

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

**Submission Title:** Feasibility Test of Terahertz Wireless Communications at 300 GHz

**Date Submitted:** 8 November 2010

**Source:** Ho-Jin Song, NTT Microsystem Integration Labs.

3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0036, Japan

hjsong@aecl.ntt.co.jp

**Abstract:** We present preliminary experiment results of terahertz wireless link at 300 GHz and discuss the feasibility of the terahertz waves for used in multi-Giga bps short range wireless communications systems.

**Purpose:** for discussion

**Notice:** This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

**Release:** The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.

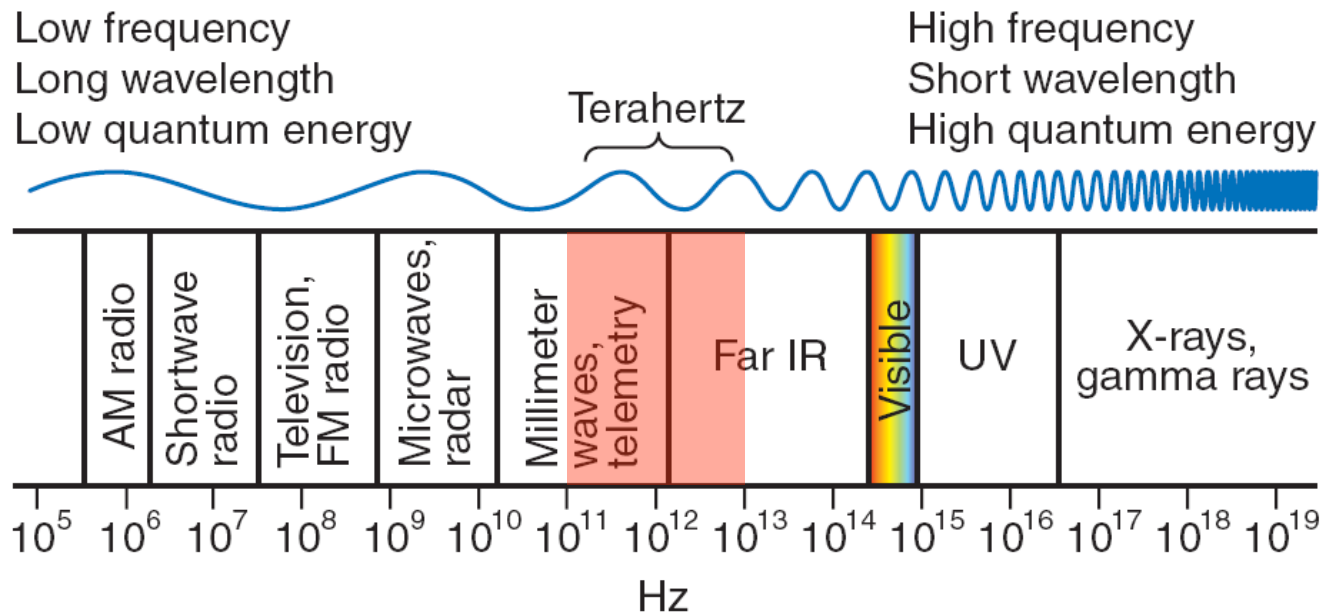
# Feasibility Test of Terahertz Wireless Communications at 300 GHz

**H.-J. Song**<sup>1</sup>, K. Ajito<sup>1</sup>, T. Nagatsuma<sup>2</sup> and N. Kukutsu<sup>1</sup>

<sup>1</sup>NTT Microsystem Integration Laboratories.

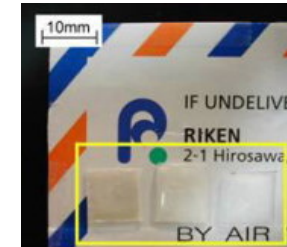
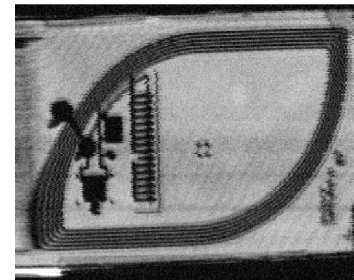
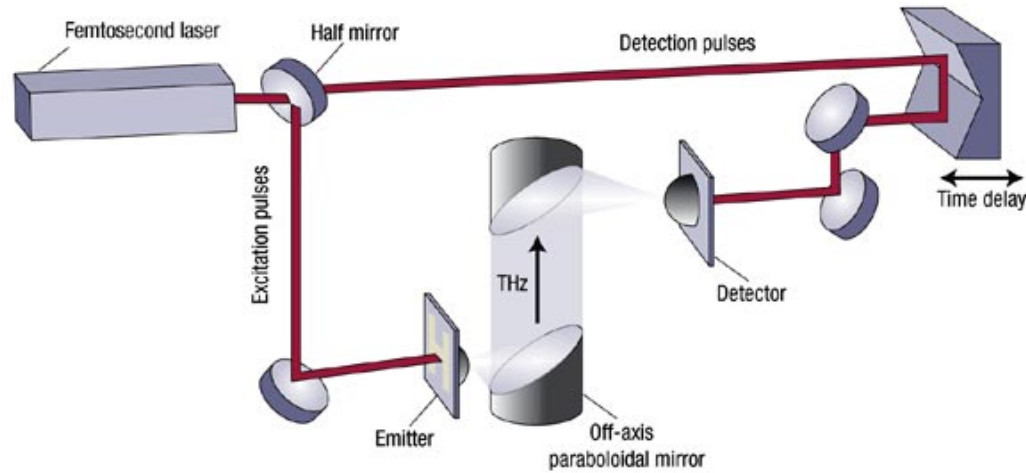
<sup>2</sup>Osaka University

# Terahertz Waves

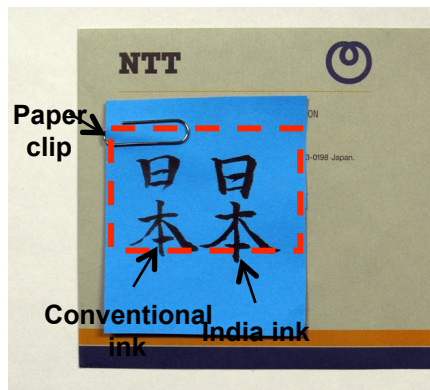


- Unique interaction pattern with molecules
  - Capable of penetrating many non-metallic materials
  - Short wavelength (compared to microwaves)
- **Sensing, imaging, security**

# Imaging for Security or Sensing



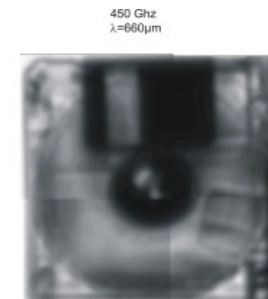
Nagoya Univ. Japan



NTT, Japan

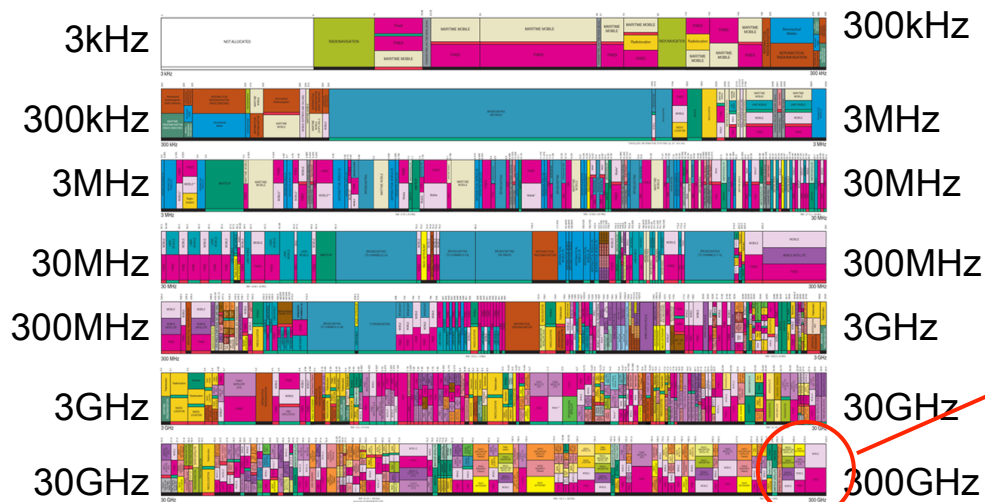


Jefferson Labs., USA

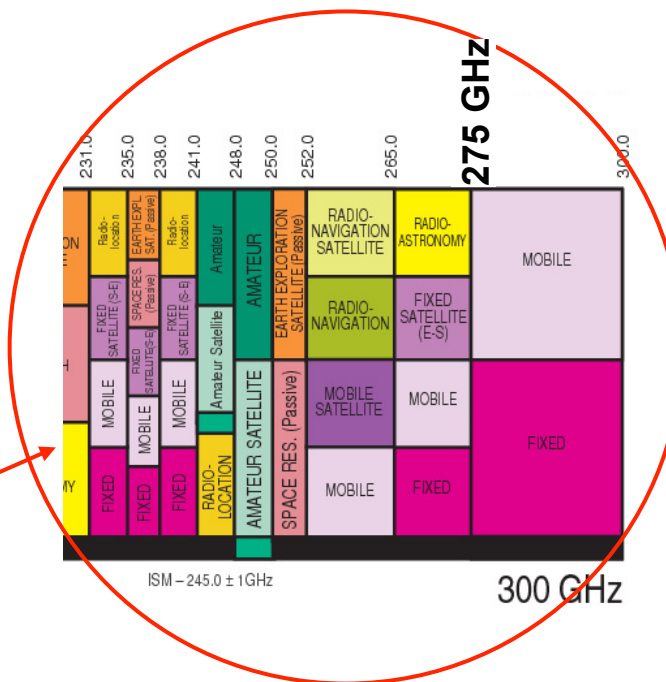


# THz Waves for Communications

- **Large bandwidth**
  - For 300 GHz, BW is approximately 150 times larger than for 3G/4G cellular system (1.9~2.1GHz)
  - 150 times **larger data capacity** (more than 10 Gbps)
  - Or much simpler system
- **No one uses these frequencies !!**



U.S. Frequency Allocation Table



# Natural Gift: Bandwidth or Height



Shaquille O'Neal  
2m 13 cm



Yao Ming  
2m 28 cm

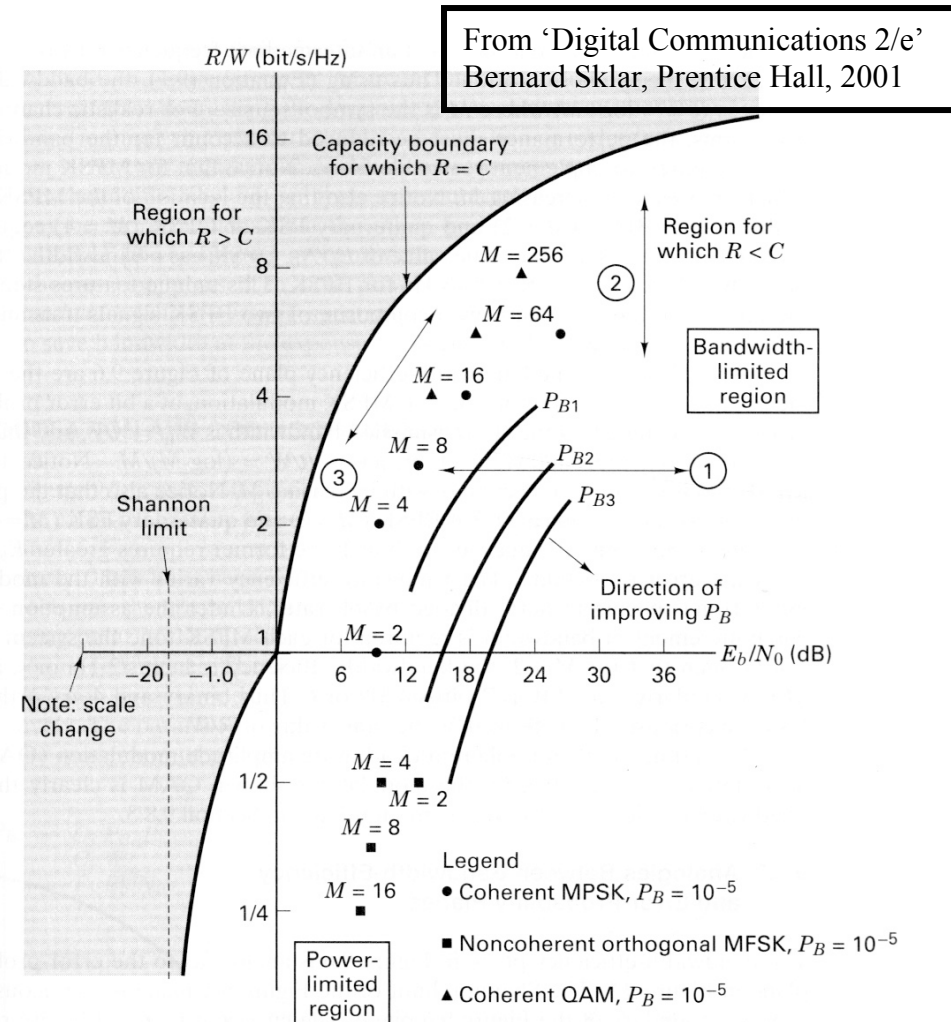
- Giant player is always attractive to NBA.
  - Height can't be earned by practice.
- So do THz-wave and its' bandwidth for communications.

# Shannon Limit

$$R \leq W \log_2 \left( 1 + \frac{S}{N_0 W} \right)$$

Maximum capacity relies on signal **Power** and **Bandwidth**.

→ Large BW can compensate for lack of power.



# Is It Possible ?

Frequency (GHz)
Distance (m)
Spectral efficiency (bit/s/Hz)
Radiated power (dBm)
Noise level (dBm/Hz)
Noise figure (dB)
Loss in Air (dB/Km)

- 1-mW out  
us 10-Gbps

- In terahertz wave bands, 25-dBi antenna is small enough.





But,

NBA is NBA,

and

Theory is just theory.

**Show me some experimental results !**

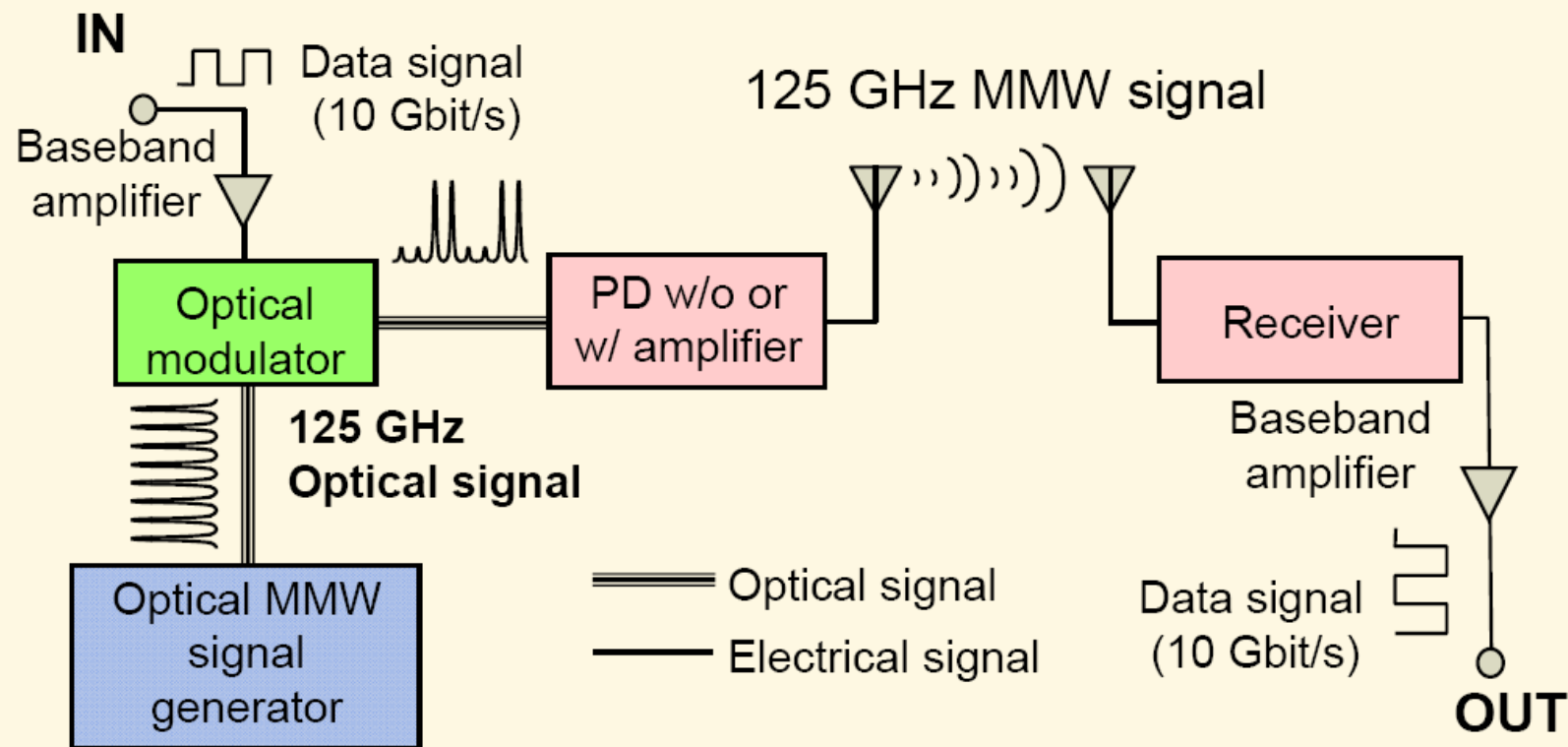
# Feasibility Test

## We need

- Transmitter
  - THz signal generator
  - Data modulation
  
- Receiver
  - THz Signal detector
  - Demodulator

# 10 Years Ago in NTT

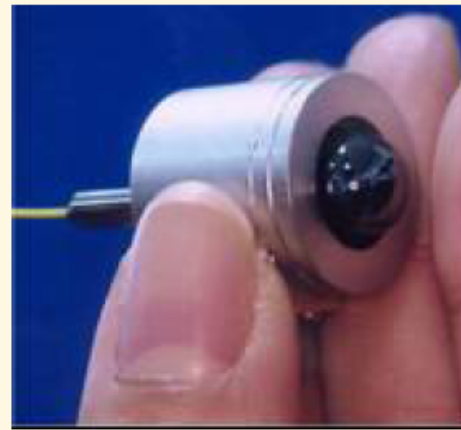
## 120-GHz-band System with Photonic Tx



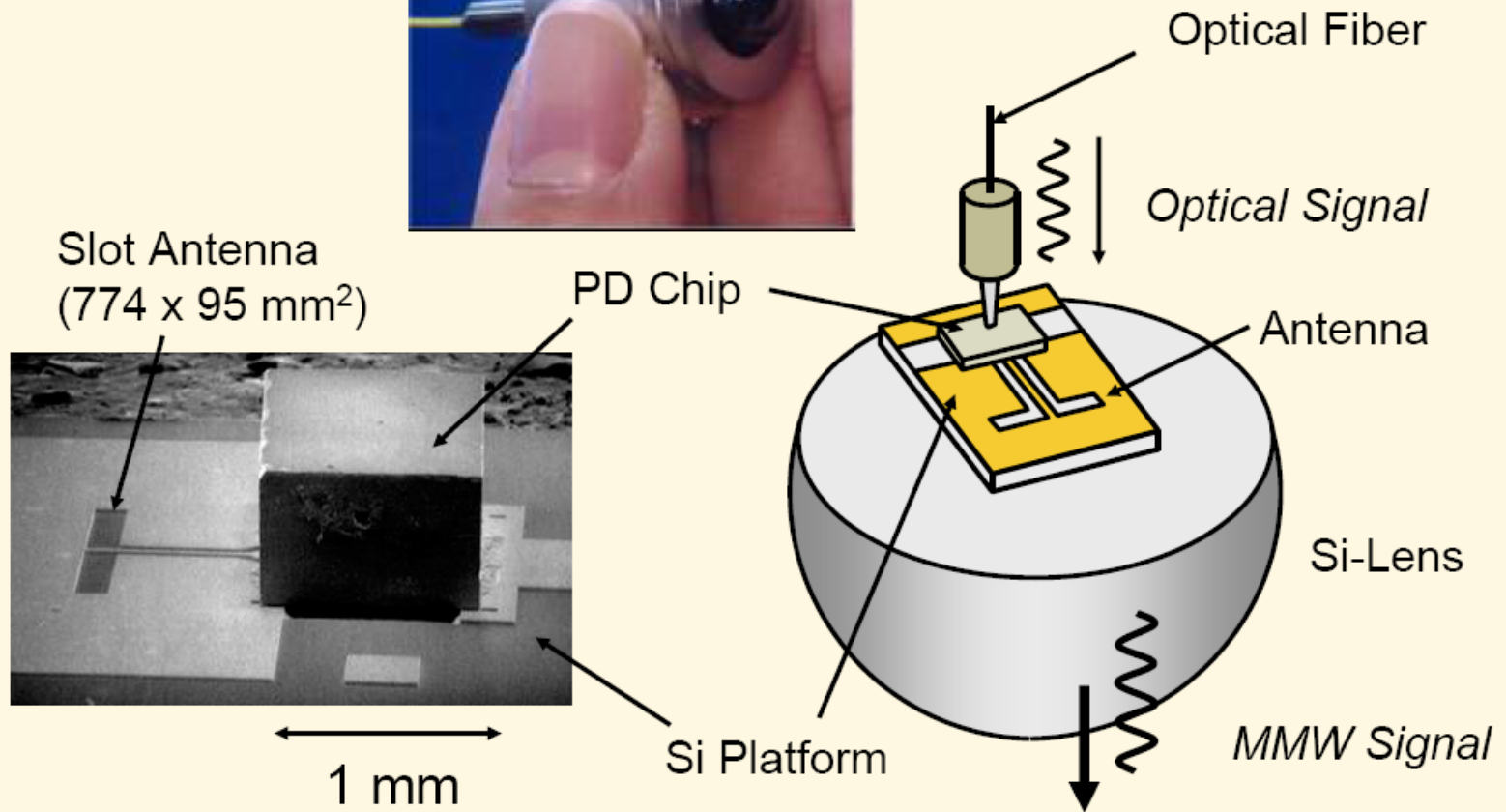
Source: IEEE 802.15-15-10-0149-01-0thz

# 120-GHz Emitter

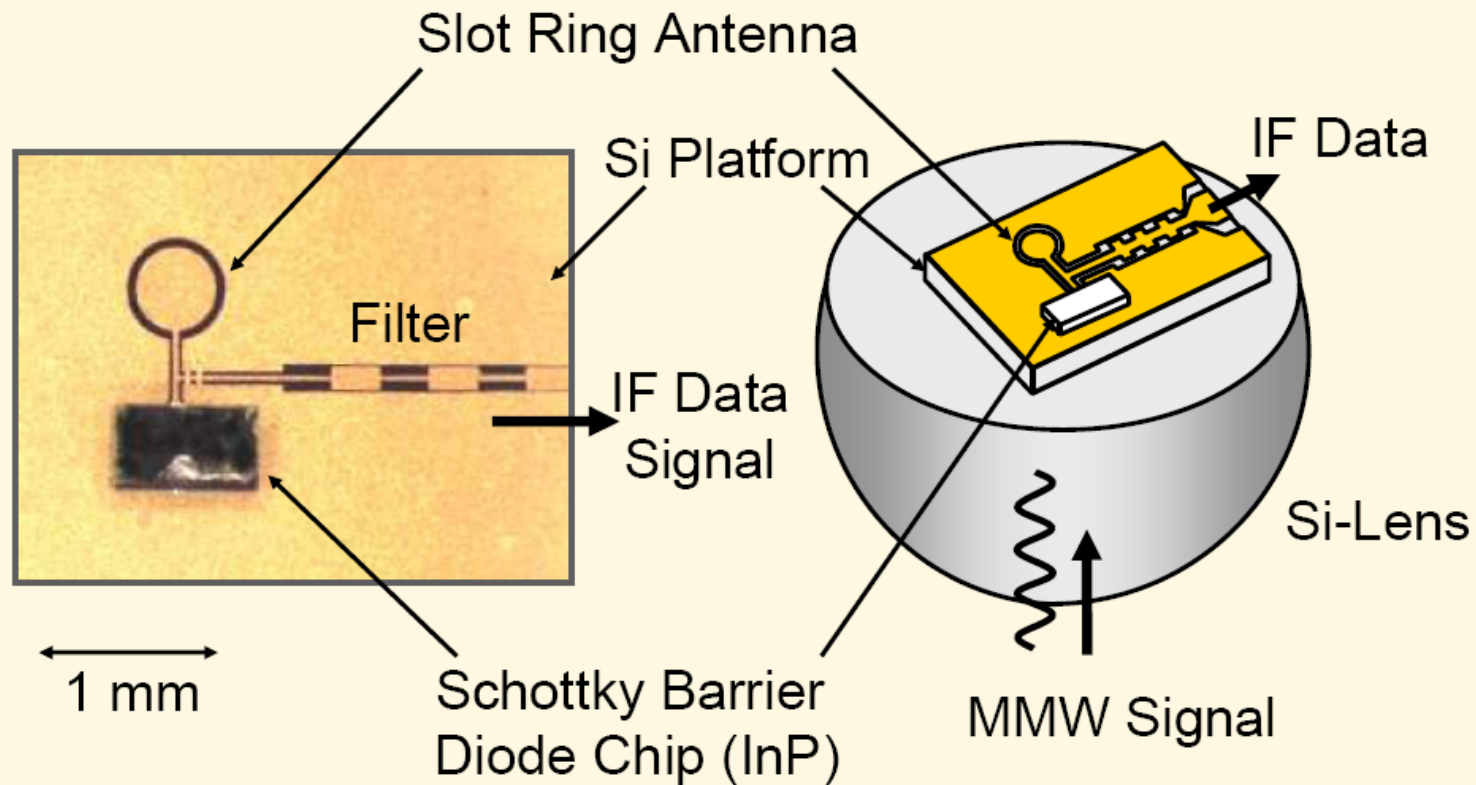
Source: *IEEE 802.15-15-10-0149-01-0thz*



Microwave Photonics 2000



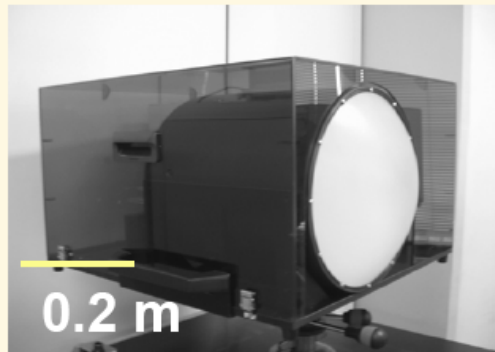
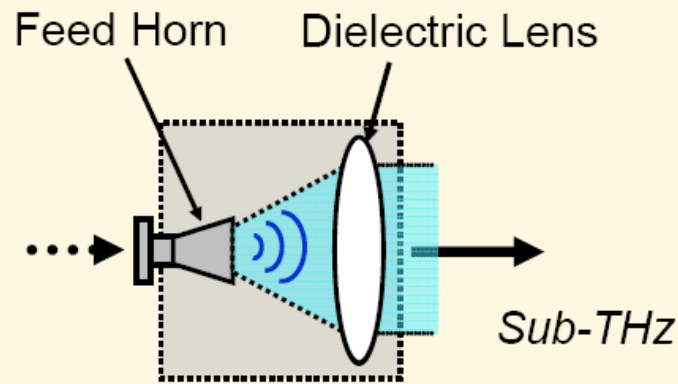
# 120-GHz Receiver for 10-Gbit/s



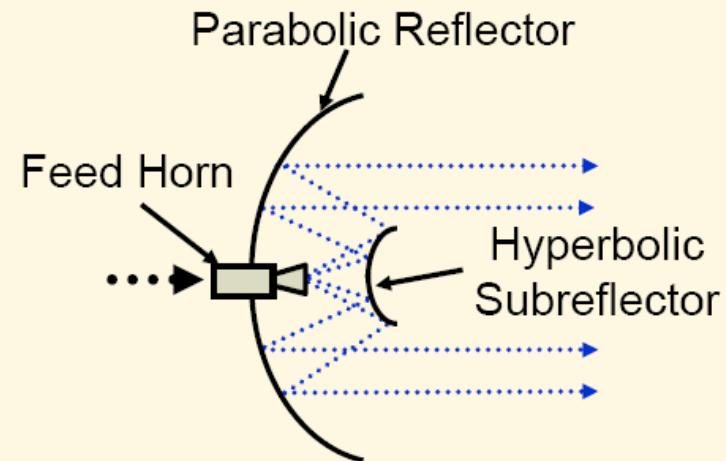
Source: IEEE 802.15-15-10-0149-01-0thz

# Antennas for Long Distance Link

## Lens Antenna



## Cassegrain Antenna

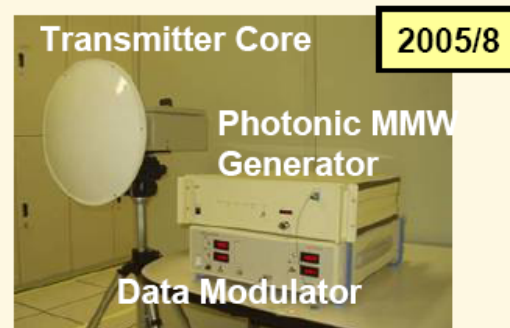
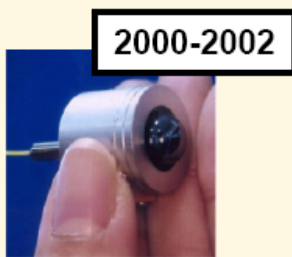


Source: IEEE 802.15-15-10-0149-01-0thz

# Hardware Evolution in 10 years

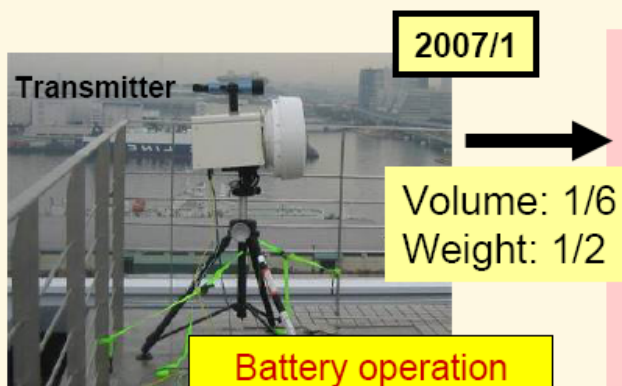
## Photonics-based Transmitter

Source: IEEE 802.15-15-10-0149-01-0thz



- Output power: 10 mW, ~2 km
- Power consumption: 600W

## Electronics-based Transmitter

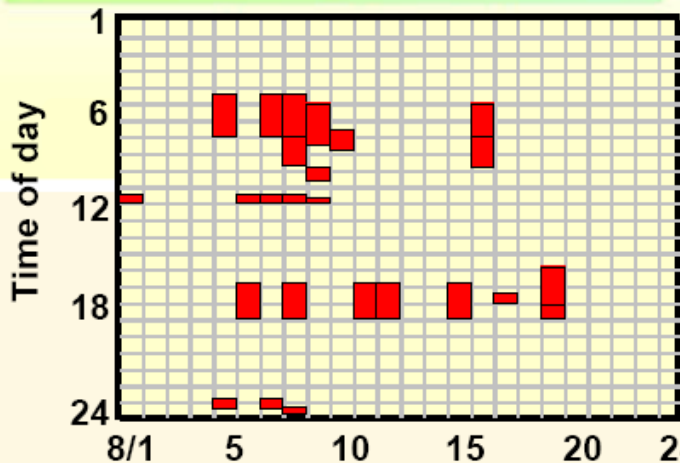
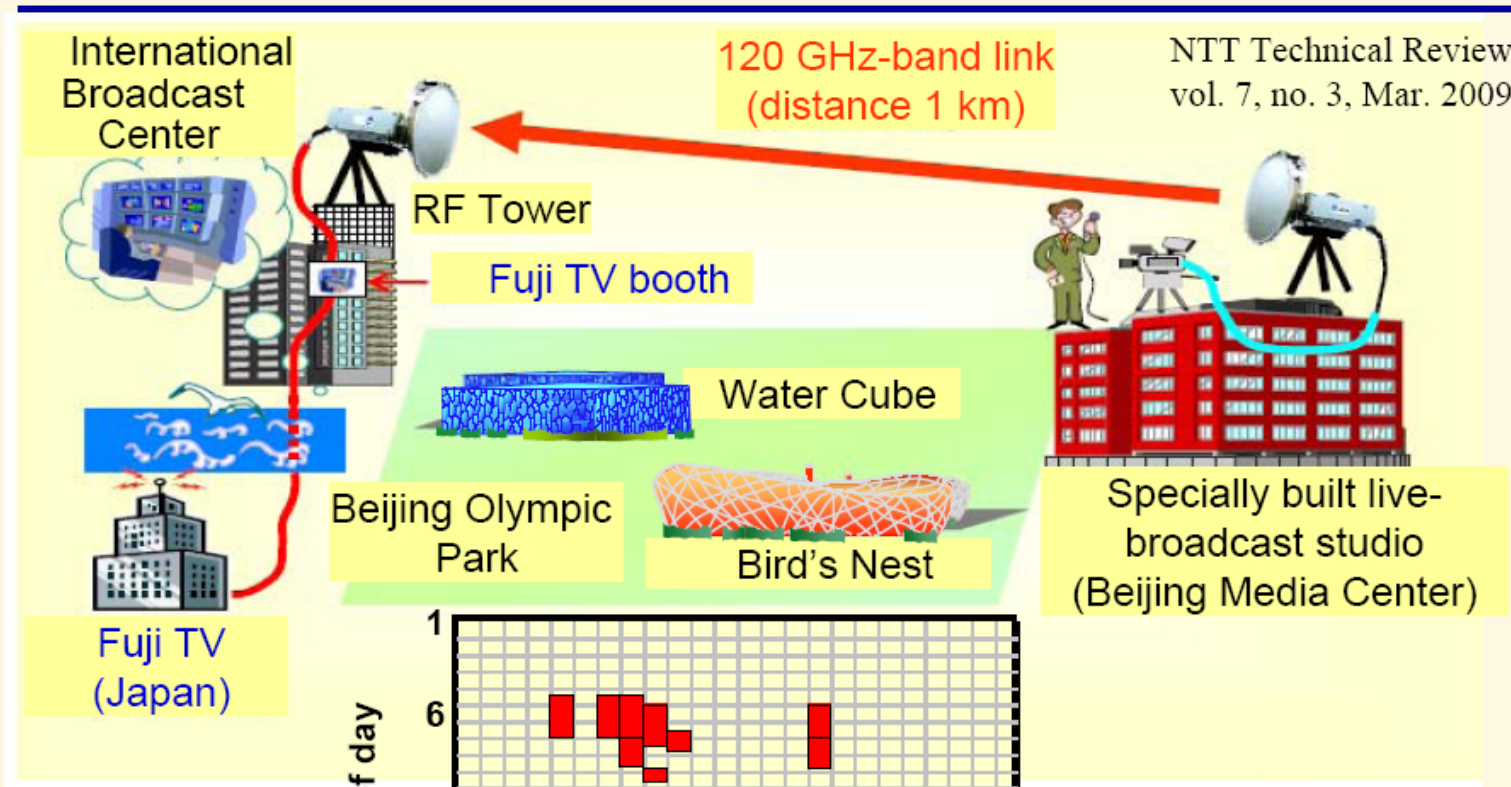


- Output power: 10 mW, 2.2 km
- Power consumption: 60 W



(NTT Technical Review, vol. 7, no. 3, Mar. 2009)

# Trials at Olympics: Configuration



TV programs with 120-GHz system

Source: IEEE 802.15-15-10-0149-01-0thz



Same Approach at THz Waves

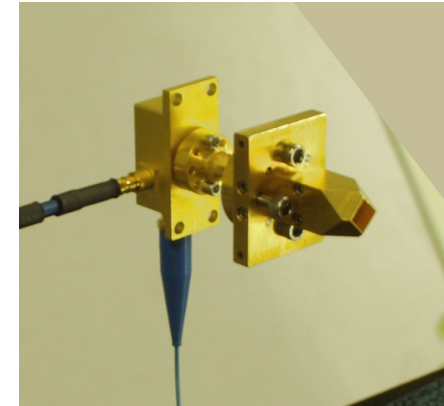
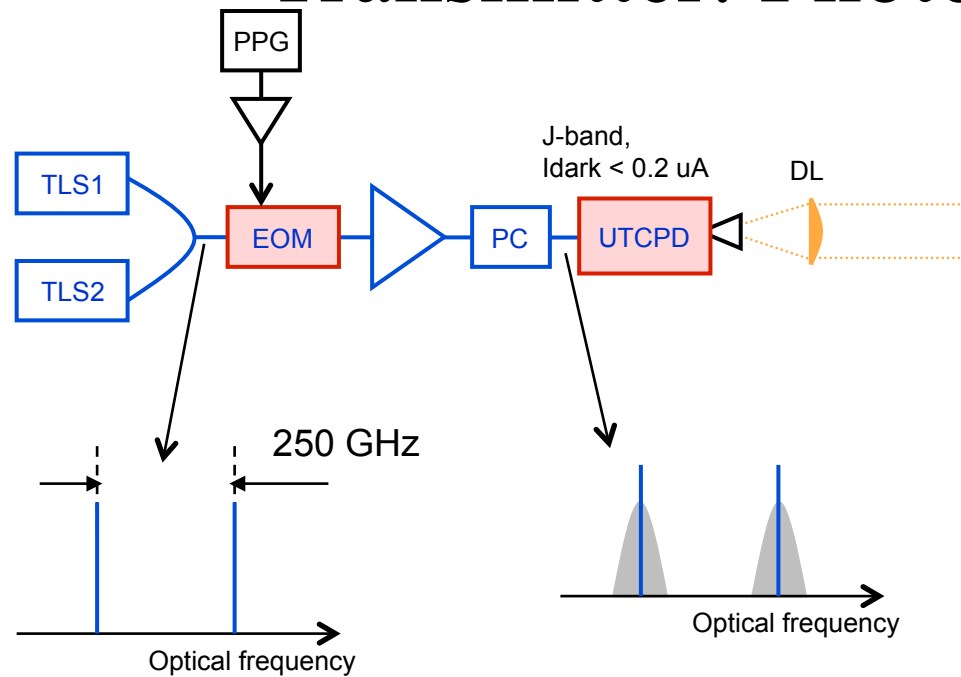
But,

Short range applications

# Possible Application

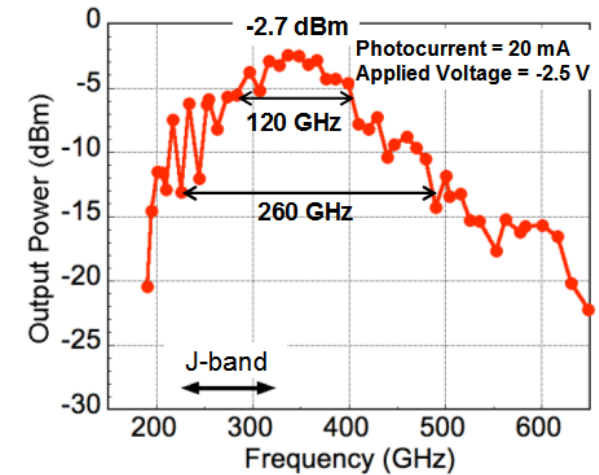
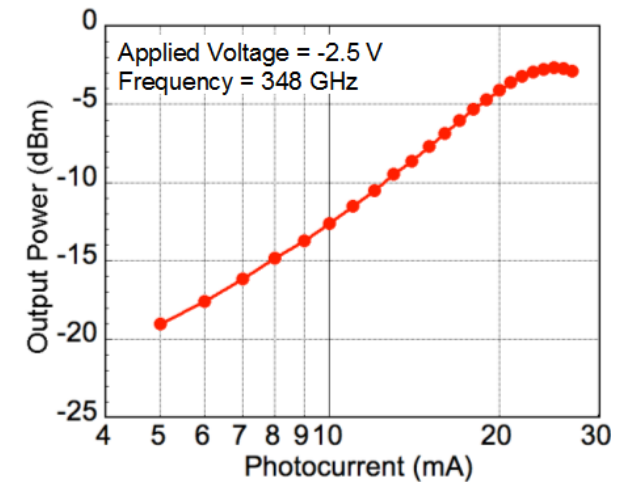
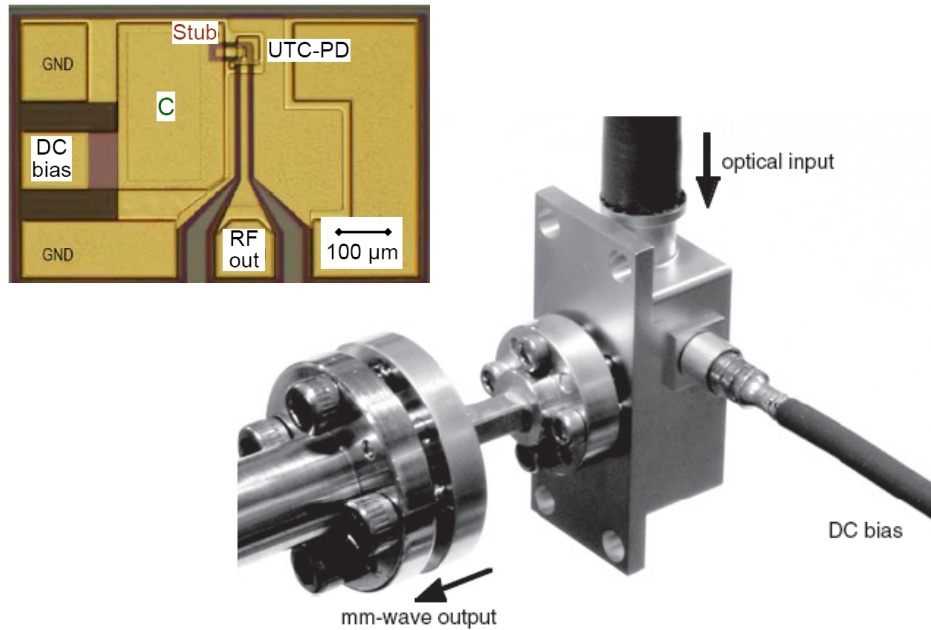


# Transmitter: Photonics tech.



- Easy to handle large data rates up to 40 Gbps
- Easy to generate THz wave signal
- Possible to integrate with optical network → ROF ?

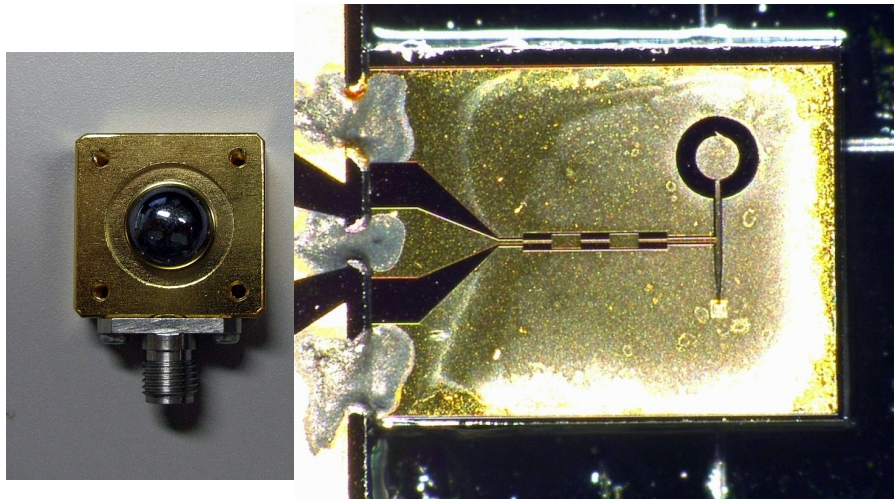
# THz Operation of UTC-PD



- Max. output : -2.7 dBm (350 GHz)
- Waveguide packaging

# Receiver: Schottky Barrier Diode Detector

NTT developed

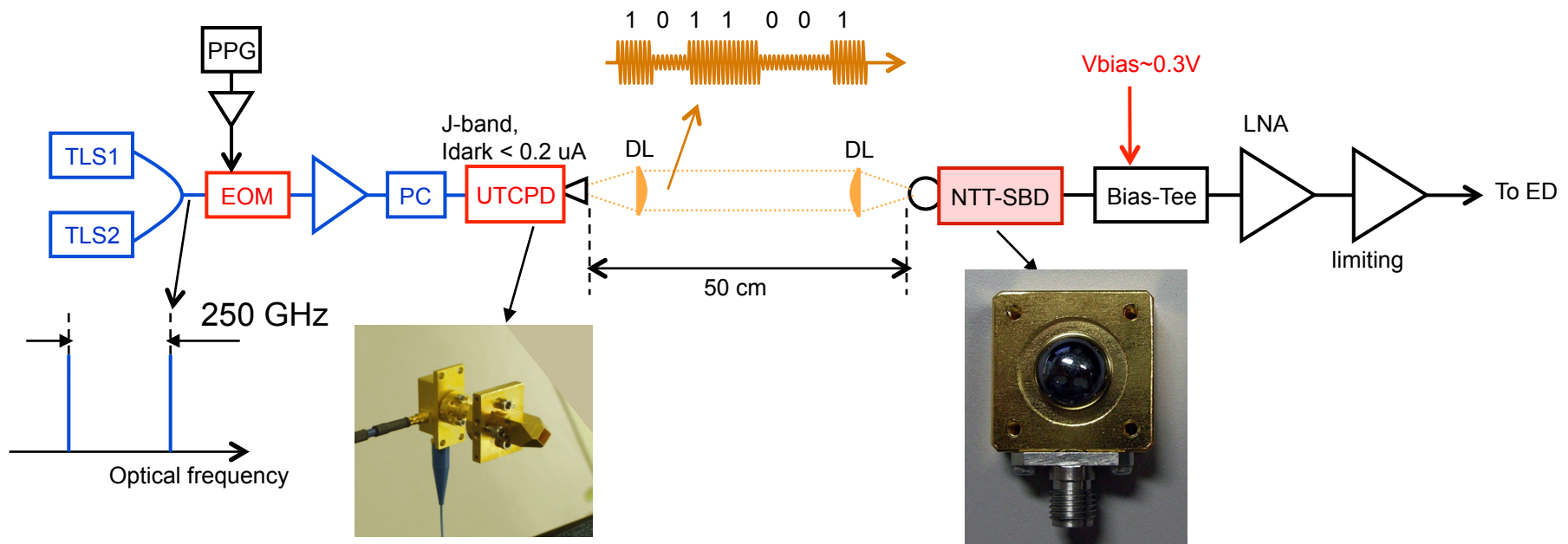


Commercial device



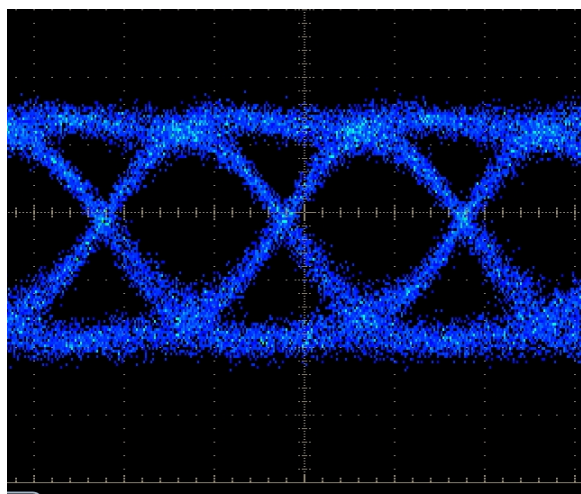
- Schottky barrier diode detectors as envelop detector for ASK signal.
- Commercial device showed better sensitivity and responsivity.
- But, both devices exhibited much worse noise performance assumed in the calculation.

# First Trial at 250 GHz

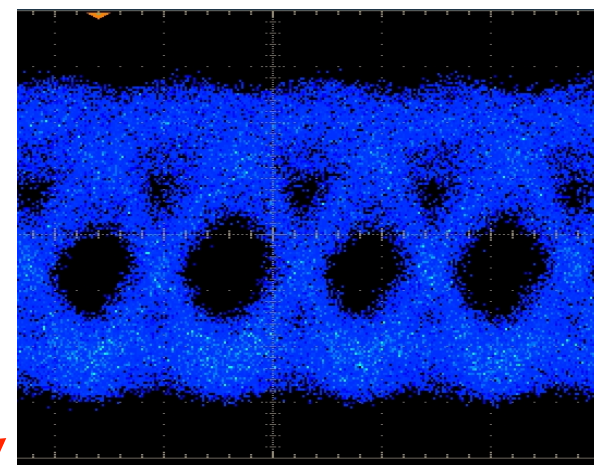
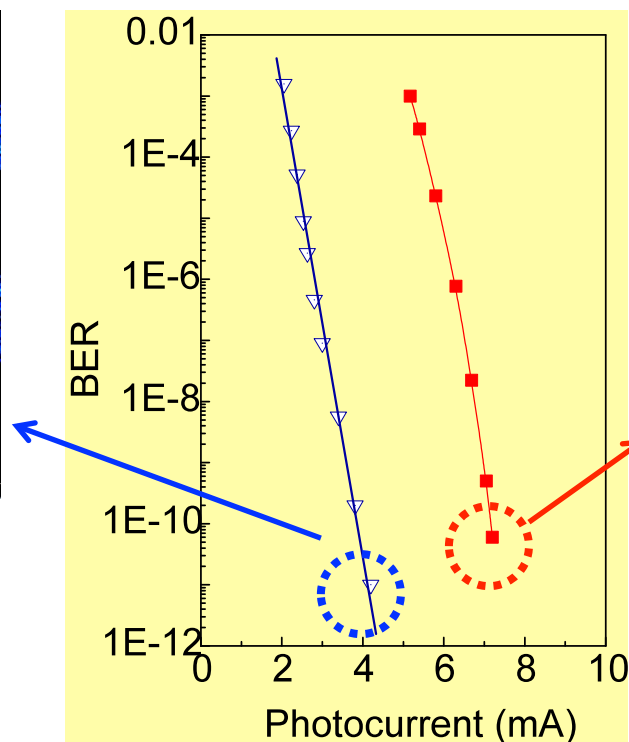


- Photonic transmitter + SBD detector receiver
- ASK modulation over 50-cm long distance
- No amplifier, but dielectric lens for both Tx/Rx
- Why 250 GHz?  $\rightarrow$  limited performance of SBD

# First Trial at 250 GHz



2 Gbps with  
commercial detector  
( $P_{TX} < 10 \text{ uW}$ )

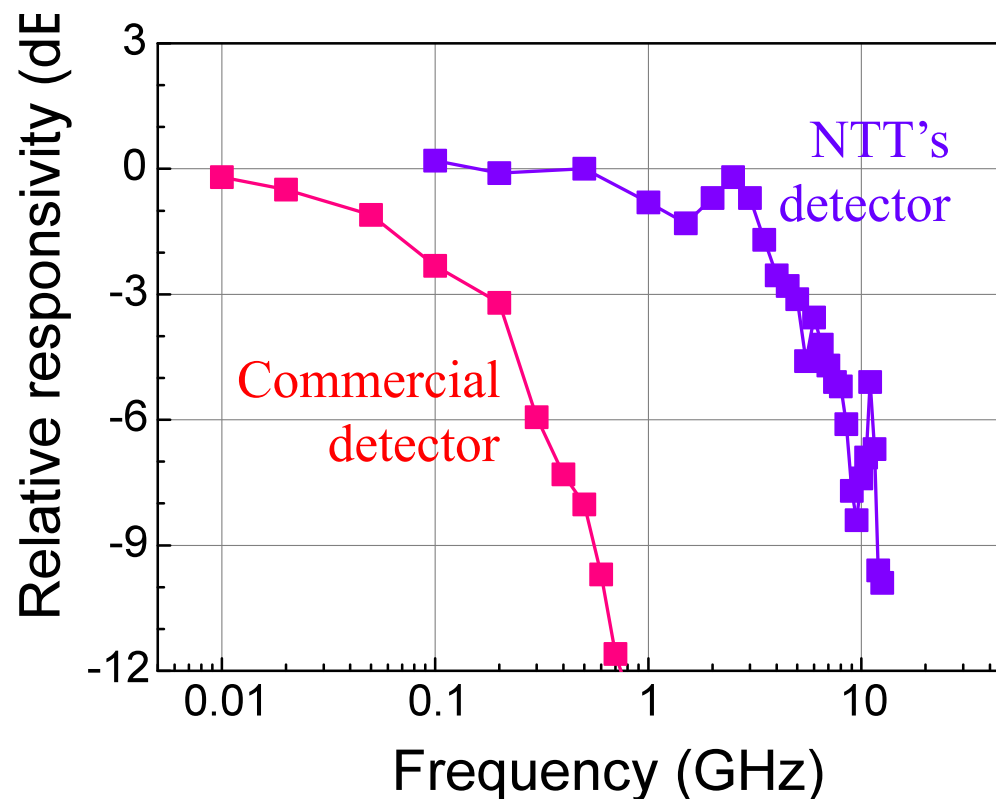


8 Gbps with  
NTT's detector  
( $P_{TX} \sim 10 \text{ uW}$ )

Electronics Letters 45(22)  
pp. 1121-1122, 2009

- We had enough power margin
  - UTC-PD can be driven up to 20 mA
  - Error free transmission up to 3-m distance
- NTT device provided higher data rate

## Problem Was Bandwidth

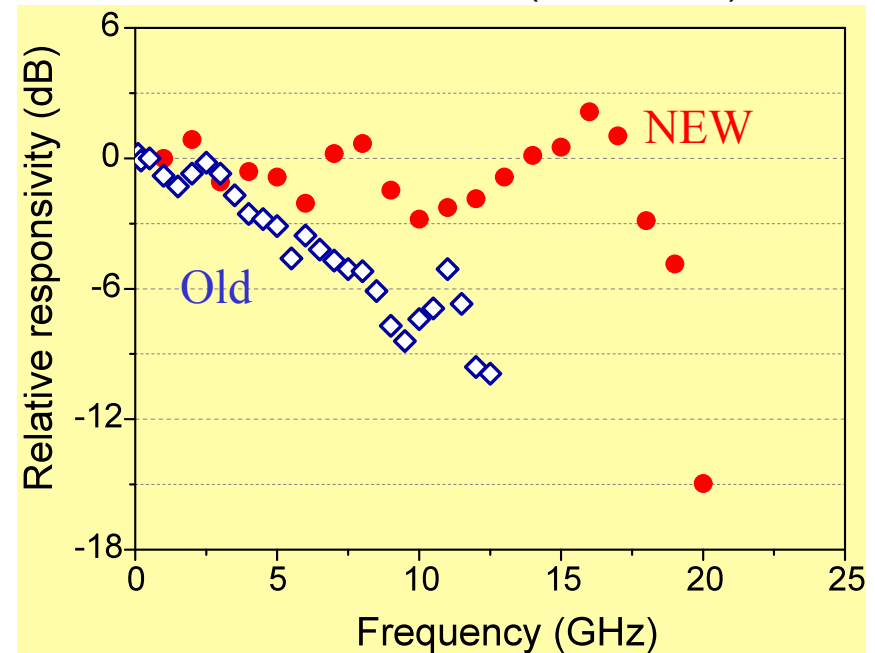
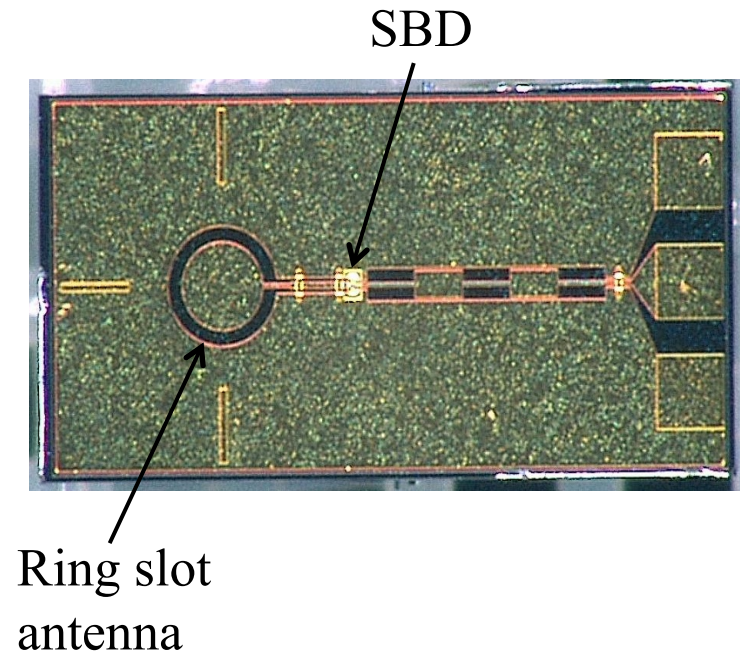


- Video bandwidth (baseband output bandwidth) of detectors limit data capacity



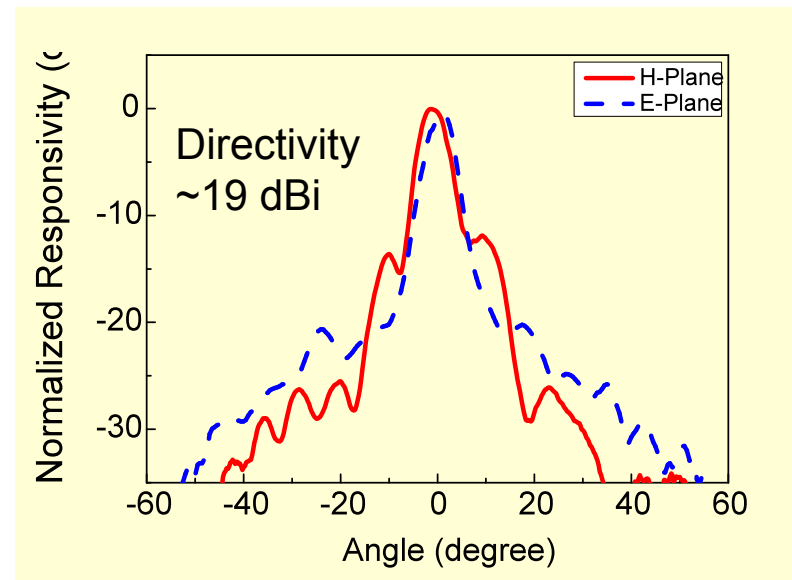
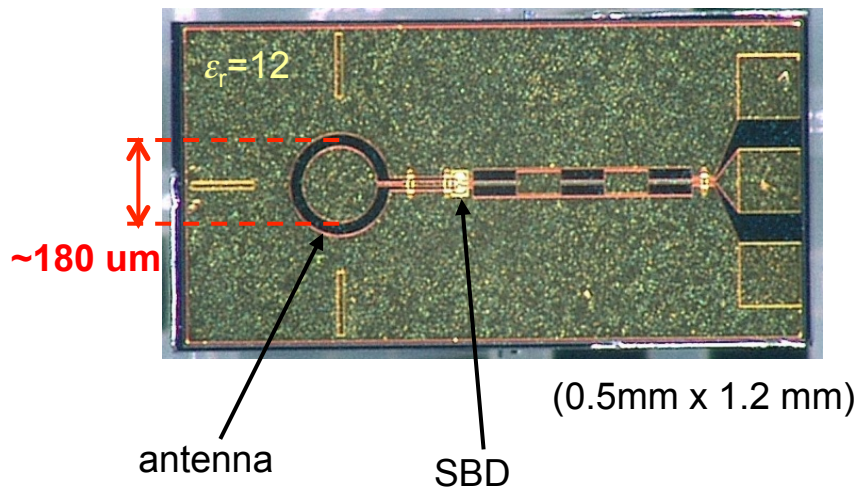
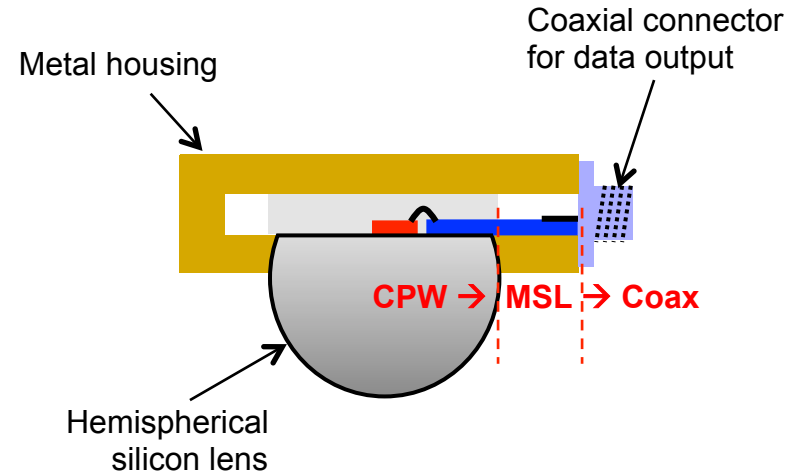
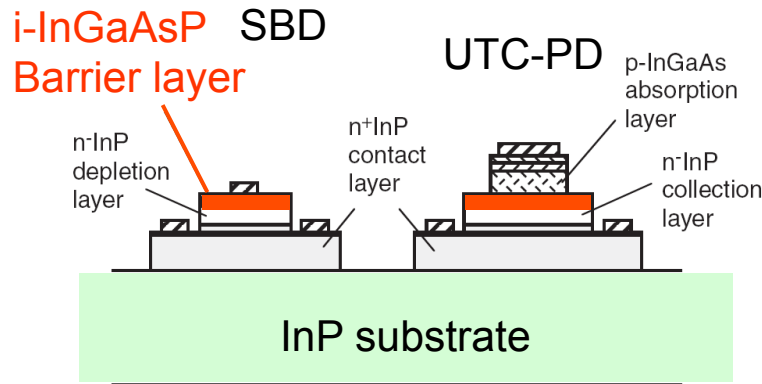
# NEW Schottky Barrier Diode Detector

Video-bandwidth (baseband)

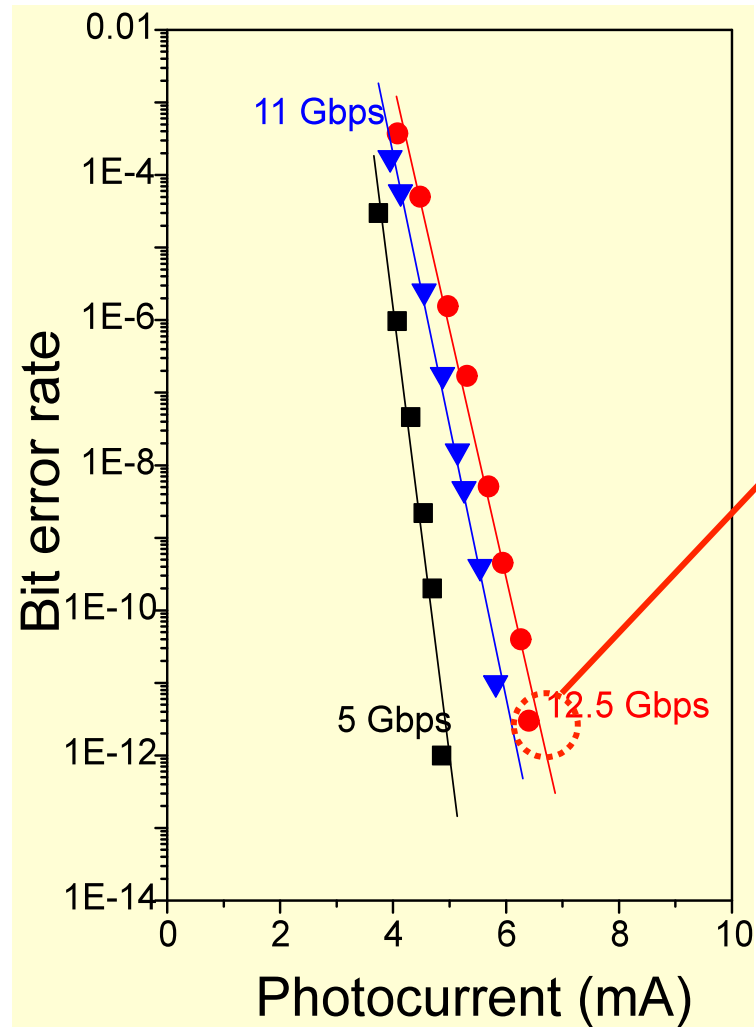


- New device provides much wider video bandwidth of around 17 GHz (cf. old ~ 4.5 GHz)
- Designed for 300 GHz operation with advanced SBD devices

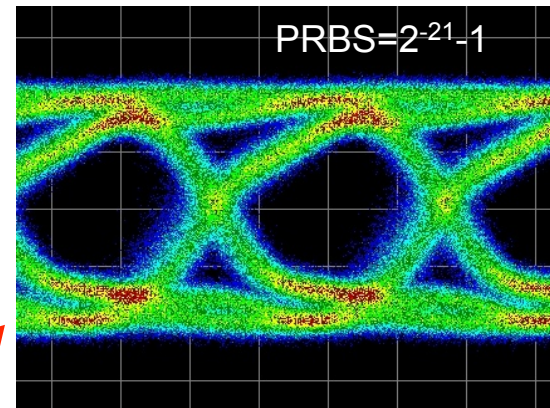
# NEW Schottky Barrier Diode Detector



# New Result with New Receiver



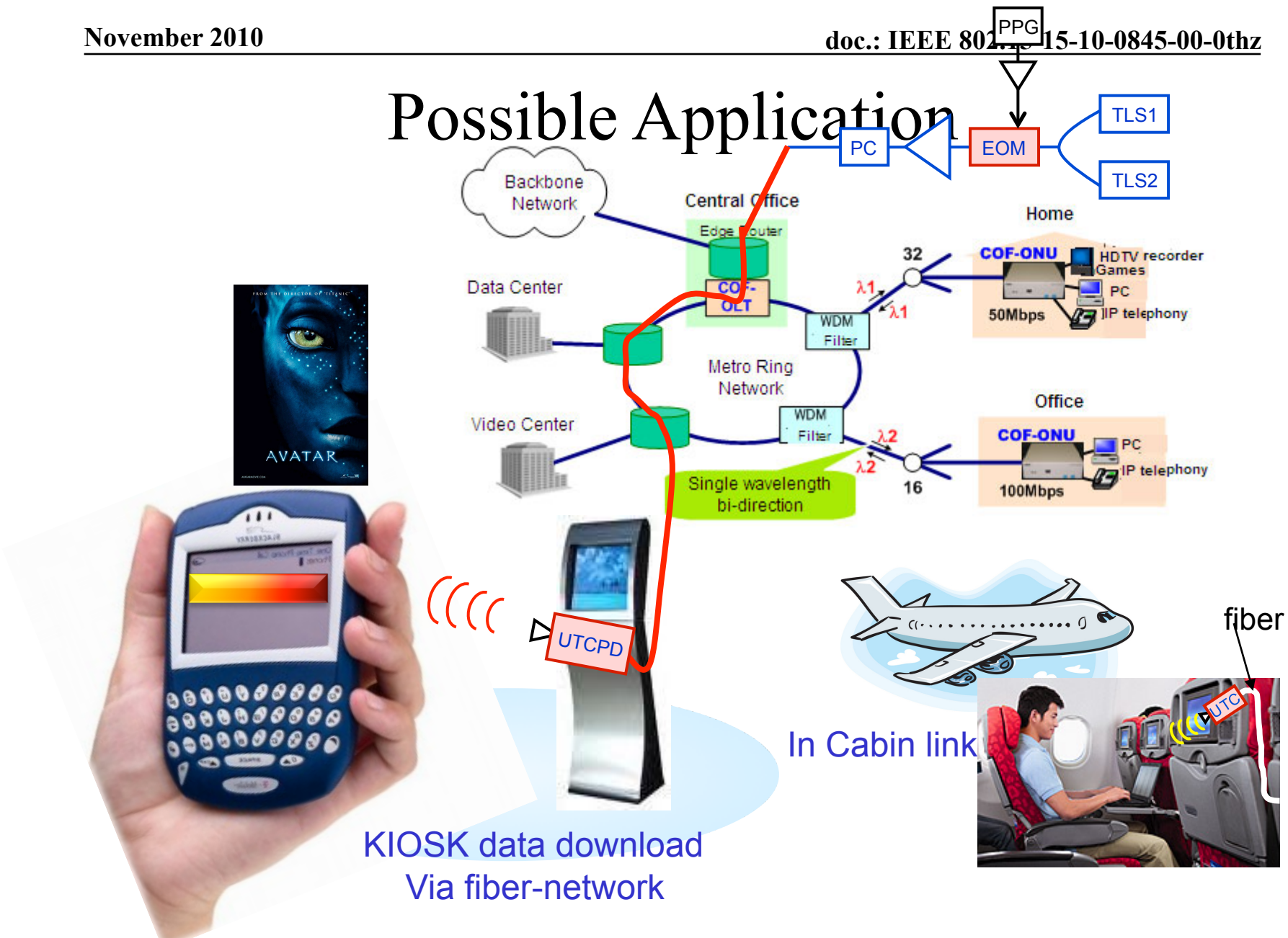
12.5Gbps



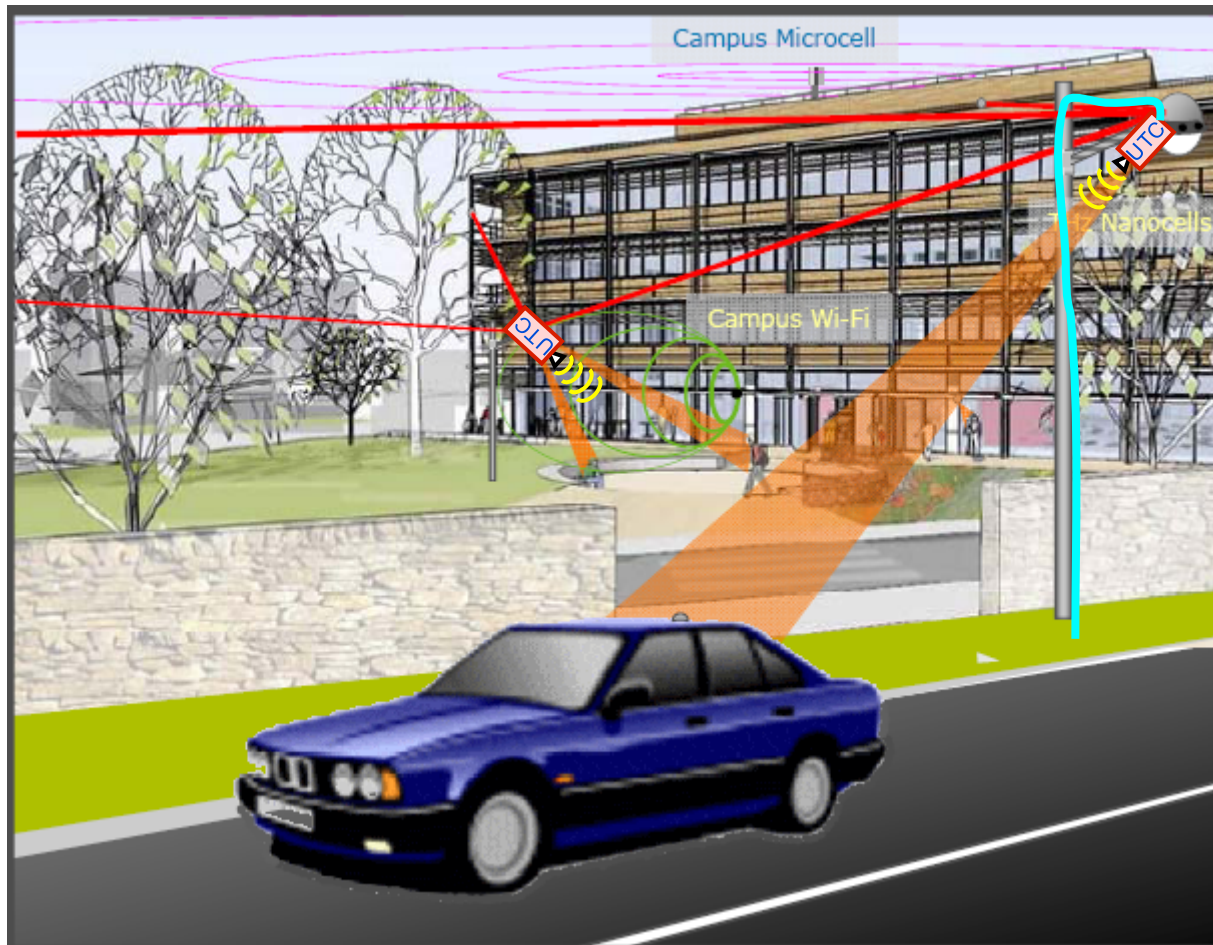
- We still have some power margin from UTC-PD
- 12.5 Gbps was limited by measurement setup (BERT)

Microwave Photonics 2010, WE3-2

# Possible Application



# Why Not ?!



IEEE 802.15-15-10-0150-00-0thz, Dr. Britz, AT&T

## Issues in THz communications

- **Frequency allocation: We need a lot**
- High performance devices, especially for mobile unit.
- Packaging materials for practical application
- Channel characterization / modeling
- Beamforming, due to Line-of-sight (LOS) operation

# Summary

- We demonstrated **terahertz-wave wireless link at 300 GHz** for feasibility test
  - Photonic transmitter + Schottky barrier diode detector receiver
  - **12.5 Gbps** error free transmission over 0.5-m distance
- Note that all the results were due to the utilization of huge bandwidth at terahertz frequencies.
  - We didn't use so much high power (< 60 uW)
  - Noise performance of receiver was much worse than calculation.
  - But, we had **BANDWIDTH**.