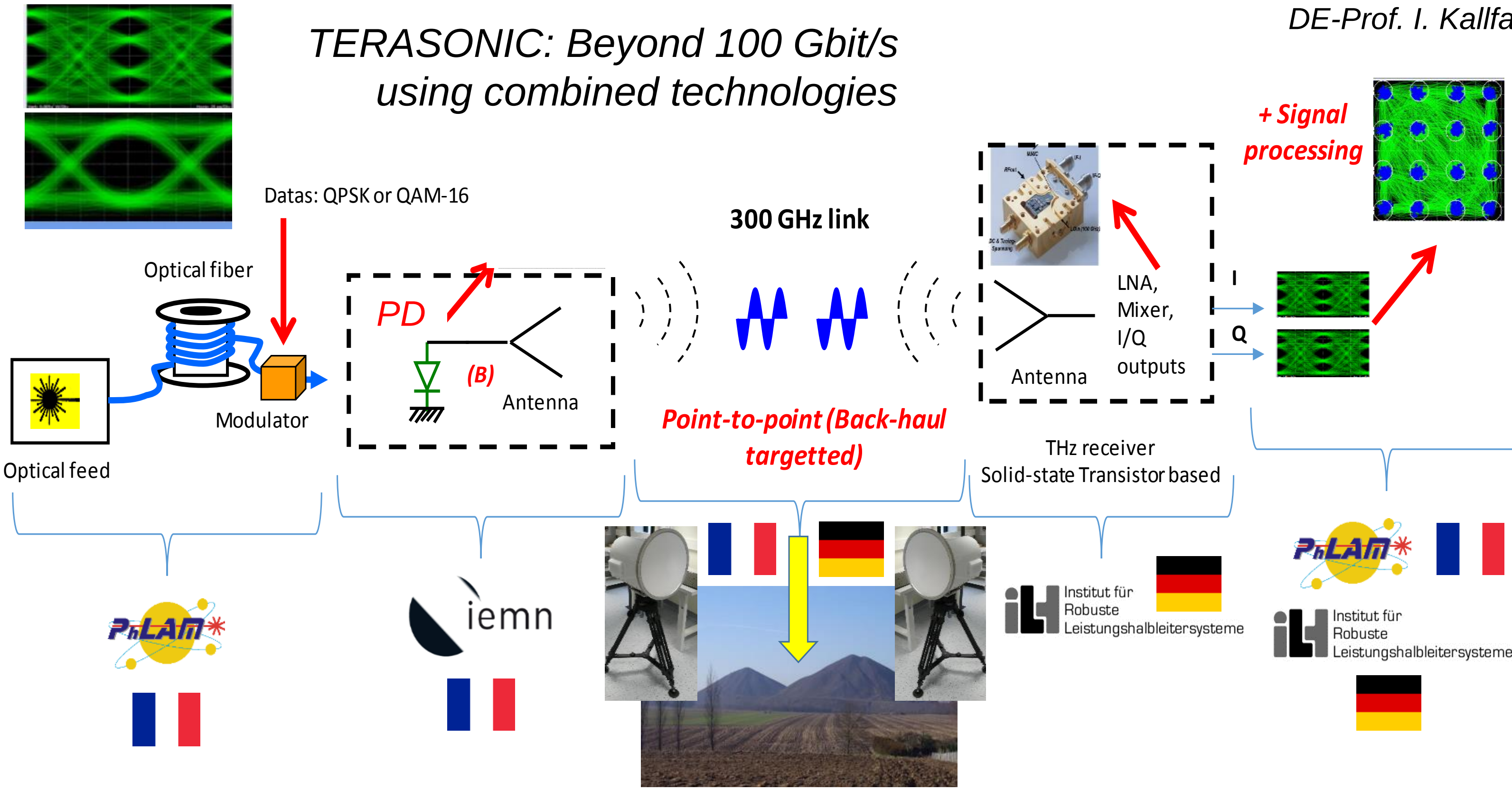
Running projects

TERASONIC ANR DFG *Project*

Increase the range of THz links: combination of photonic approaches and electronic based

FR-Prof. G. Ducournau
DE-Prof. I. Kallfass

TERASONIC: Beyond 100 Gbit/s using combined technologies



Couple of challenges

Advances in terahertz communications accelerated by photonics

Tadao Nagatsuma, Guillaume Ducournau & Cyril C. Renaud

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

Item	Target	Technology options
Data rate	100 Gbit/s ~ 1 Tbit/s	Multi-band (multi-carrier) system Ultra-wideband optical modulators
Link distance	1 km ~ 5 km	Integrated photodiode arrays Use of amplifiers and integration
Efficiency	-	Photonic integration (III-V photonics/Si photonics)
Key component	-	Low-loss waveguide/interconnect Wide-band antenna Wide-band passive devices (filter/coupler/diplexer) New materials & devices (metamaterial, graphene, plasma-wave, etc.)
Miscellaneous	-	Propagation model Standardization Spectrum regulation

'system-level'

Active devices

Circuits

Antennas

(fix or reconfigurable)

Radio channel

Robust system, in 'real-life' case, using III-V or Silicon photonic devices (for integration level)

Thus… a huge space for research and industrial opportunities

Use the photonics: bandwidth OK, BUT… need power… photonics to be combined with active devices.

If limited power/distance + compact/density required (kiosk, data-center) => simple links using SiPho is possible (decrease the cost + industrial foundries in Europe available!)

Arrays of Photonic devices has to be investigated: smart solution for beam-steering

Photonics = technological enabler (driver)=> has to be used where it is relevant:

- bandwidth and signal integrity, seamless connection with optical waves
- integrated with electronic devices (silicon for mass, III-V or TWT for dedicated scenarios?)
- frequency invariant photomixing process: high purity carriers to drive electronic-based systems

Every system also need integration! Need to think about THz generic interconnexions…

Thanks to…

- THz photonics group, IEMN: J.F. Lampin, E. Peytavit, M. Vanvolleghem, F. Pavanello, P. Latzel, S. Bretin, M. Billet, …
- IEMN MBE team and charac. Center S. Lépilliet, …
- Technology: M. Zaknoune
- T. Nagatsuma from OSAKA Univ (10 Gbit/s coherent link)
- Telecom platform: R. Kassi
- PhLAM laboratory P. Szriftgiser, M. Douay, …
- ST-IEMN common lab: D. Gloria, F. Gianesello, C. Luxey

CPER PHOTONICS FOR SOCIETY (2016-2020)

ANR COM'TONIQ

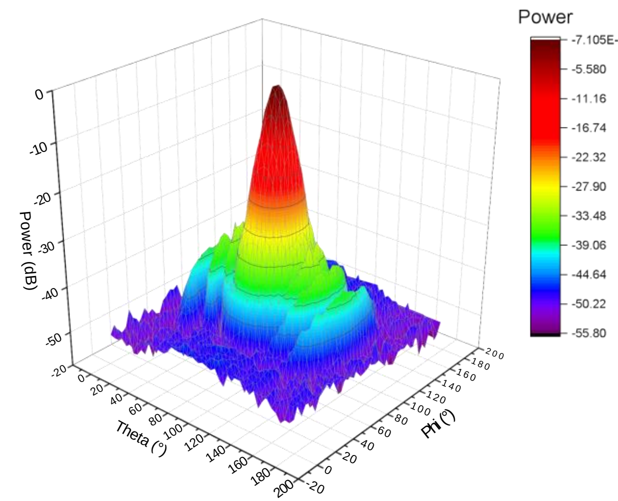
ITN MITEPHO

« WITH » project: CNRS and IMEP-LAHC RIKEN, Tohokhu Univ, OSAKA Univ
2010-2013
T. Nagatsuma & S. Histake, T. Otsuji
UM2, LAHC.

« WITH », « OSMOTUS », « COM'TONIQ »

TERALINKS project

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR



Thank you.