# Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

**Submission Title:** THz-band indoor network based on photonics technology

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**Re:** n/a

**Abstract:** This contribution describes a few demonstrations that configures terahertz-band (@300GHz) indoor network based on photonics technology reported by ETRI so far.

**Purpose:** Information of SC_THz

ETRI

# THz-band indoor network based on photonics technology

Seung-Hyun CHO, Sang-RoK MOON, Eon-Sang KIM, Wonkyoung LEE, Minkyu SUNG, Sooyeon KIM

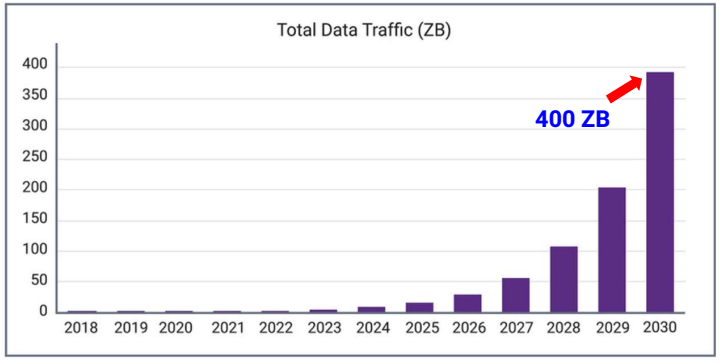

July, 2023

# Outlines

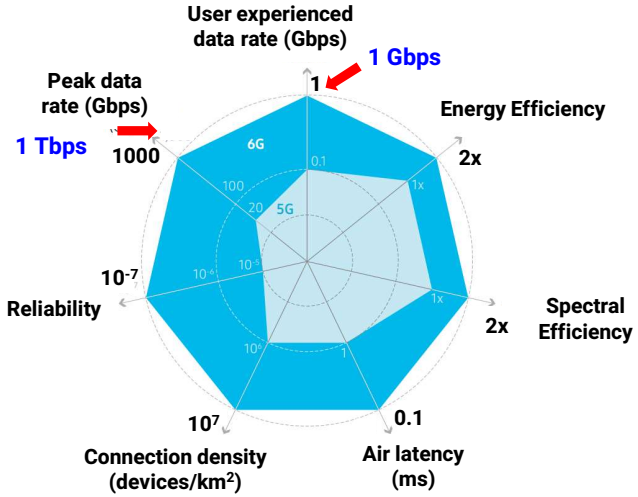
- Why do we need a THz-band Communications?
- Is it necessary to use photonics technology for THz transmission?
- How to realize THz transmission systems
- What will we prepare for THz-band indoor network?
- Summary

# Why do we need a THz-band communications?

## The advent of the 6G era



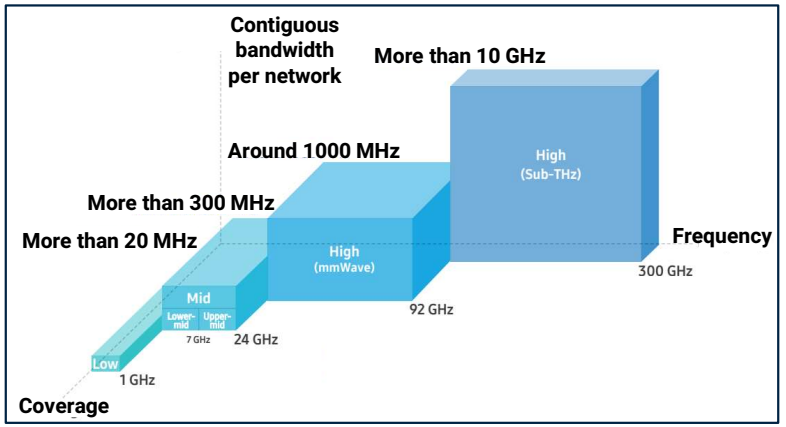

**Explosive growth in data traffic by 2030**



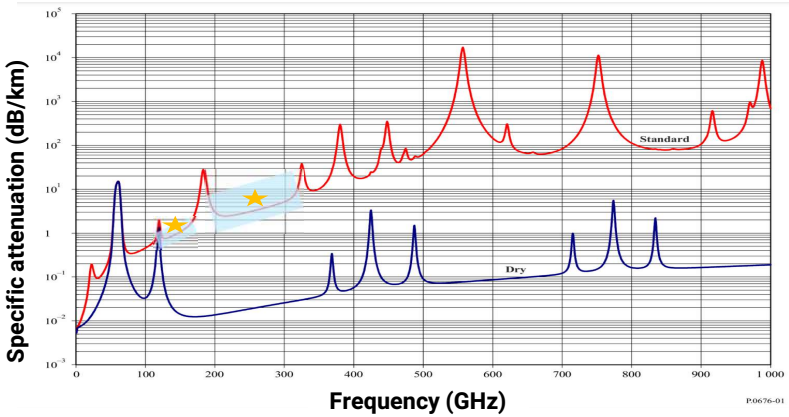

**Enhancement of key requirements form 5G to 6G**

Ref.: Total Data Traffic Forecast through 2030. Source: "Impact of AI on Electronics and Semiconductor Industries", IBS, April 2020. & White paper "6G the next hyper-connected experience for all, Samsung Research, 2020.

## Candidate band for 6G




**Dimension of 6G spectrum grouping**




**Specific attenuation due to atmospheric gases, calculated at 1 GHz intervals, including line centres**

Ref.: White paper "6G the next hyper-connected experience for all, Samsung Research, 2020. & ITU-R P.676-6: Attenuation by Atmospheric Gases (ITU, 2022)

# Why do we need a THz-band communications?

## Expected key 6G services (hyper-reality)


**Truly immersive XR**


**3D hologram display over mobile devices**

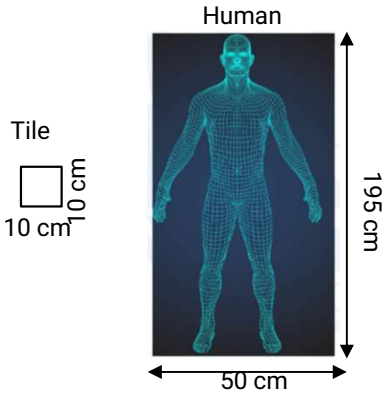

**Digital replica: bridge the real and virtual worlds**

Ref.: White paper "6G the next hyper-connected experience for all, Samsung Research, 2020.

## Required data throughput for 3D hologram

**Bandwidth requirement will grow up to Tbps for holographic telepresence applications**

| | Dimensions | Bandwidth |
|---|---|---|
| Tile | 10 x 10 cm | 30 Gb/s |
| Human | 195 x 50 cm | 4.62 Tb/s |




Source: 20th Century Fox

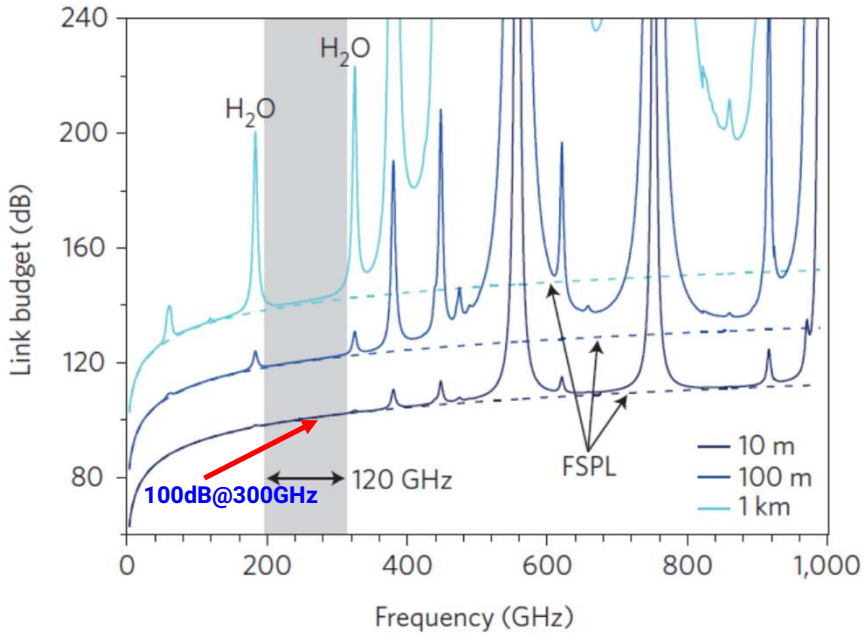
Ref. : R. Li et al., "Towards a new internet for the year 2030 and beyond," 3rd annual ITU-IMT 2020/5G Workshop on Demo Day, July, 2018.

# Why do we also need a THz-band indoor network?

## ~80% of mobile data occurs indoors


Ref.: A global leader in infrastructure solutions for communications networks, CommScope, 2020. & "Microsoft introduces the world to 'holoportation'" in Techradar 2016.

## THz transmission suitable for indoor application



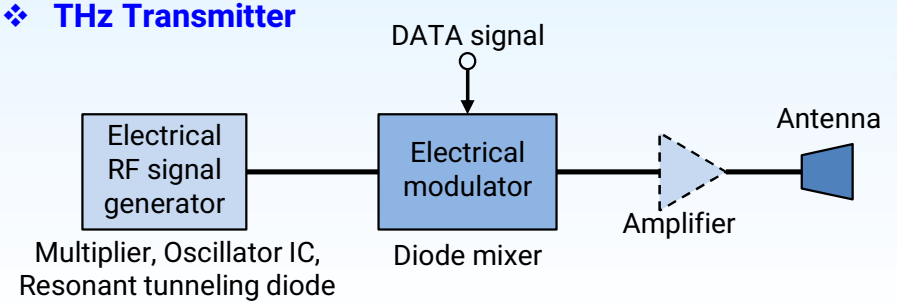

**Link budget at THz frequencies for the isotropic case at 23 °C and 2.59% water content in air composition (tropical climate)**

Ref : T. Nagatsuma et al., "Advances in terahertz communications accelerated by photonics," Nature Photonics 10, 371 (2016).

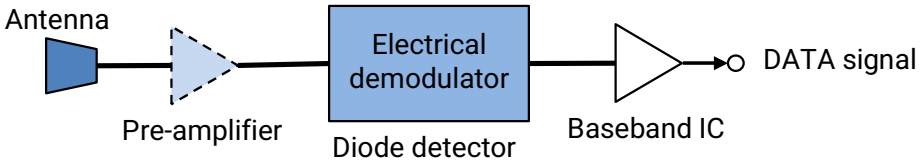
# Is it necessary to use photonics technology for THz transmission?

## THz transmission based on electronics

### ❖ THz Transmitter




### ❖ THz Receiver



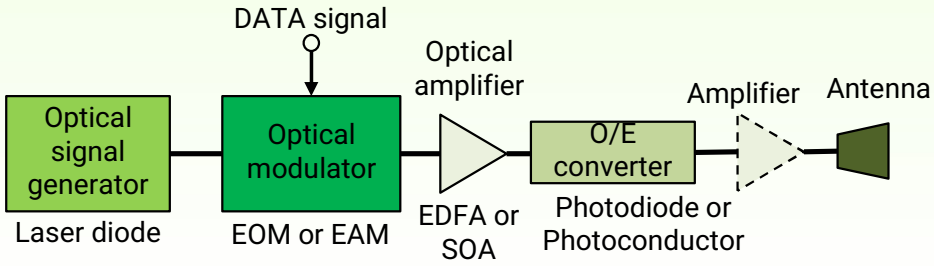

- **Available frequency: < 300GHz (III-V & Si)**
- **Max. data rate: 120Gb/s (III-V & Si)@300 GHz**
- **Max. transmission distance: 10m )@300 GHz (III-V, 50dBi antenna + THz amp)**

- **Easy to miniaturize, integrate, low-power consume**
- **Utilizing matured III-V semiconductor fab. process**
- **Need to overcome SNR degradations caused by frequency multiplier chain**

Ref.: Tadao Nagatsuma et al., "Recent progress and future prospect of photonics-enabled terahertz communications research," IEICE Trans. Electron. vol. E98-C, no.12, pp. 1060, 2015.

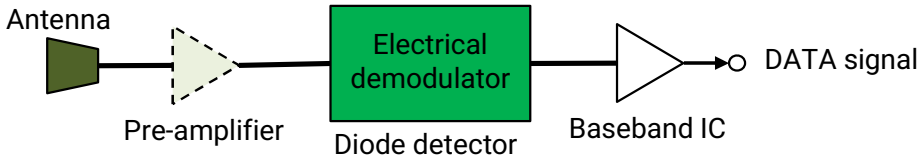
## THz transmission based on photonics

### ❖ THz Transmitter




* EOM: Electro-Optic Modulator, EAM: Electro-Absorption Modulator

### ❖ THz Receiver



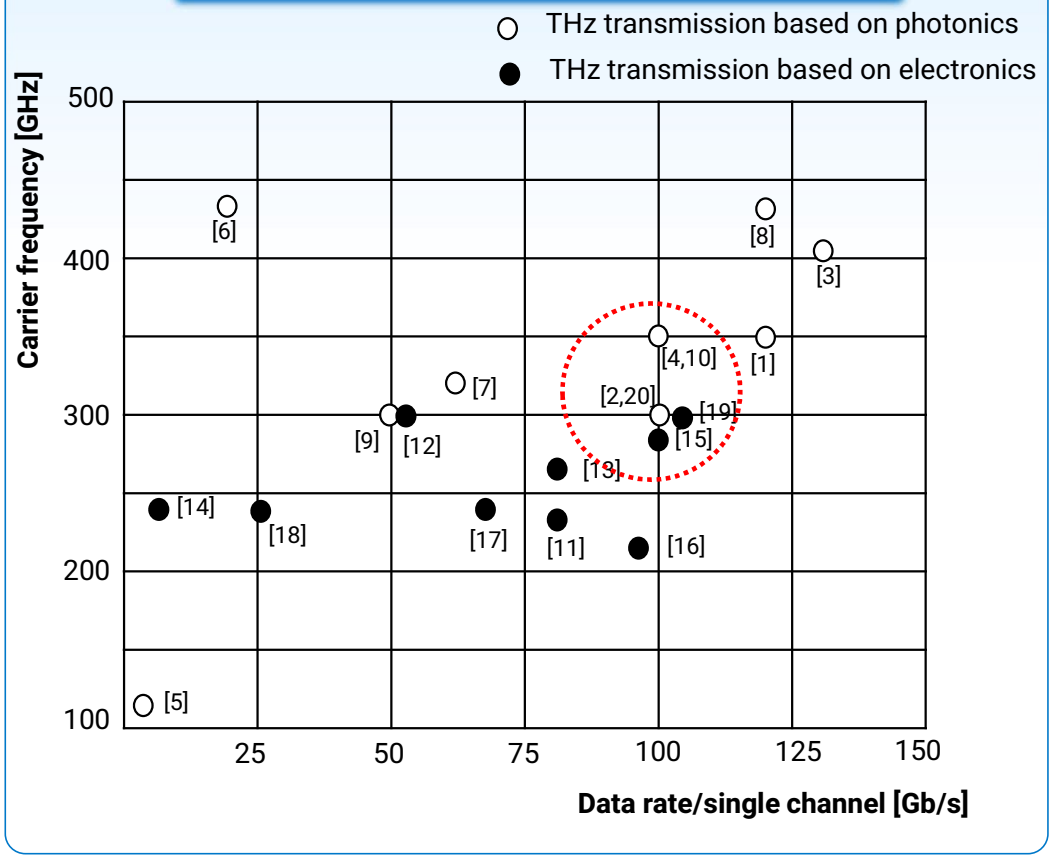

- **Available frequency: < 1THz**
- **Max. data rate: 110Gb/s (Single ch.), 600Gb/s (Multi-ch. PDM)@300 GHz**
- **Max. transmission distance: 110m@300 GHz (w THz amp)**

- **Utilizing matured optical communication technology with ultra-wideband and low-loss characteristics**
- **Easy to get relatively high SNR and extend coverage**
- **Need a effort to miniaturize, integrate, low-power consume by using a PIC technology**

Ref.: Tadao Nagatsuma et al., "Advances in terahertz communications accelerated by photonics," Nature Photonics, vol. 10, pp. 371, 2016.

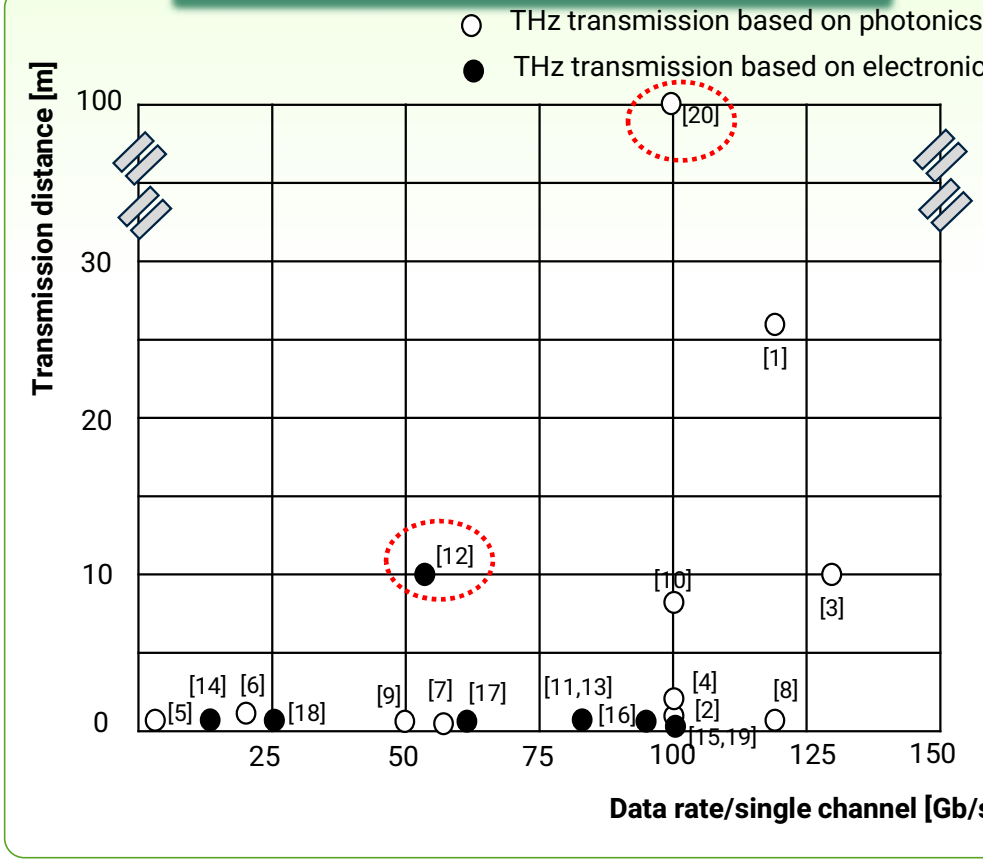
# Is it necessary to use photonics technology for THz transmission?

## Data rate vs. carrier frequency




- Many reports of 100Gb/s near 300 GHz.
- Still photonics technology better than electronics technology.
- Careful consideration should be needed for various applications.

## Data rate vs. transmission distance




- Transmission distance of less than 1m at various data rate.
- The best result was 110Gb/s-110m.
- Still need to extend transmission distance (coverage).

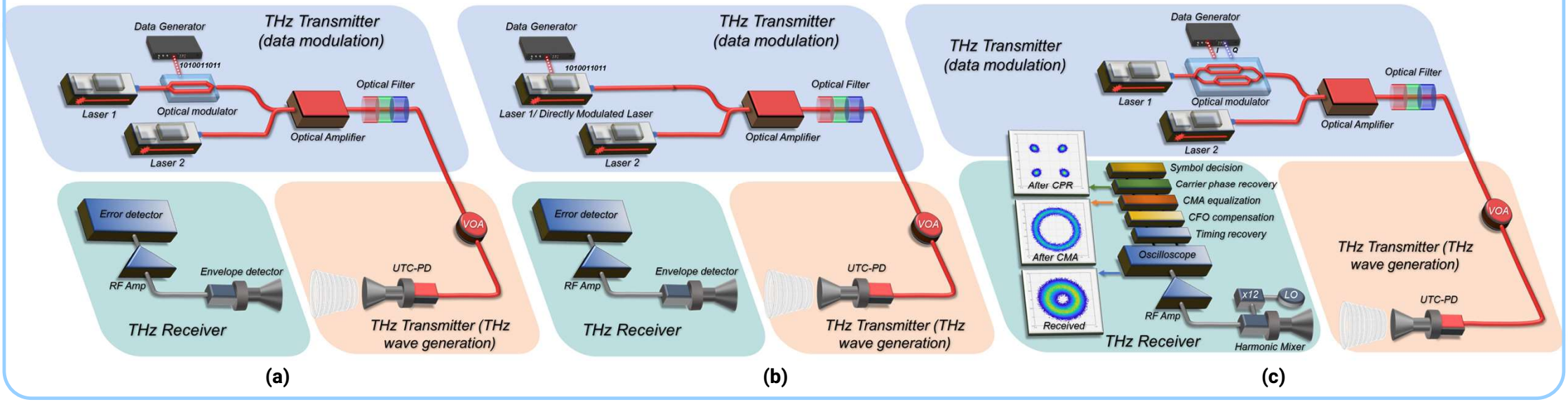
Ref.: Please see the summarized table in the next slide

# References for previous slide

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| [1] | Probabilistic shaping for better spectral efficiency | 350 GHz | 120 Gb/s | PS-16QAM-OFDM | 26.8 m | 2020 | Zhejiang Univ. |
| [2] | Real-time digital coherent optical modem | 300GHz | 100 Gb/s | PDM-QPSK | 0.5m | 2020 | HHI |
| [3] | Integrated Dual-λ DFB LDs & Probabilistic shaping | 408 GHz | 131 Gb/s | 16QAM-OFDM | 10.7 m | 2019 | DTU |
| [4] | Enhanced UTC-PD | 350 GHz | 100 Gb/s | 16QAM | 2 m | 2018 | Zhejiang Univ. |
| [5] | DFB-LD based commercial optical transceiver | 138 GHz | 5.5 Gb/s | NRZ-OOK | 1.5m | 2018 | Polytechnique Montréal |
| [6] | Six-channel WDM/PDM-QPSK | 437.5 GHz | 120 Gb/s (6×20 Gb/s) | QPSK | 10-km SMF 142 cm wireless | 2018 | DTU |
| [7] | Coherent THz-over-Fiber architecture | 325 GHz | 59 Gb/s | 64QAM-OFDM | 2 km SMF 5 cm wireless | 2017 | Univ. of Dusburg |
| [8] | Coherent transmission using optical frequency comb | 425 GHz | 120 Gb/s (net: 106 Gb/s) | 16QAM | 50 cm wireless | 2017 | Zhejiang Univ. |
| [9] | Si Photonics | 300 GHz | 50 Gb/s | NRZ | 2 m | 2022 | ETRI |
| [10] | THz repeater | 300 GHz | 100 Gb/s | 16-QAM | 8 m | 2022 | ETRI |
| [11] | 0.13 um SiGe HBT | 220~260 GHz | 81 Gb/s | 64-QAM | 1 m | 2019 | IHCT, Univ.of Wuppertal |
| [12] | 35 nm InGaAs mHEMT | 285-315 GHz | 56 Gb/s | 16-QAM | 10 m | 2019 | Univ. of Stuttgart |
| [13] | 40 nm CMOS | 265.68 GHz | 80 Gb/s | 16-QAM | 0.03 m | 2019 | Hiroshima Univ. |
| [14] | 130 nm SiGe BiCMOS | 240 GHz | 15.6 Gb/s | 16-QAM | 0.15 m | 2019 | IHP |
| [15] | 80-nm InP HEMT | 272-302 GHz | 100 Gb/s | 16-QAM | 2.22 m | 2018 | NTT |
| [16] | 0.13 um SiGe HBT | 230 GHz | 90 Gb/s | 16-QAM | 1 m | 2018 | IHCT, Univ. of Wuppertal |
| [17] | 0.13 um SiGe HBT | 225-255 GHz | 65 Gb/s | 4-QAM | 1 m | 2018 | IHCT, Univ. of Wuppertal |
| [18] | 130 nm SiGe BiCMOS | 240 GHz | 25 Gb/s | BPSK | 0.15 m | 2018 | IHP |
| [19] | 40 nm CMOS | 300 GHz | 105 Gb/s | 32-QAM | No air transmission | 2017 | Hiroshima Univ. |
| [20] | KK SBD Rx, THz amplifiers | 300 GHz | 100 Gb/s | QPSK | 110 m | 2018 | KIT |

# How to realize THz transmission systems

## Architectures of THz transmission technology based on photonics




(a) (b) (c)

**(a) External modulation/incoherent detection**

- **Conventional approach using external optical intensity modulator and laser diodes.**
- **Up to 40Gb/s data rate.**
- **Cost-effective SBD-based receiver was employed for envelope detection.**

**(b) Direct modulation/incoherent detection**

- **Cost-effective solution using directly modulated laser diode as a data modulator.**
- **Up to 25Gb/s data rate.**
- **To extend the transmission distance and data rate, adiabatic chirp management skill was utilized.**

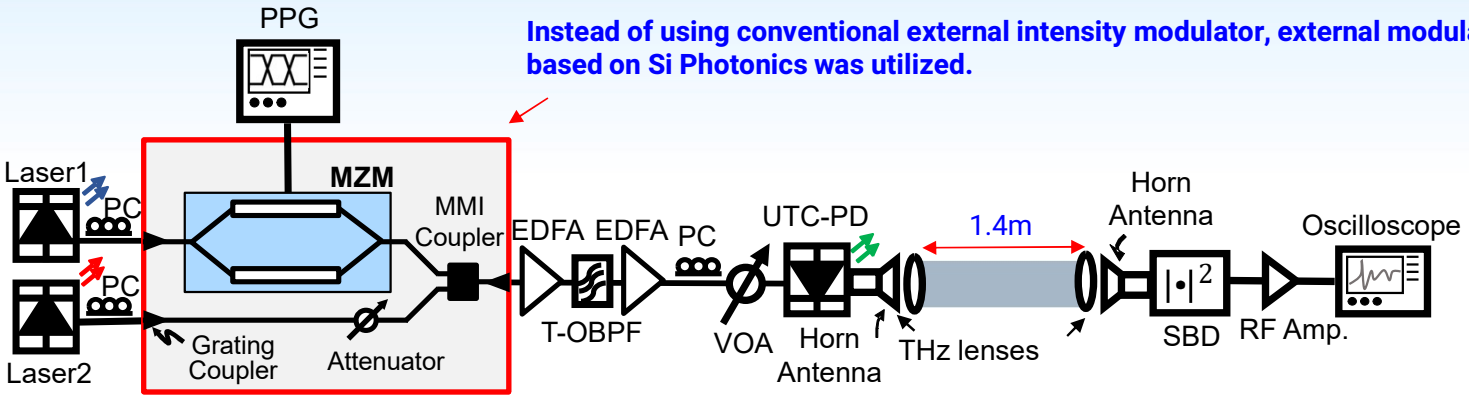
**(c) Optical IQ modulation/coherent detection**

- **Filed modulation using optical IQ modulator and coherent detection using THz mixer based receiver.**
- **Up to 120Gb/s data rate.**
- **Easy to increase data rate & transmission distance.**
- **Relatively expensive implementation.**

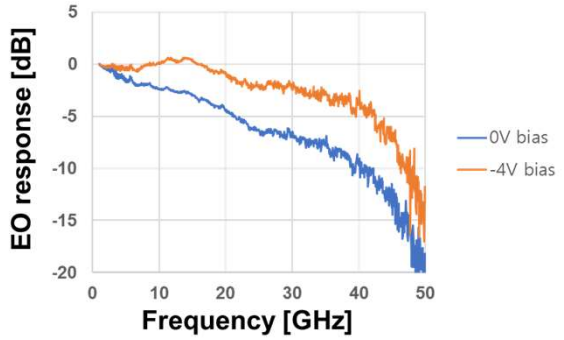
Ref.:Minkyu Sung et al., "Design Considerations of Photonic THz Communications for 6G Networks," IEEE Comm. Mag. 28(5), pp.185, 2021.

# How to realize THz transmission systems

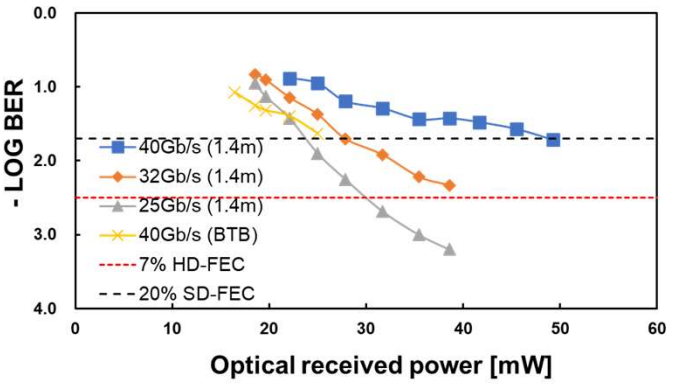
## External modulation/incoherent detection scheme



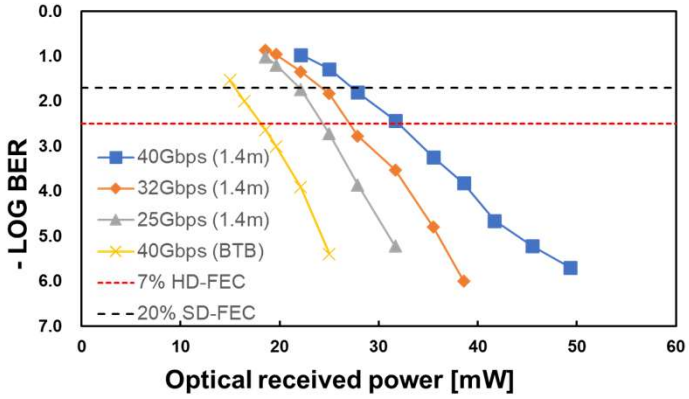

[Experimental setup]




[Measured EO response of MZM based on SiP]




[Measured BER by varying data rate w/o DFE]

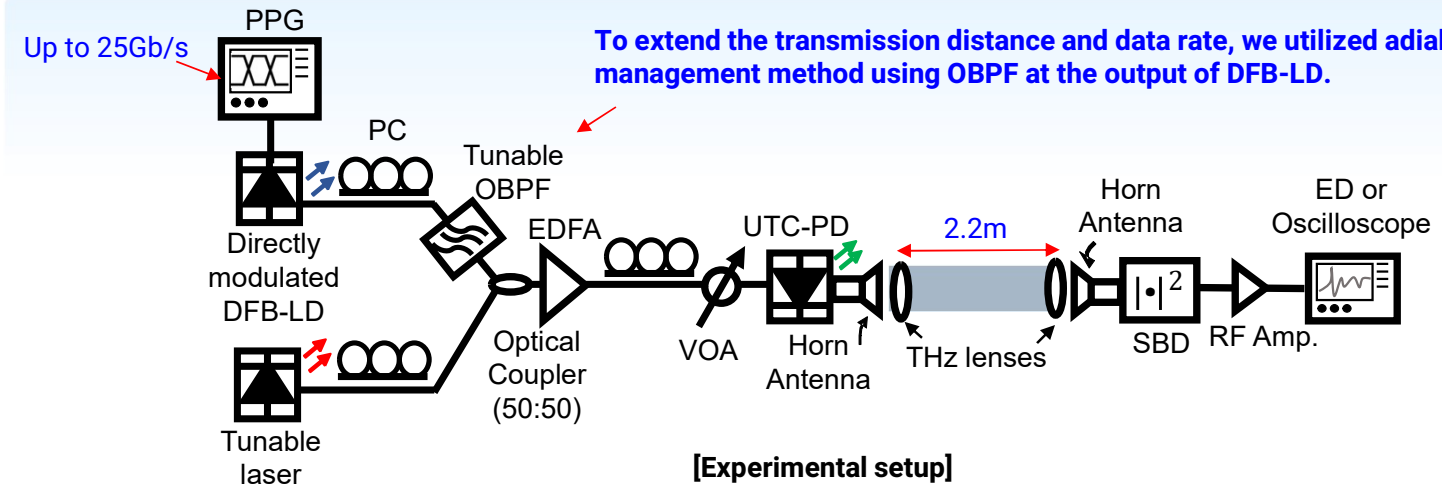



[Measured BER by varying data rate w/ DFE]

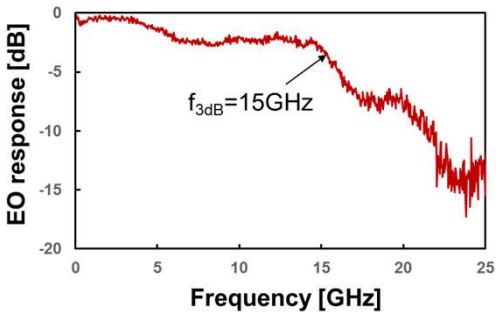
Ref: Sang-Rok Moon et al., "Demonstration of photonics-aided terahertz wireless transmission system with using silicon photonics circuit," Opt. Express 28, pp. 24918 (2020).

# How to realize THz transmission systems

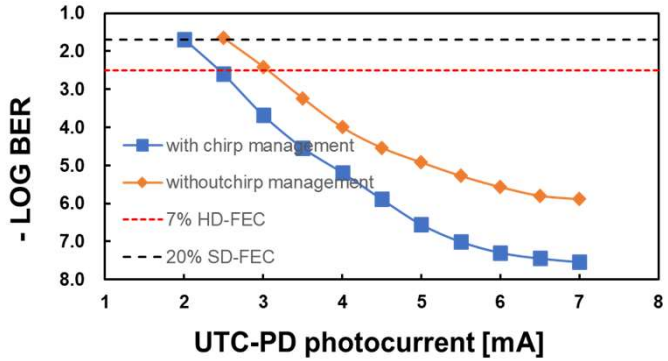
## Direct modulation/incoherent detection scheme



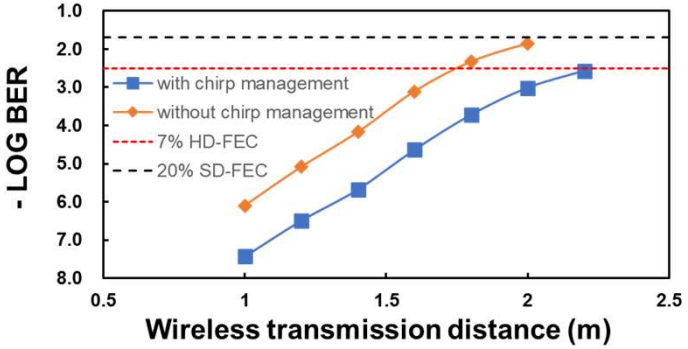

[Experimental setup]




[Measured EO response of DFB-LD]




[Measured BER with and without chirp management]

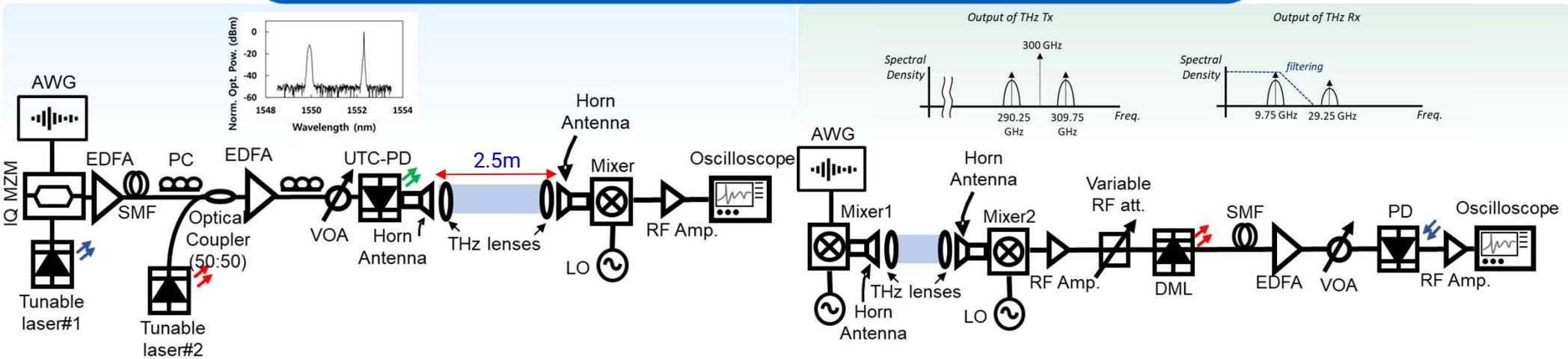



[Measured BER by varying transmission distance]

Ref: Eon-Sang Kim et al., "Cost-effective photonics-based THz wireless delivery system using a directly modulated DFB-LD," Optics. Comm. vol.492, pp.126969, 2021.

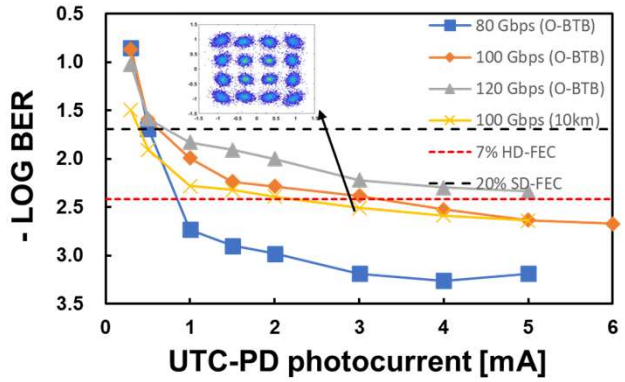
# How to realize THz-band indoor network

## Optical IQ modulation/coherent detection scheme

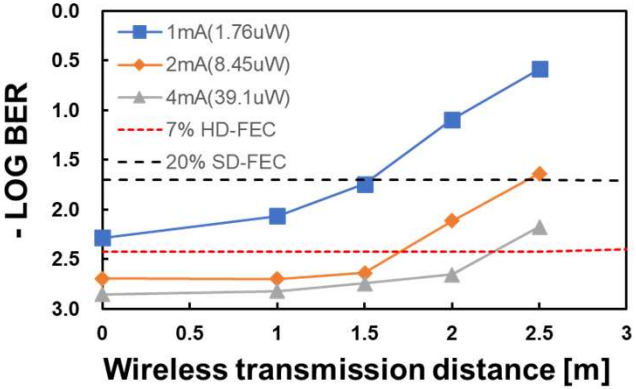



[Experimental setup for downlink]

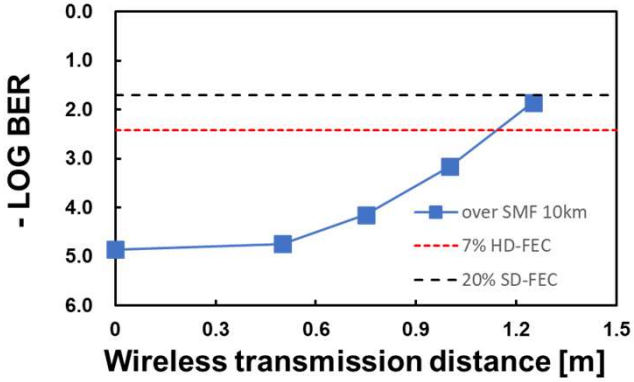
[Experimental setup for uplink]




[Measured BER by varying data rate for downlink]




[Measured BER by varying tr. distance for downlink]

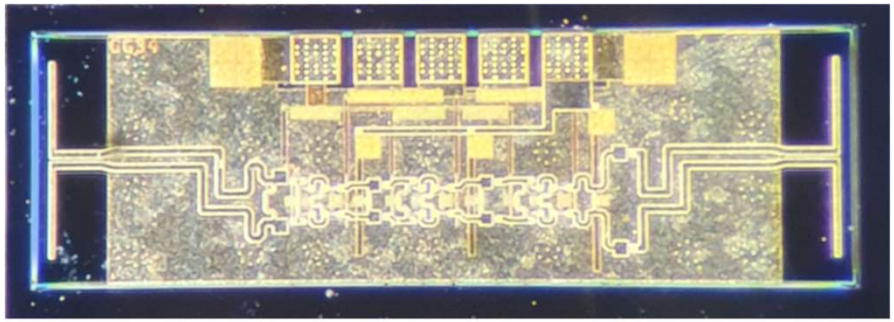



[Measured BER by varying tr. distance for uplink]

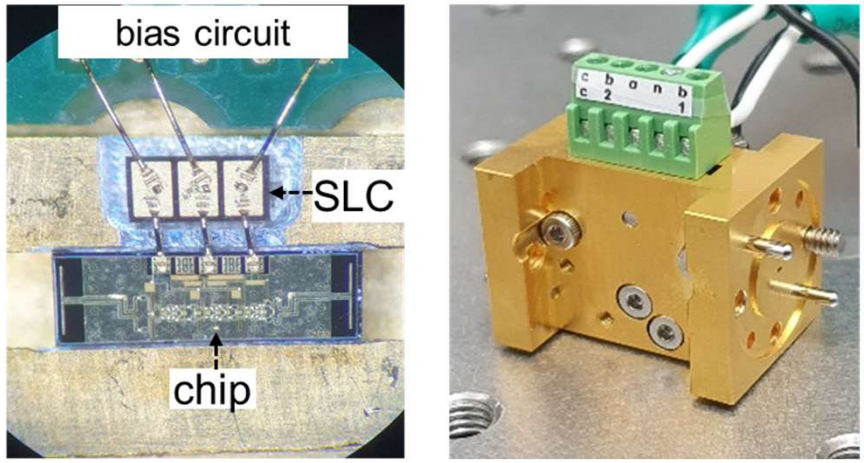
Ref: Sang-Rok Moon et al., "6G Indoor Network Enabled by Photonics- and Electronics-Based sub-THz Technology," J of Light. Tech. vol.40 (2), pp. 499, 2022.

# How to realize THz-band indoor network

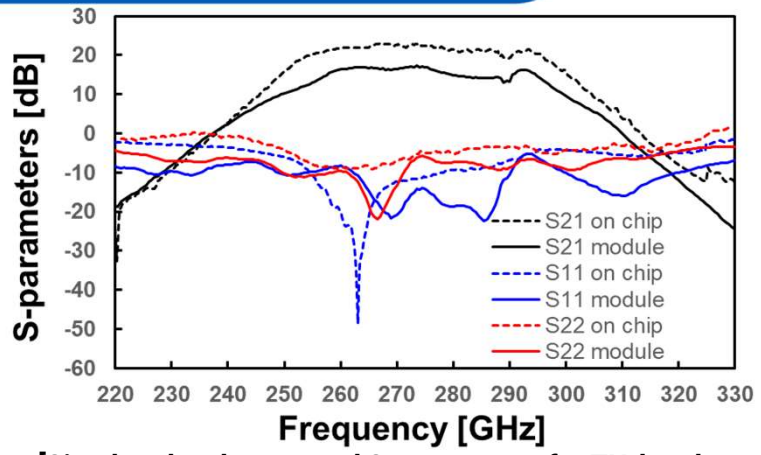
## THz-band amplifier (using 250nm InP HBT process)



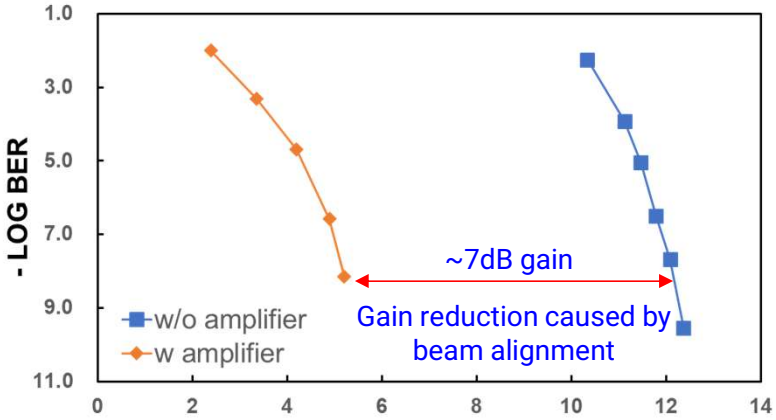
[THz-band amplifier IC with waveguide transition]




[Assembled module of THz-band amplifier]




[Simulated and measured S-parameters for TH-band amplifier]

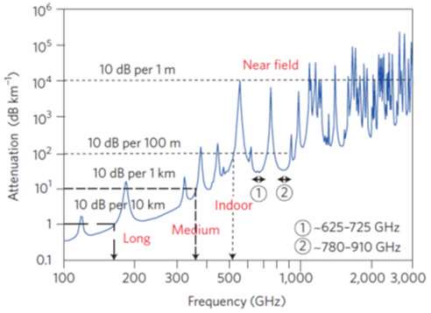



[Measured BER characteristics w&wo THz-band amplifier (NRZ-10Gb/s)]

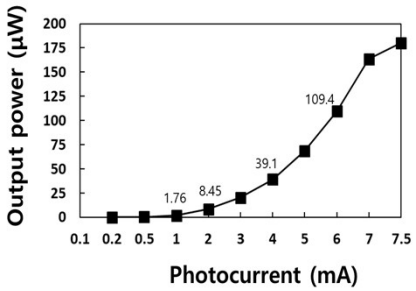
Ref: Sooyeon Kim et al., "Cost-effective photonics-based THz wireless delivery system using a directly modulated DFB-LD," submitted to MOTL (under review)

# Technical challenges

## Improvement of output

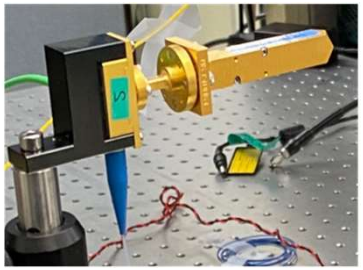



THz-band attenuation

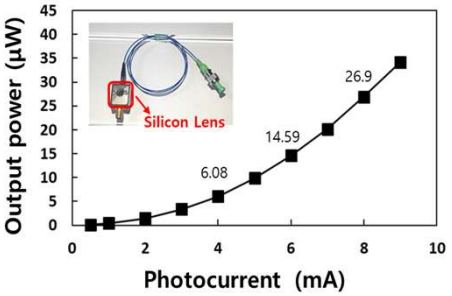



UTC-PD output power

## Size (form factor) Reduction

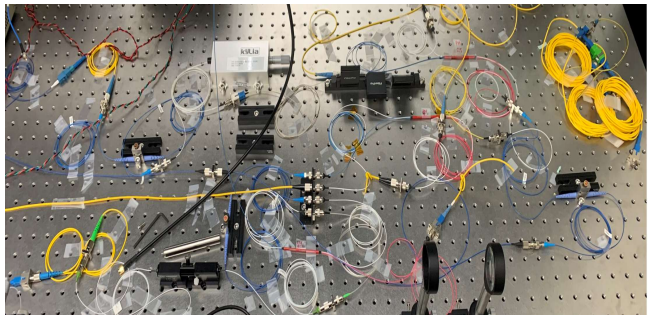


UTC-PD w/ horn antenna




Lens type UTC-PD & power

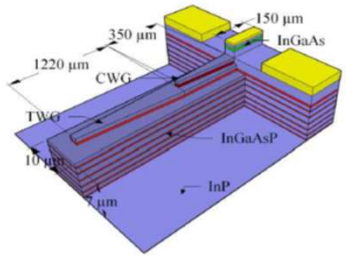
## Photonic Integration



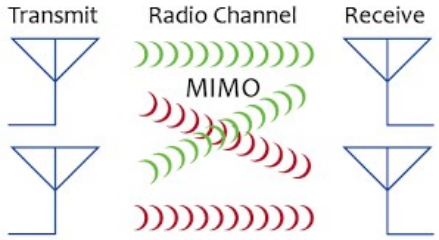
THz signal generator using fiber-optics: **2m x 1m**

THz signal generator using PIC (expectation) :**10 mm x 14 mm**

## Polarization dependency of UTC-PD




Internal structure of UTC-PD




2x2 MIMO with PDM

# Summary

- The necessity of THz-band communications
  - advent of 6G era
  - hyper-reality services
  - indoor network application
- THz transmission based on photonics
  - electronics vs. photonics
- Demonstrations of THz transmissions by using photonics
  - architectures
  - modulation/detection methods
  - indoor network demonstrations
- Technical challenges to overcome
  - Still have lots of works to do

# Thank you