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

Submission Title: Towards 100-Gbit/s Wireless Using Terahertz Waves
Date Submitted: 9 March, 2010
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Re: IEEE 802.15-15-10-0149-00-0thz

Abstract: Presentation of NTTs work towards 100-Gbit/s Wireless Using Terahertz Waves

Purpose: Information on development of future THz communication systems

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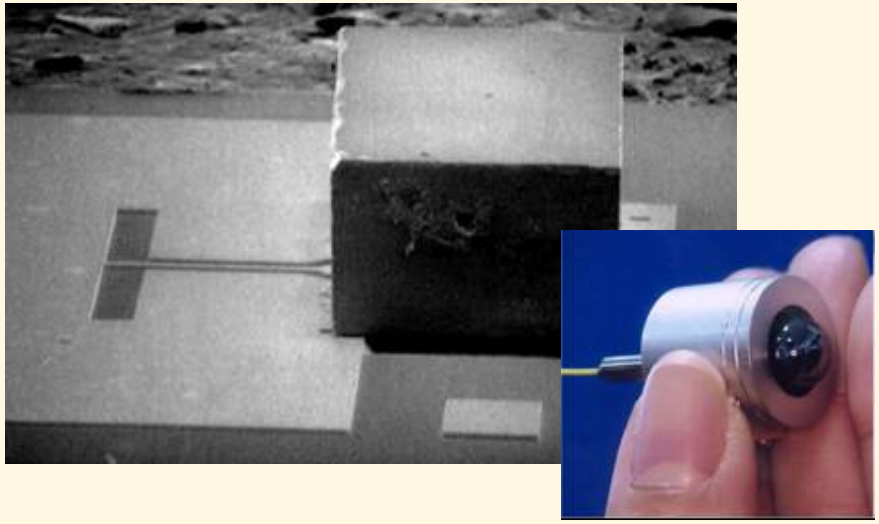
Towards 100-Gbit/s Wireless Communications Using Terahertz Waves



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Acknowledgments

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T. Ishibashi (NTT Electronics), H. Ito (Kitasato U.)

Y. Fujimoto (Osaka U.), K. Miyake (Osaka U.),
K. Takada (Osaka U.), M. Kawamura (Osaka U.)

Fuji Television Network Inc, NHK (Japan Broadcasting Corporation)

Members of Study Group on THz ICT at Kinki Bureau of Telecommunications in Ministry of Internal Affairs and Communications (MIC)

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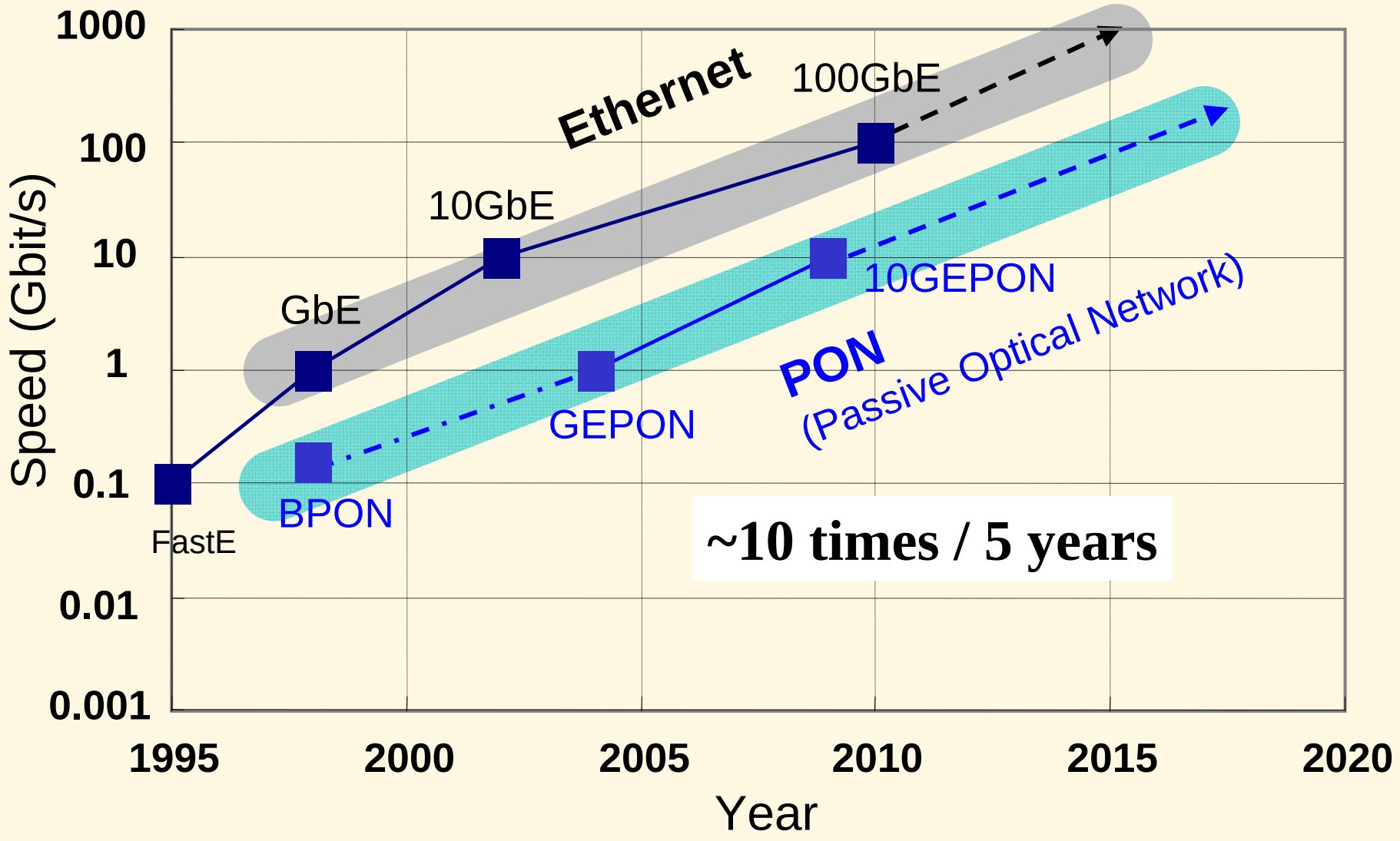
Outline

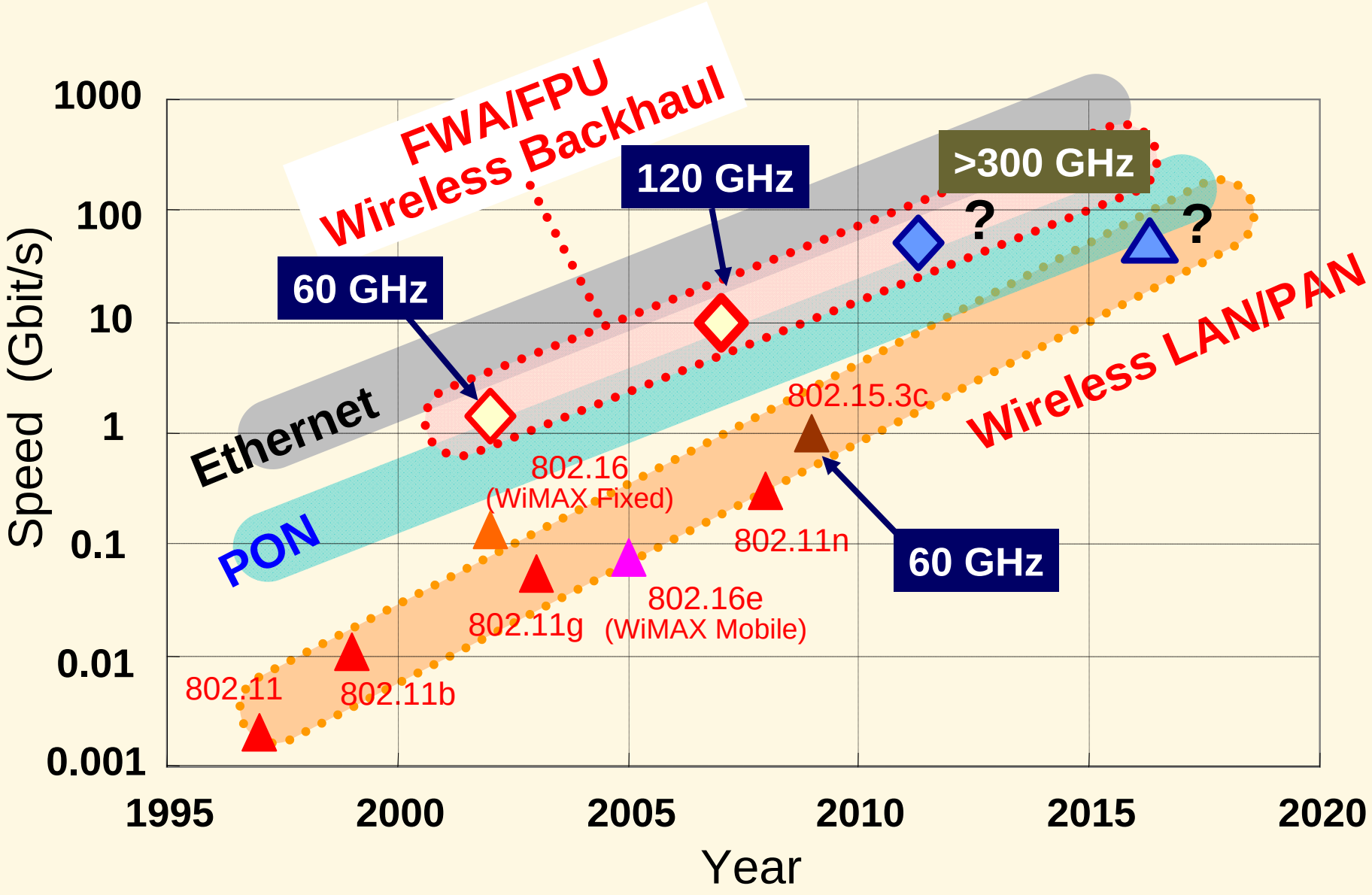
- Background & Needs
- 10-G wireless with 120-GHz Bands
- Exploring 300-400 GHz Band
- Summary

- **Background & Needs**
- 10-G wireless with 120-GHz Bands
- Exploring 300-400 GHz Band
- Summary

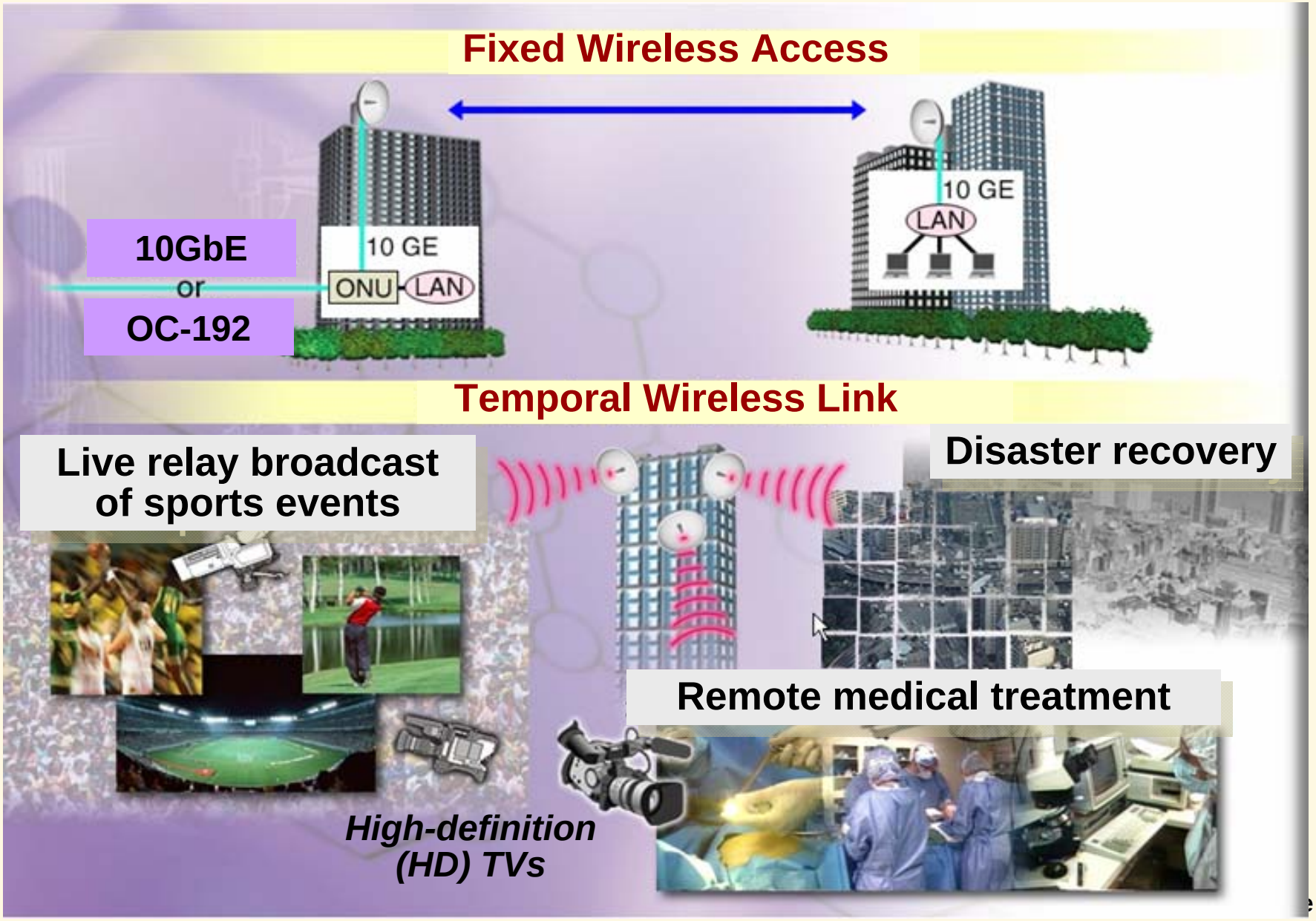
Trends in Wired Communications



Trends in Wireless Communications

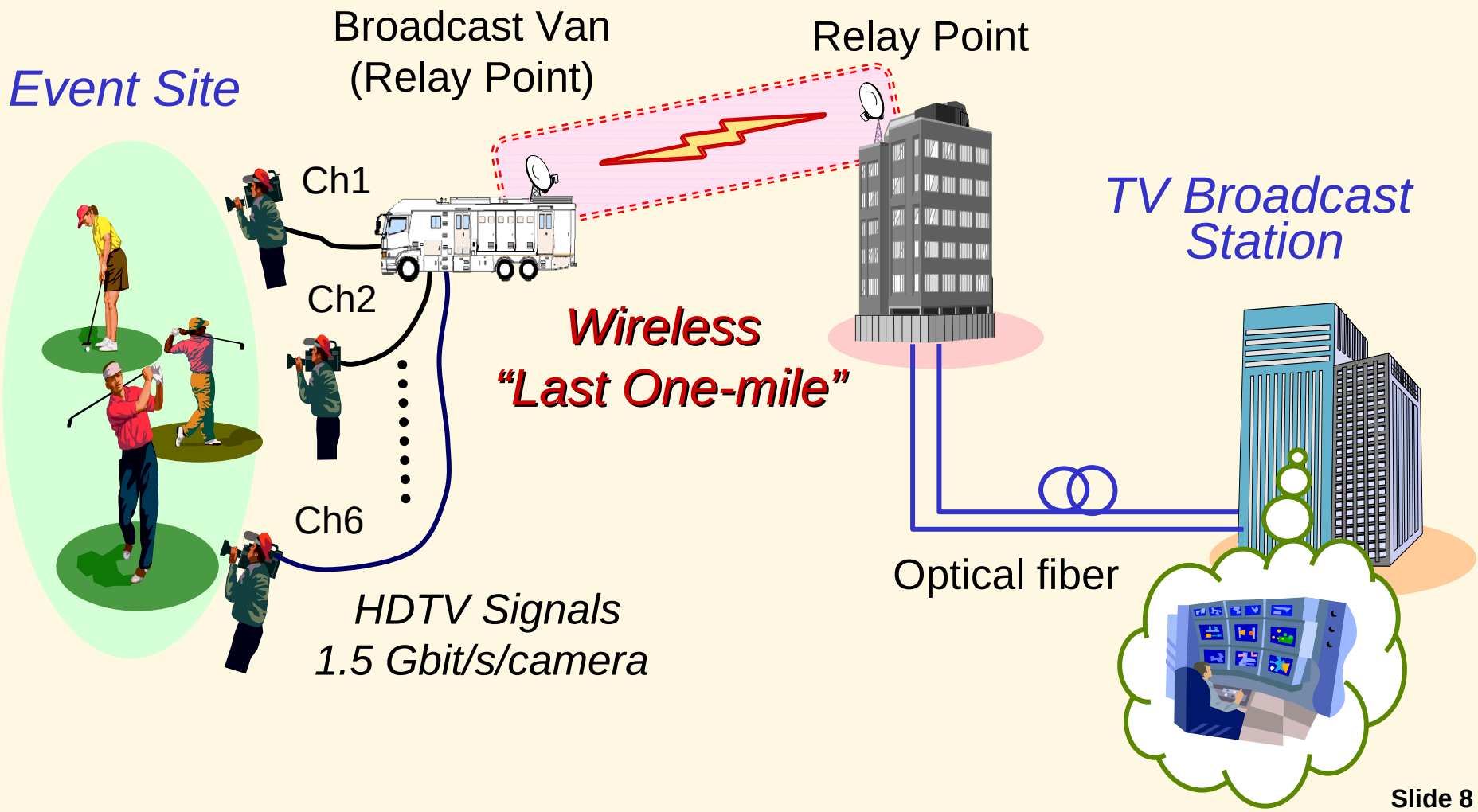


Current Applications of 10-G Wireless



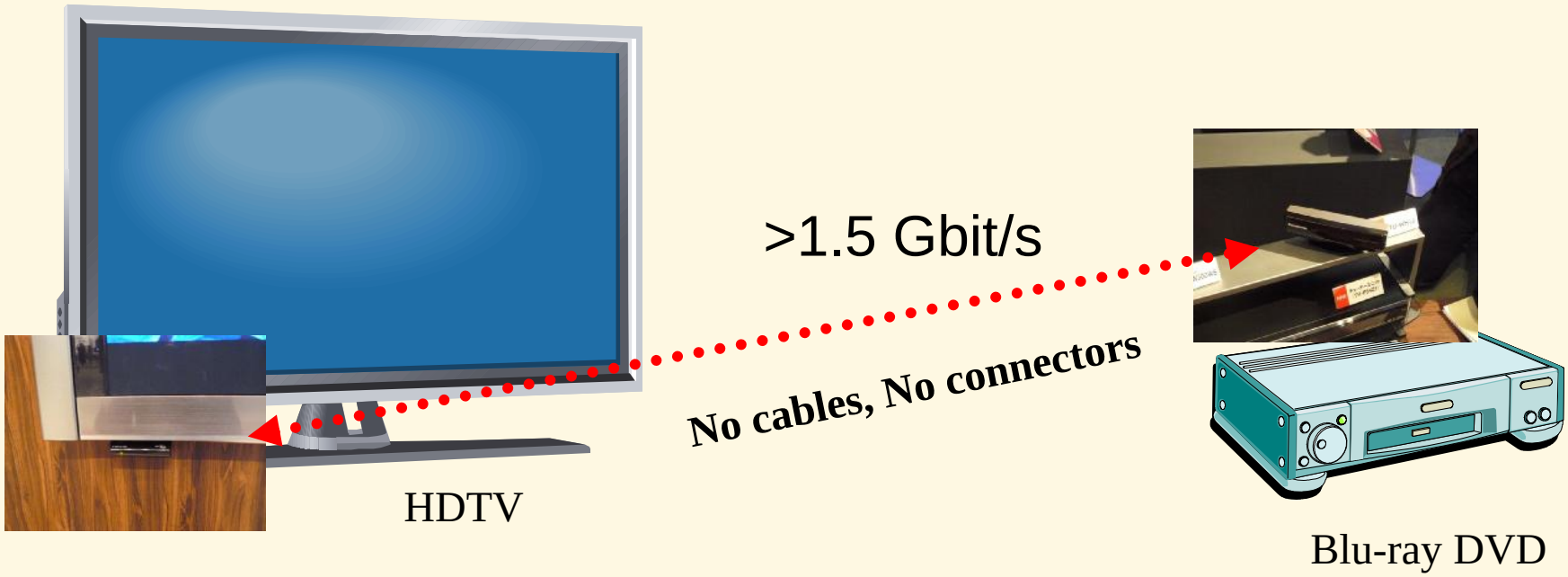
Urgent Needs in Broadcast

Multi-Channel Transmission of Uncompressed HDTV Data



Gigabit Wireless in Home Networks

Transmission of uncompressed HD (High Definition) data



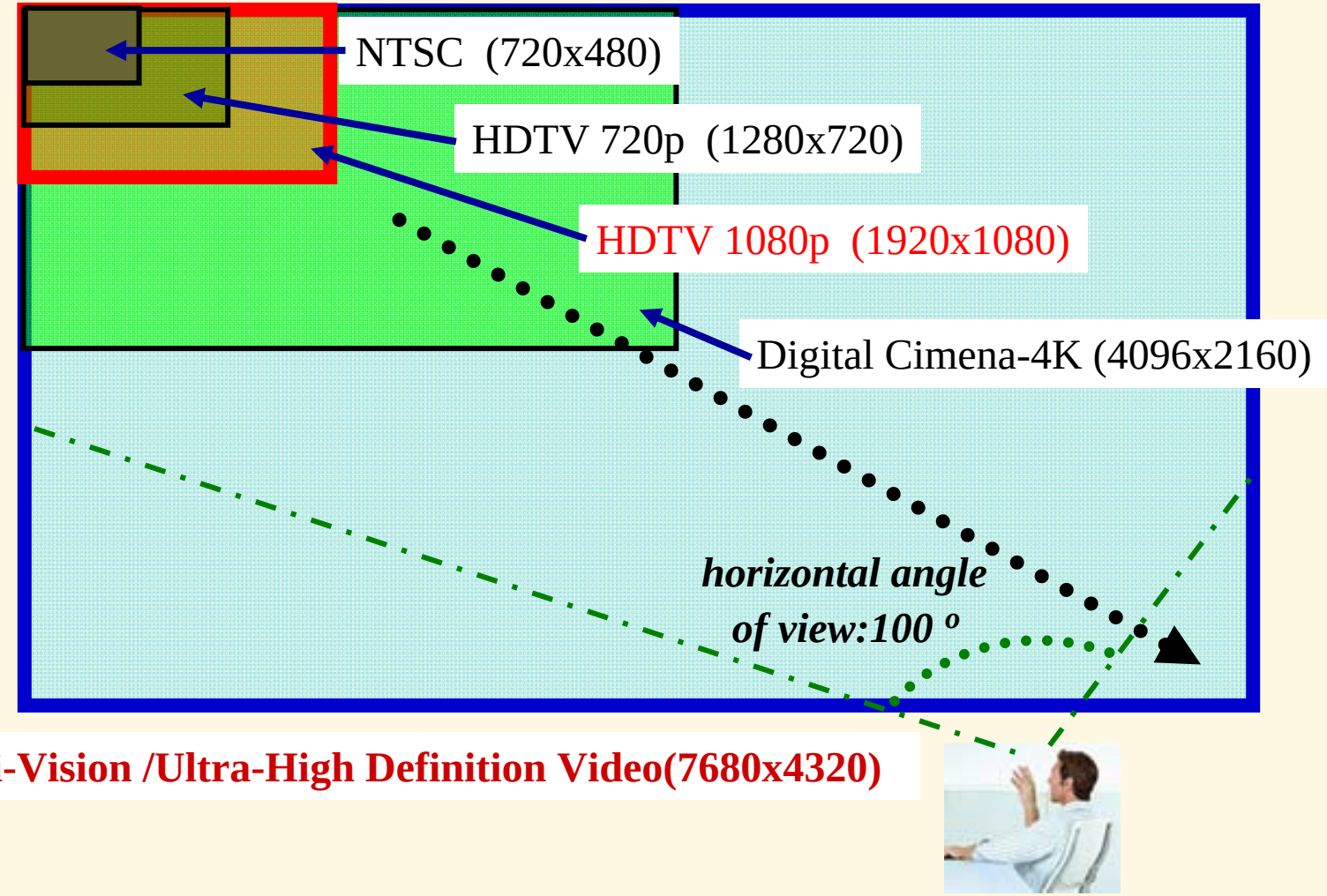
- Wireless HD: 3.8 Gbit/s with 60 GHz
  Panasonic “VIERA”, Sony “BRAVIA”
- Wireless HD Interface (WHDI): 1.5 Gbit/s with 5 GHz
  Sharp “AQUOS”
- WiGig Alliance: 6 Gbit/s with 60 GHz

Next Generation HDTV "UHD"

Super Hi-Vision (Ultrahigh Definition) TV by NHK, Japan

7680 x 4320 resolution

Uncompressed video signal: ~24 Gbit/s

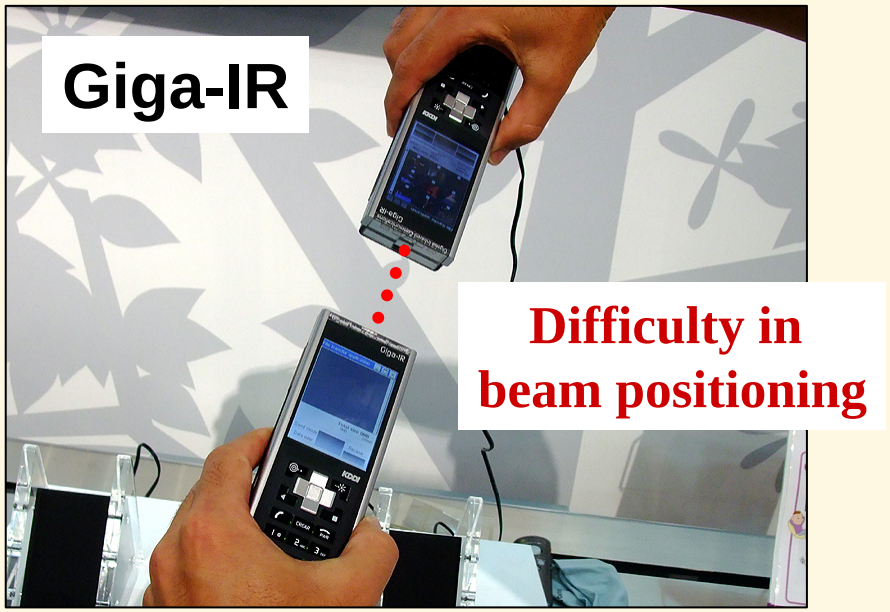


Super Hi-Vision /Ultra-High Definition Video(7680x4320)

Close Proximity Wireless Transfer

Link Distance:10 mm to 100 mm

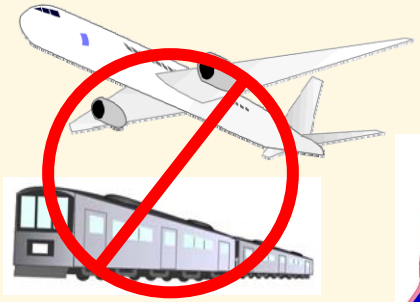
4.48GHz: 560 Mbit/s
Under-70dBm/MHz (average)
Corresponds to low-intensity
radio wave regulation

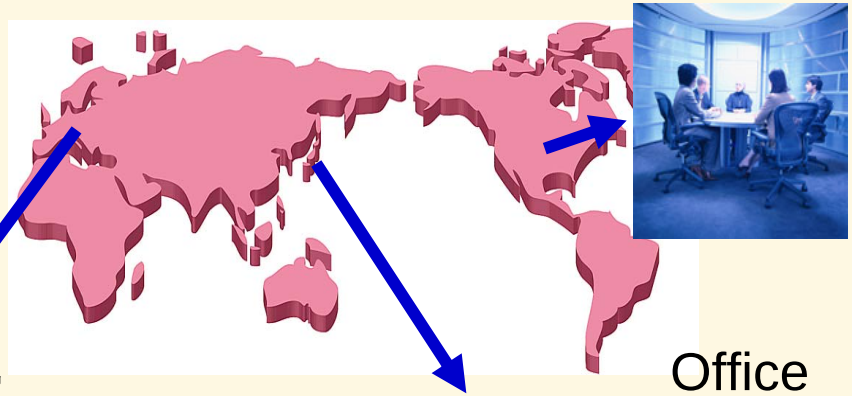


Infrared light data communication
with laser diode：1 Gbit/s

Future Applications (1)

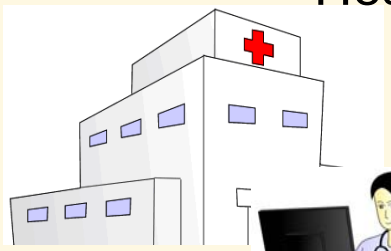
Elimination of bottlenecks in the speed of wired and wireless communications in the core/access networks





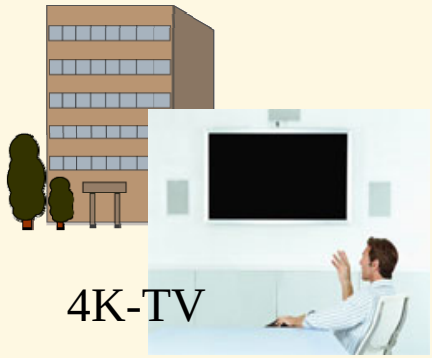
Office

Hospital

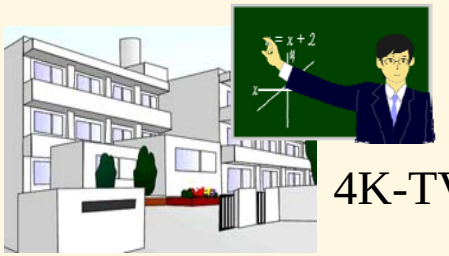


4K-TV

UHD-TV



4K-TV



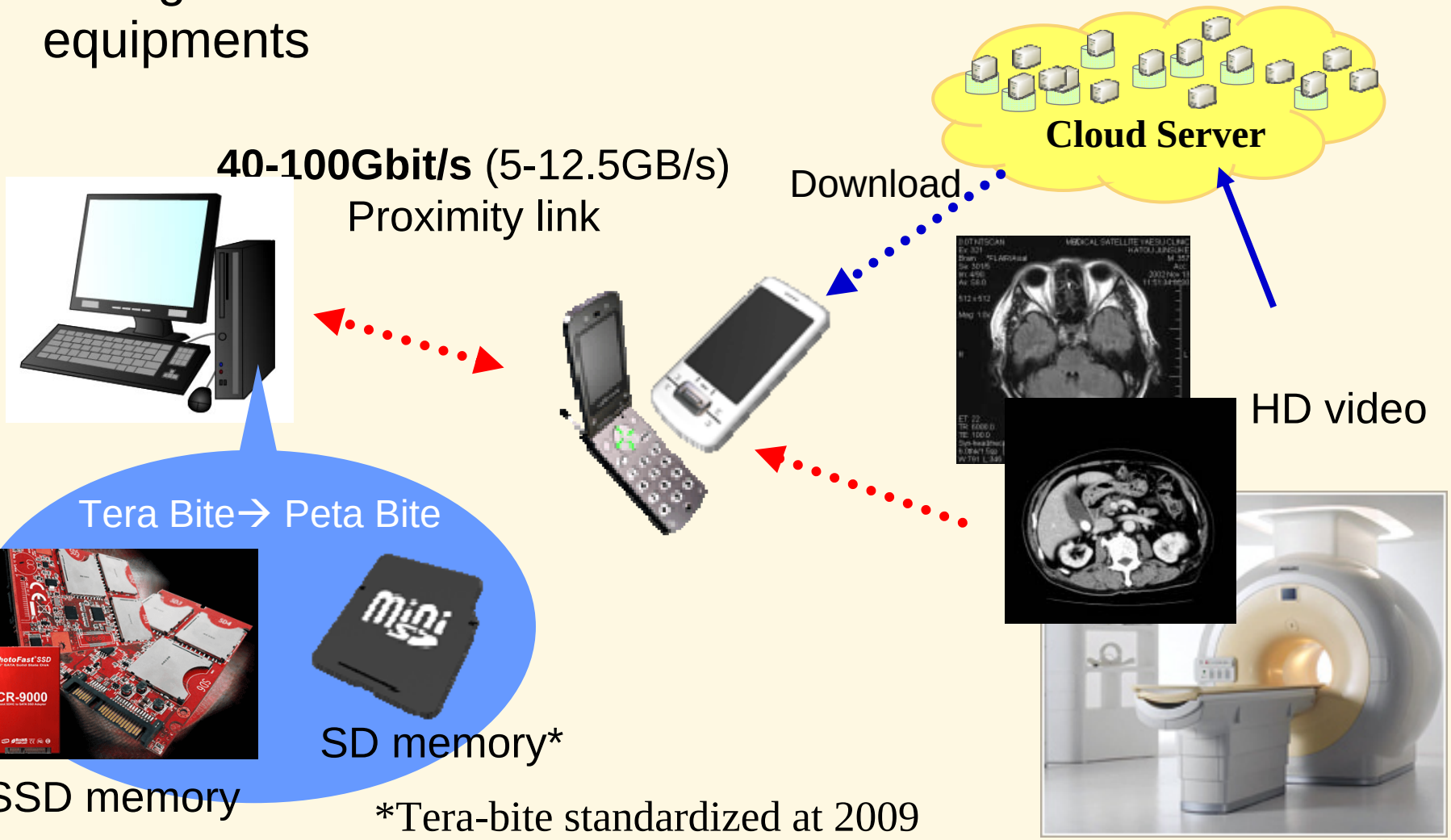
4K-TV

School

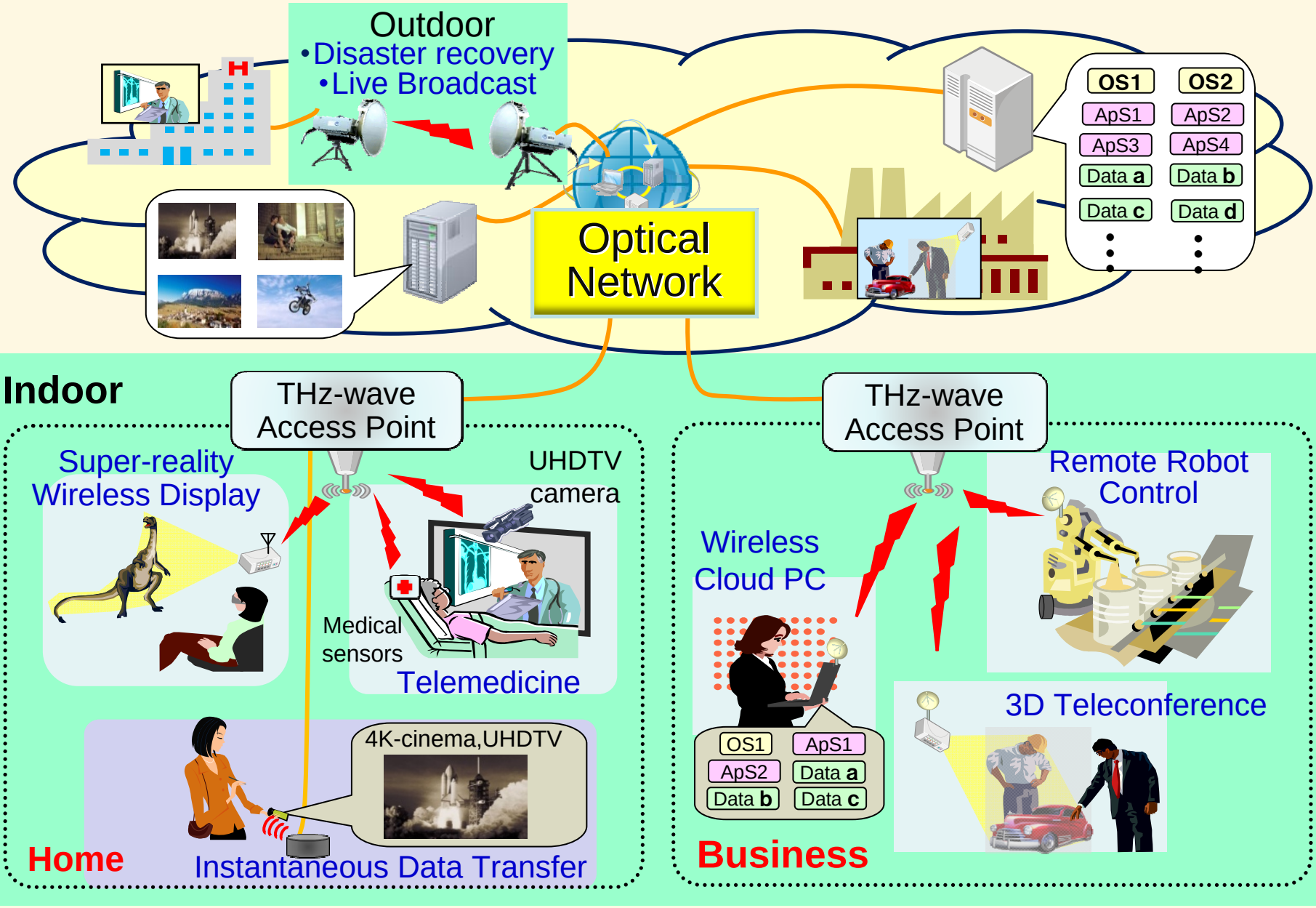
Highly-realistic sensation teleconference, telemedicine, remote-education

Future Applications (2)

Increasing needs in instantaneous transfer of high-volume storage data in consumer devices as well as in medical equipments



Application Scene (THz ICT Study Group, Japan)

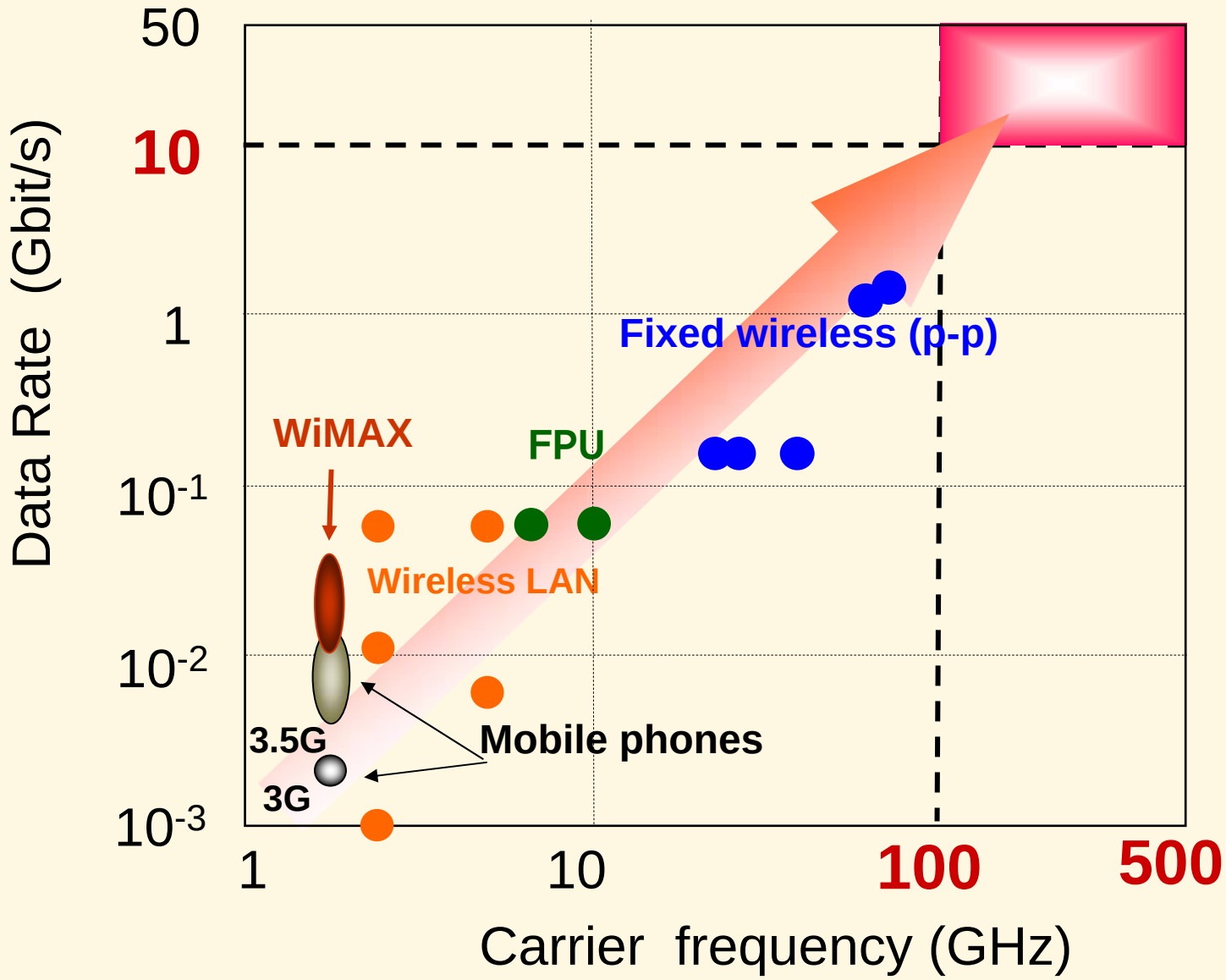


Towards 100 Gbit/s Wireless

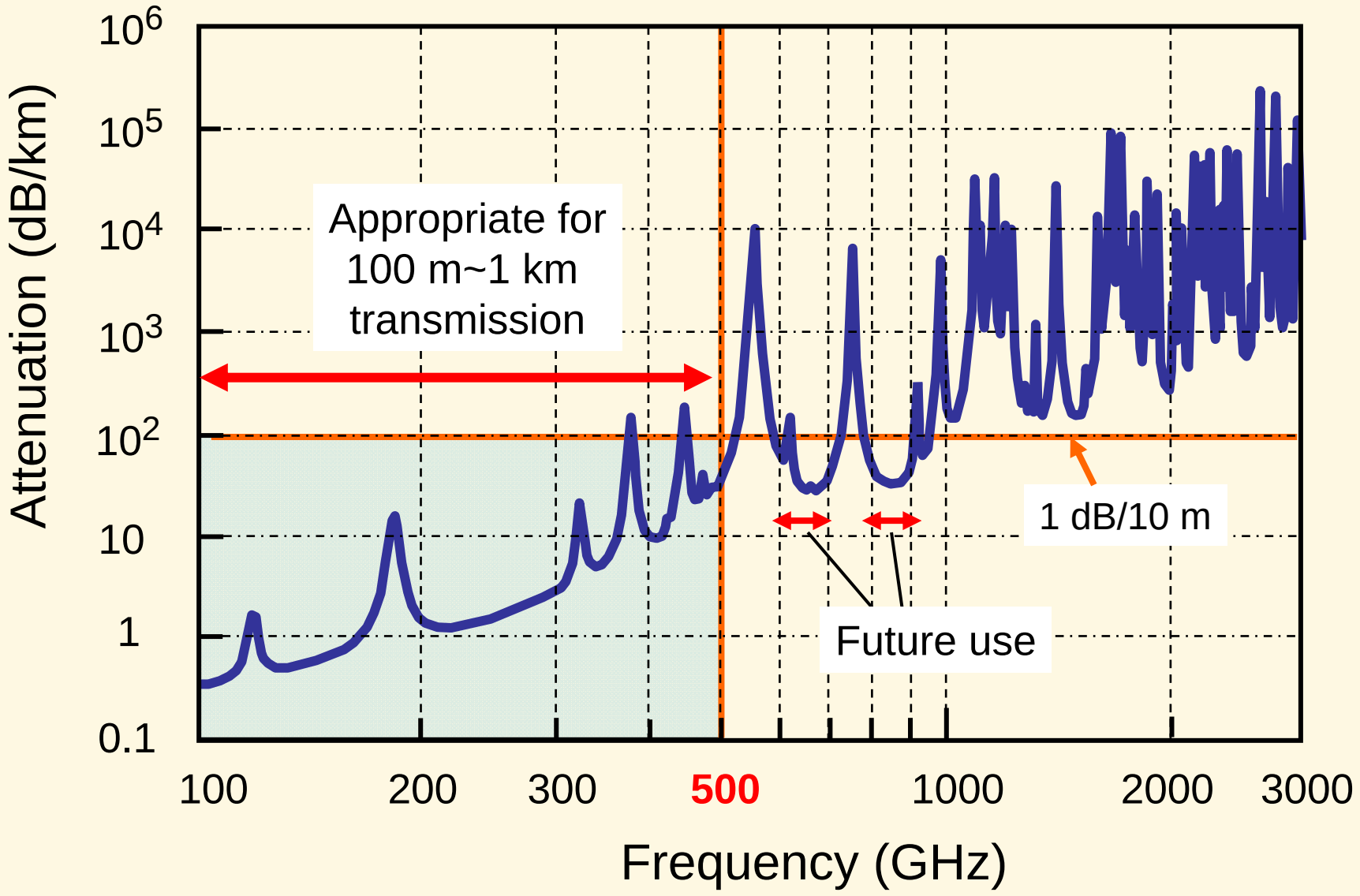
- ✓Multi-value modulation at 60 GHz
- ✓Free-space optics (Infrared light)
  with WDM
- ✓Use of “terahertz” carrier frequency
  with simple modulation format (ASK)

Not yet allocated for specific use at >275 GHz !!!

Wireless Data Rate vs. Carrier Frequency

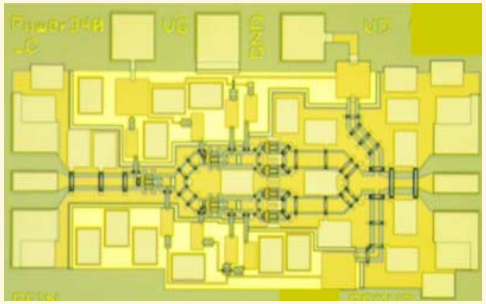


Atmospheric Attenuation

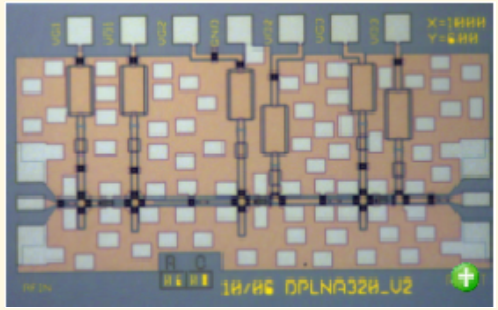


Progress in Transistors and ICs

Transistor Technology	f_t (GHz)	f_{max} (GHz)
15nm InAlAs/InGaAs MHEMT	610	305
45nm SOI CMOS	485(NFET) 345(PFET)	-
GaAsSb/InP DHBT	670(480)	350(420)
50nm InP HEMT#	385	>1000
35nm InP HEMT##	480	1200

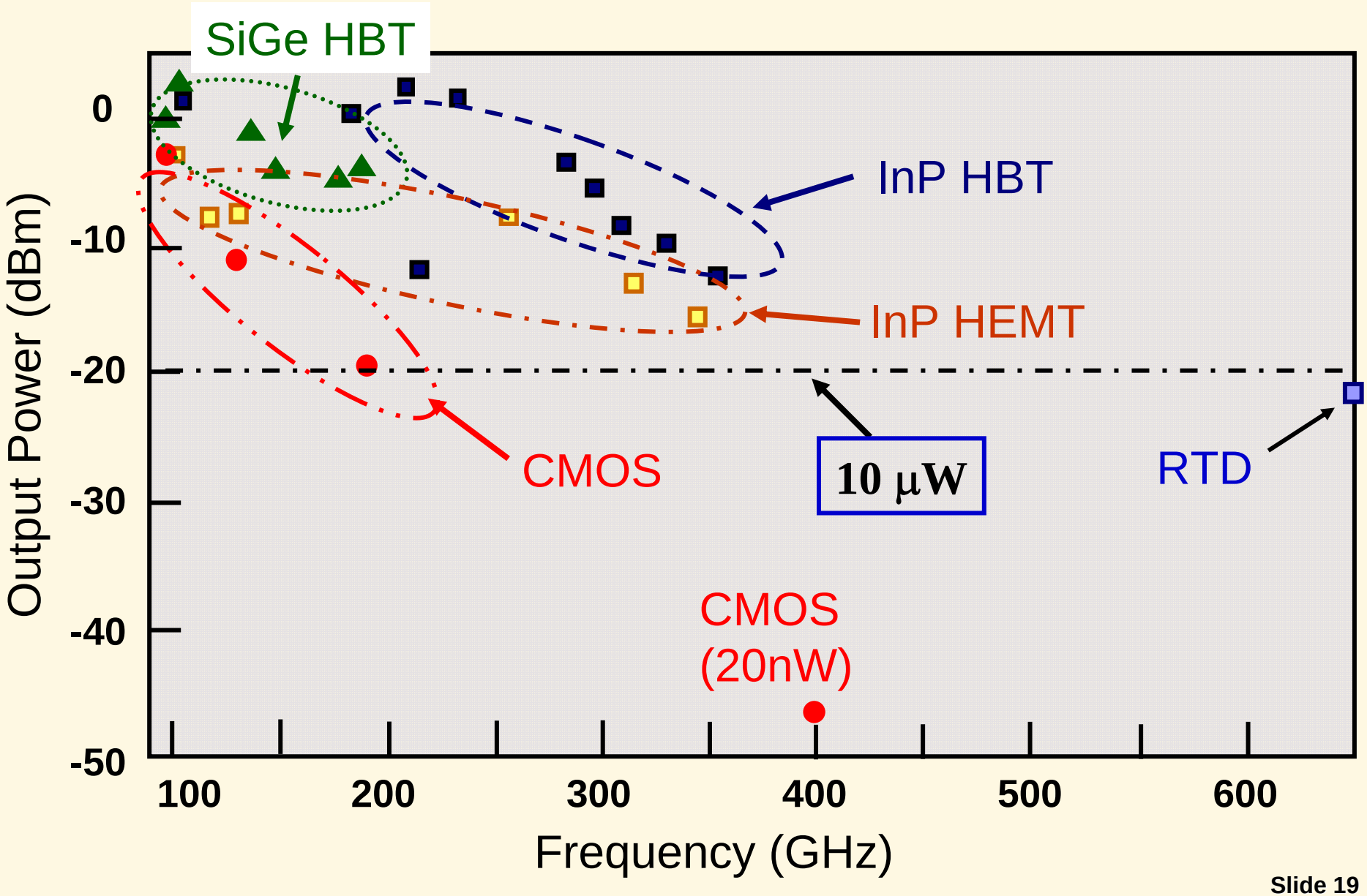


Amplifier:12 dB Gain @335 GHz



Amplifier:13-15 dB Gain @300-345 GHz

Progress in Electronic Oscillators



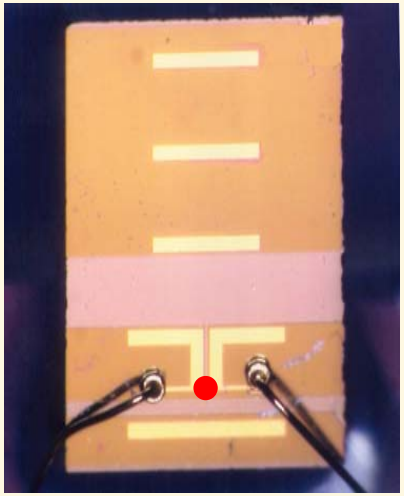
Small Antennas

For TV

For GPS

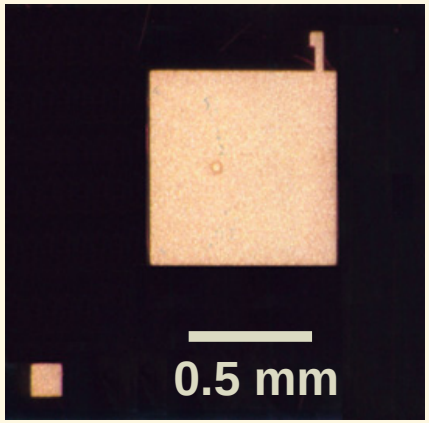
300GHz
Horn Antenna

120GHz
Yagi-Uda Antenna



0.5 mm

120GHz
Patch Antenna



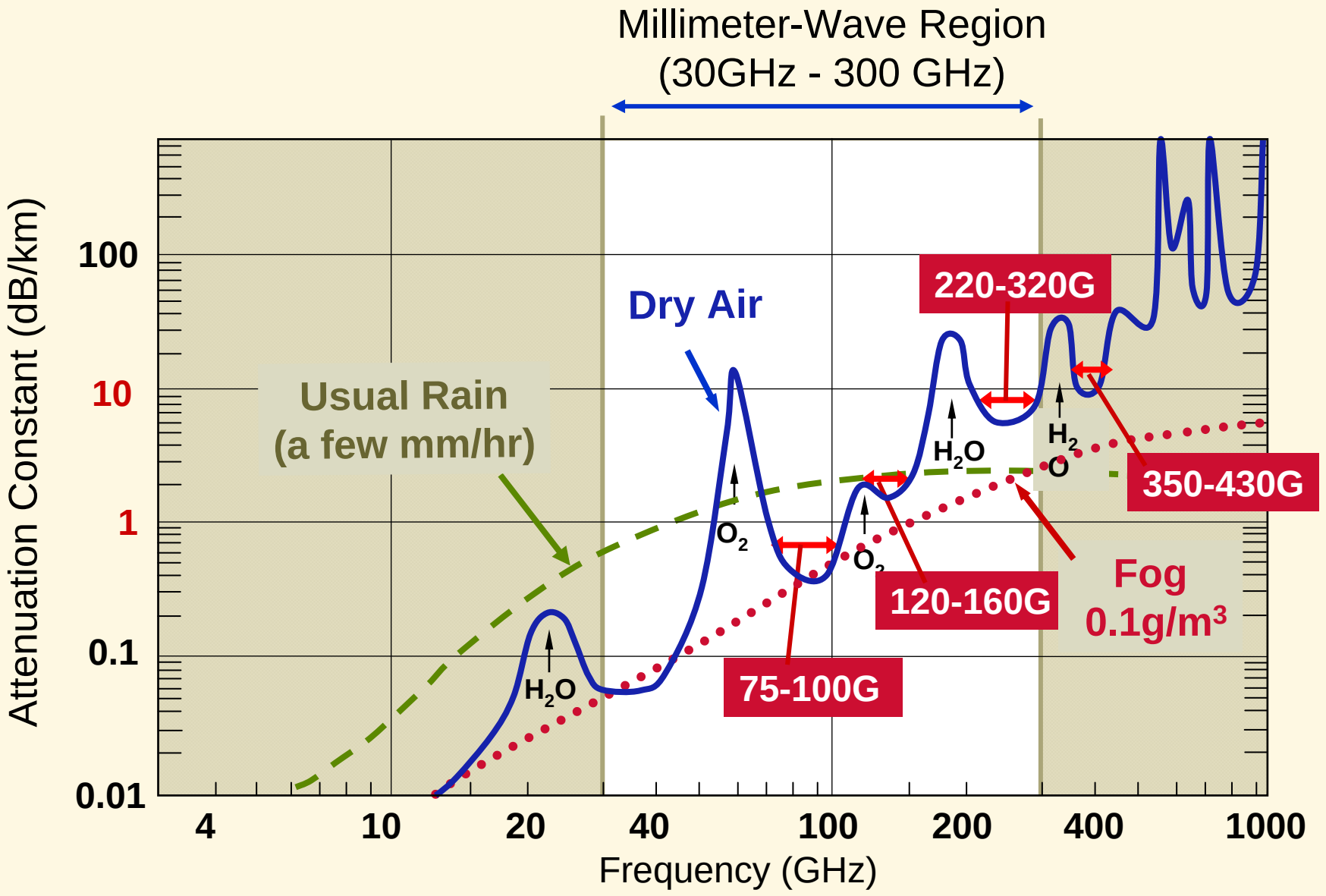
300-500 GHz

+ MEMS &
Metamaterials

Like “IrDA” Module!

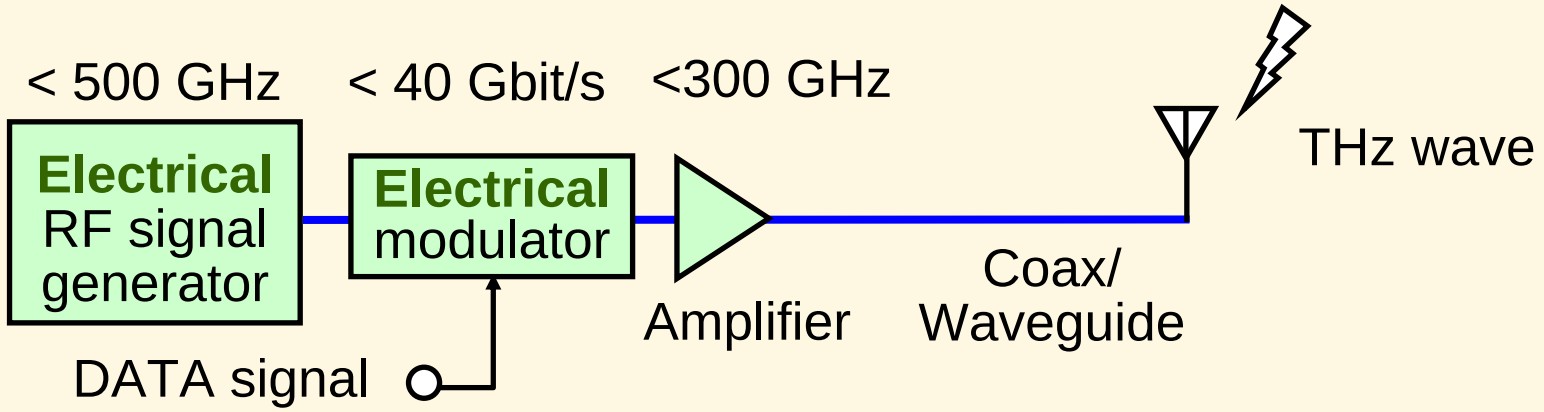
- Background & Needs
- **10-G wireless with 120-GHz Bands**
- Exploring 300-400 GHz Band
- Summary

Choice of Radio-Waves: 120-GHz Band

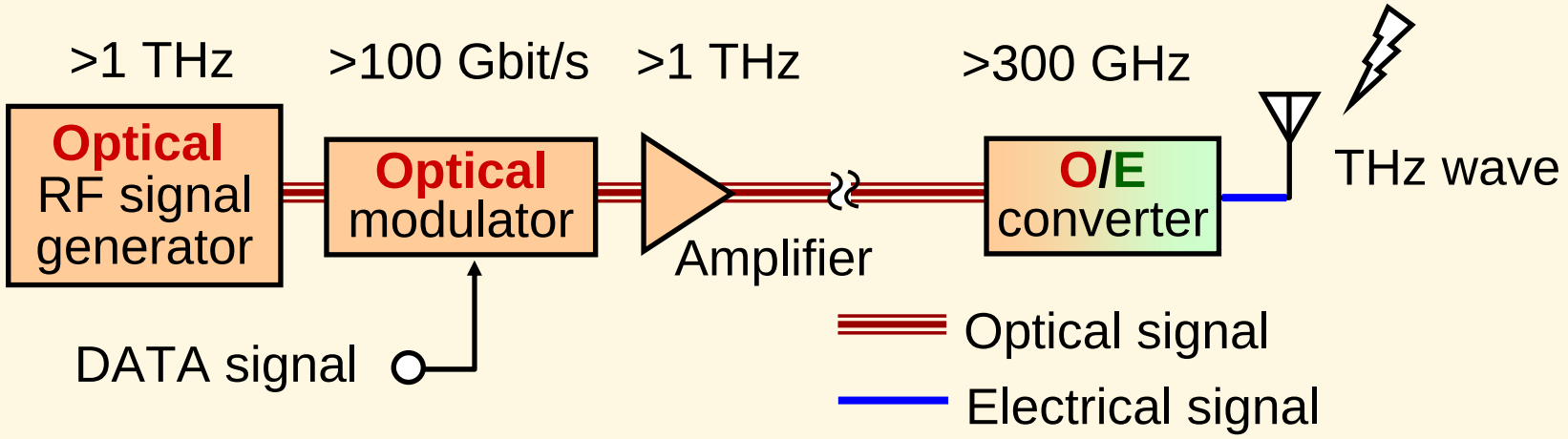


Approaches: Electronics vs. Photonics

◆ *"Electronics" based Tx*



◆ *"Photonics (O/E)" based Tx*

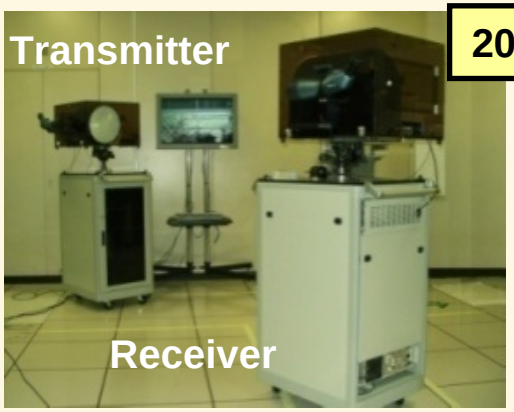


Hardware Evolution in 10 years

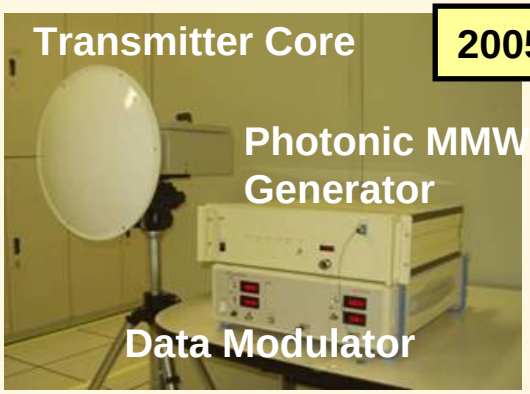
Photonics-based Transmitter

2000-2002

2004/7



2005/8



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

Electronics-based Transmitter

2007/1

Battery operation

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

Volume: 1/6
Weight: 1/2

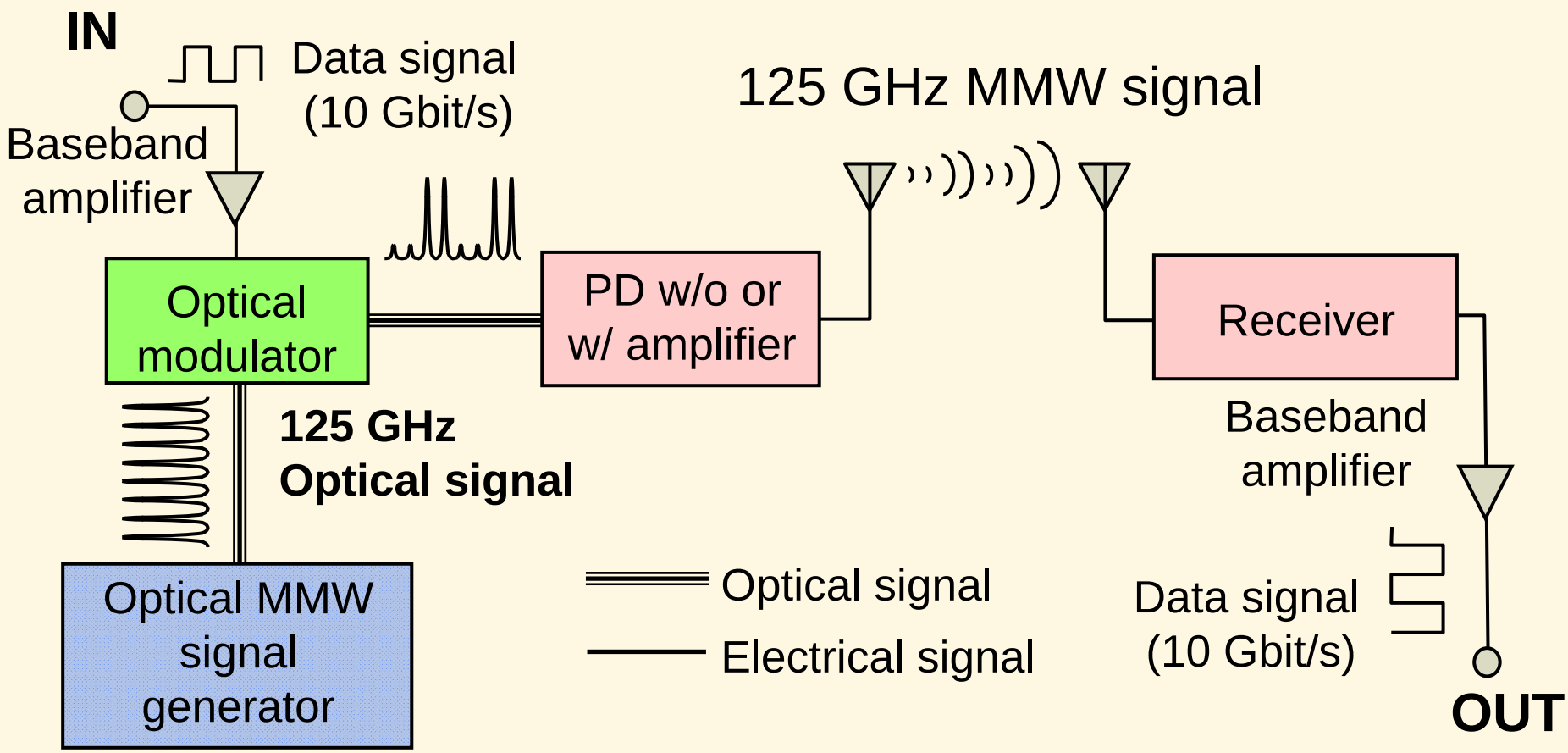
2008/5

Mobility, Portability

Easy set-up system

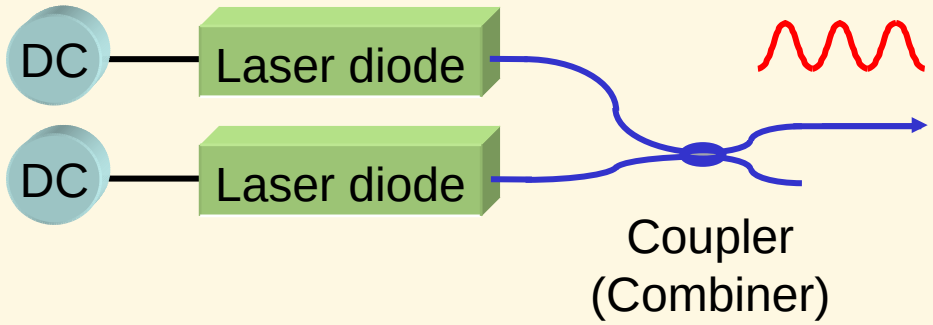
(NTT Technical Review, vol. 7, no. 3, Mar. 2009)

120-GHz-band System with Photonic Tx

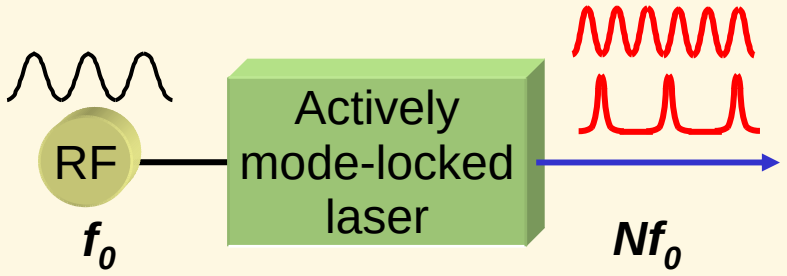


A. Hirata et al., IEEE Trans. Microwave Theory Tech., Vol. 54, pp. 1937-1944, 2006.

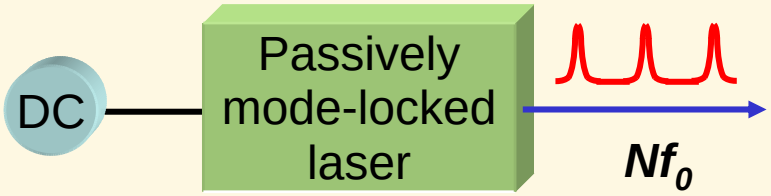
Optical MMW/THz Carrier Generators (1)



Heterodyning two lasers
~10 THz

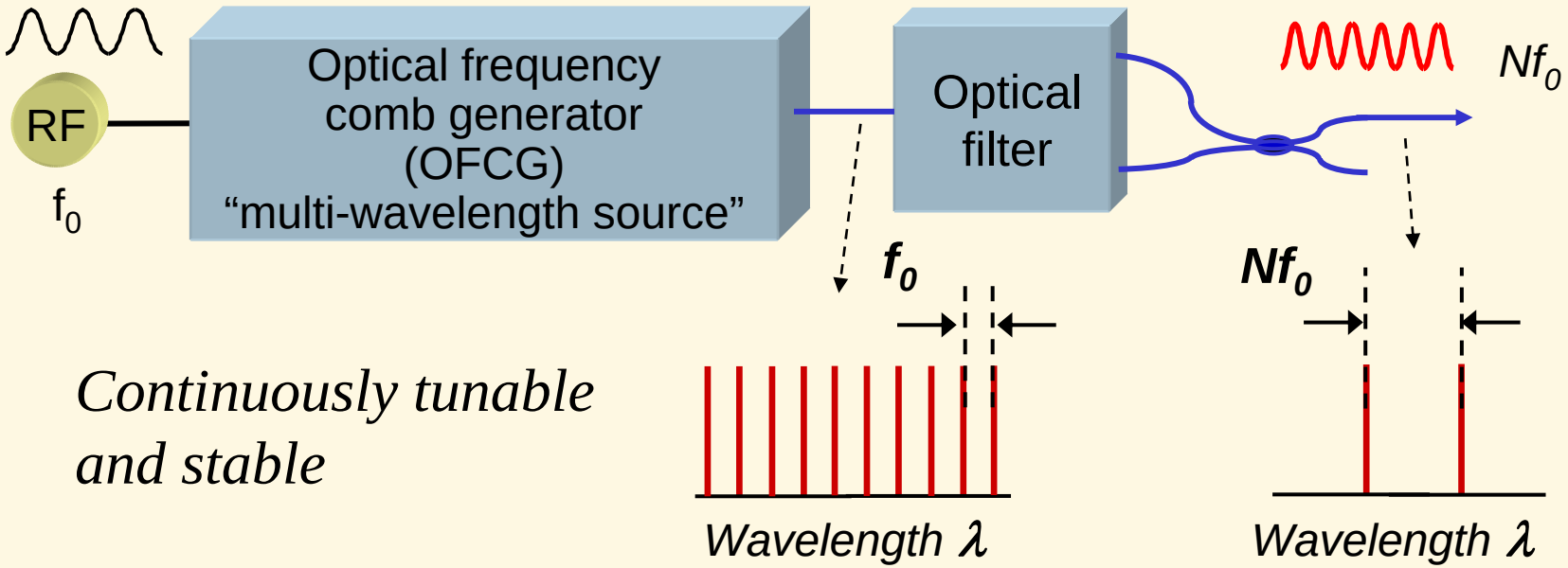


Actively mode-locked laser
~300 GHz



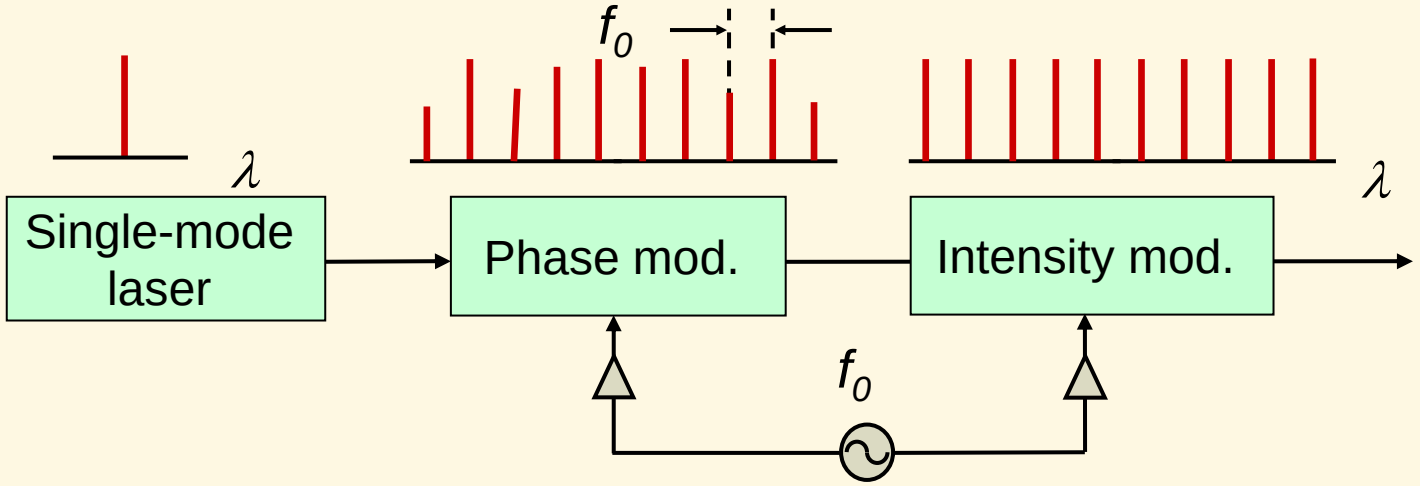
Passively mode-locked laser
~1 THz

Optical MMW/THz Carrier Generators (2)



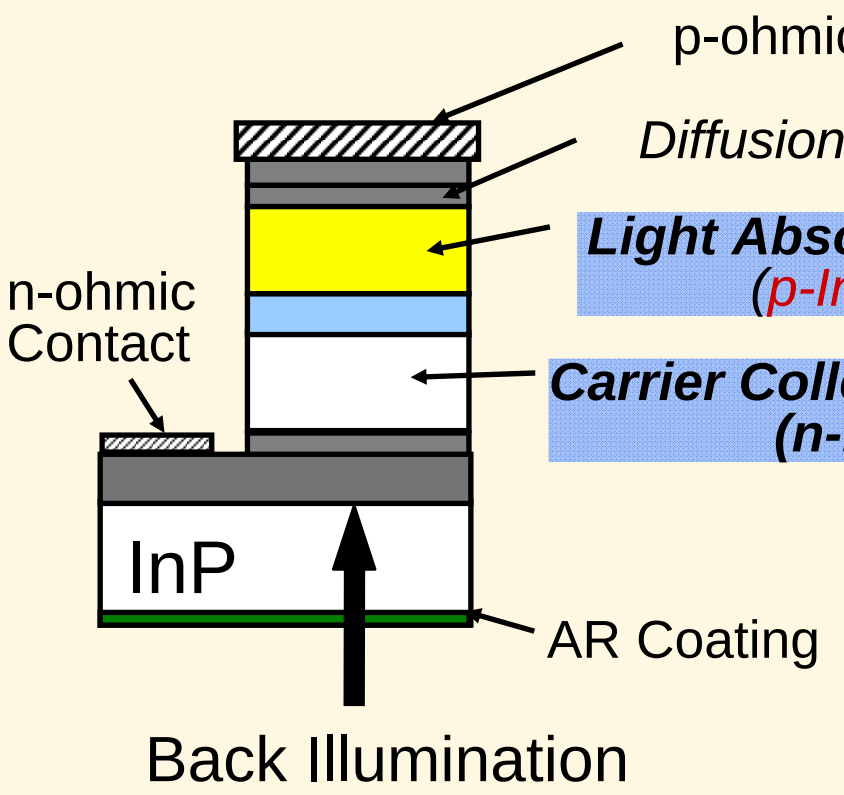
Continuously tunable and stable

Example of OFCG

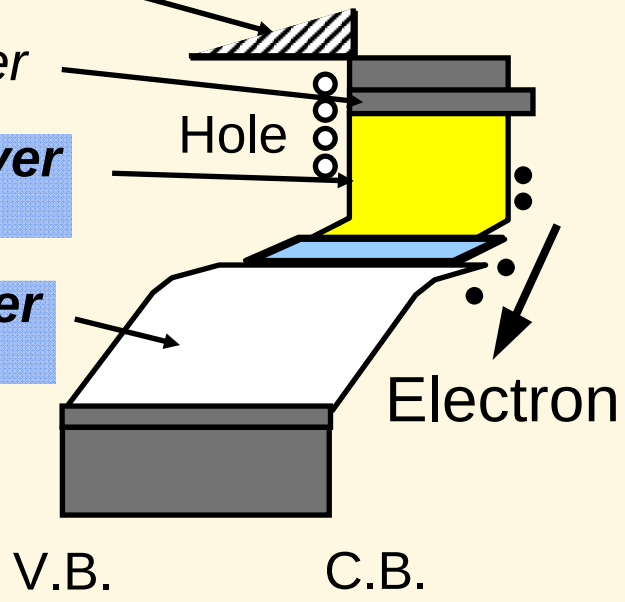


High-Power O-E Converter “UTC-PD”

Layer Structure

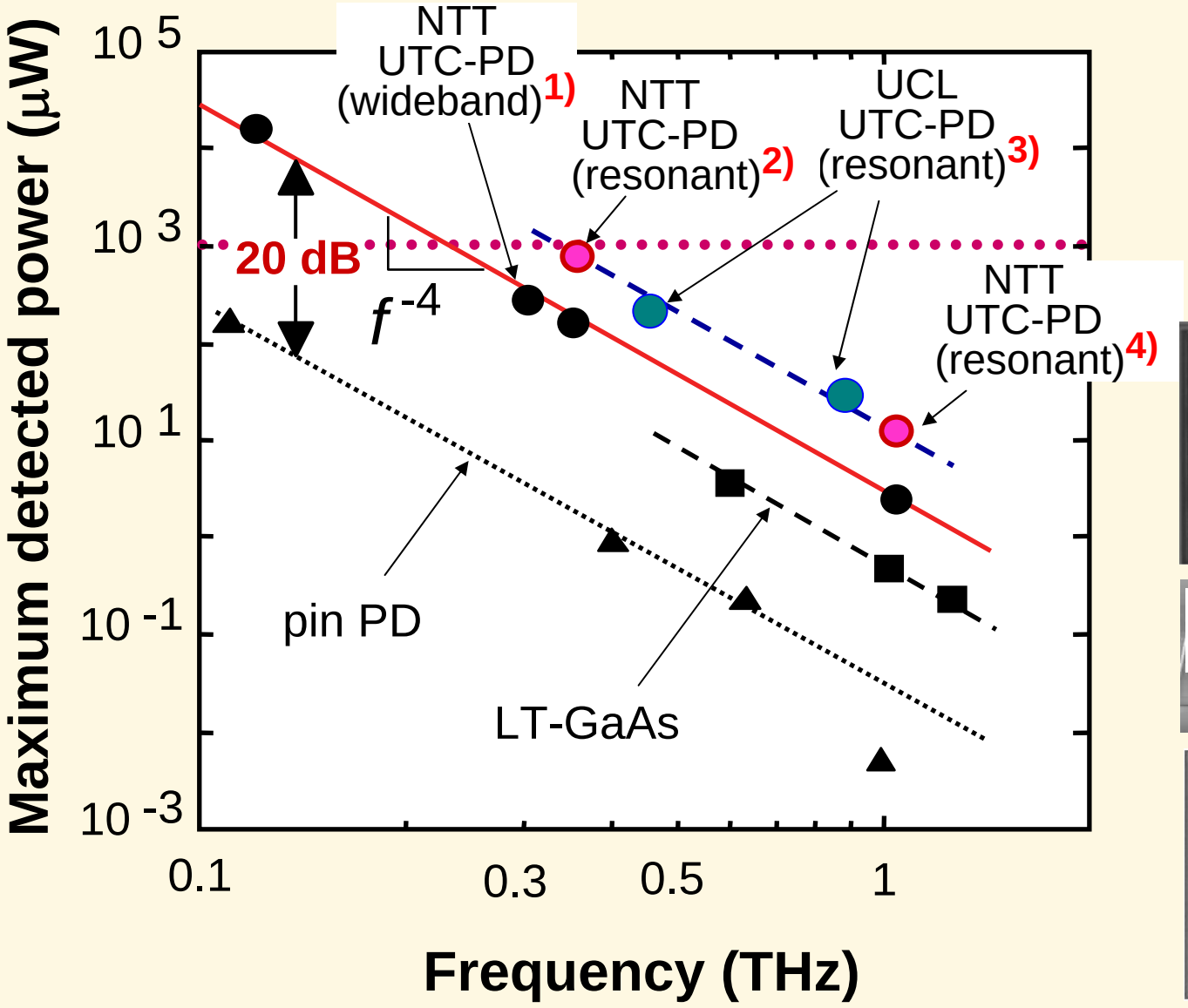


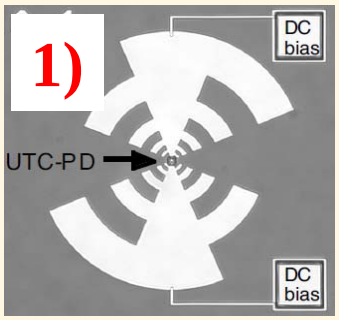
Band Diagram

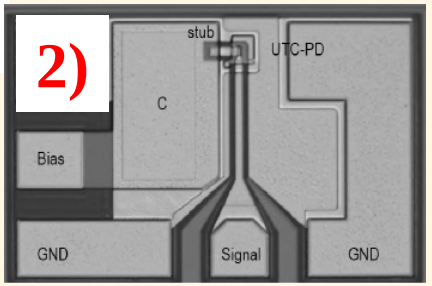


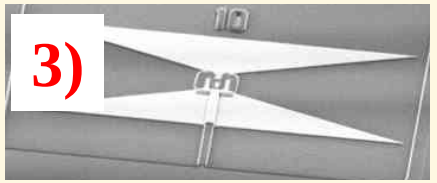
UTC-PD: Uni-Traveling-Carrier-Photodiode

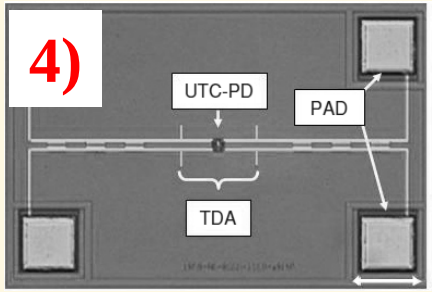
Output Power from UTC-PDs











120-GHz Emitter

Microwave Photonics 2000

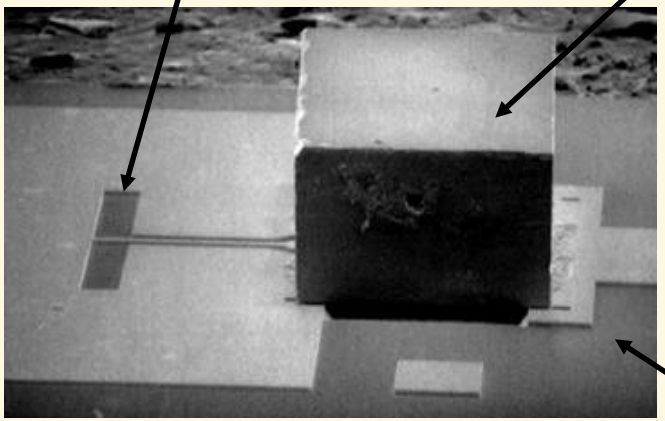
Optical Fiber

Optical Signal

Slot Antenna
(774 x 95 mm^2)

PD Chip

Antenna



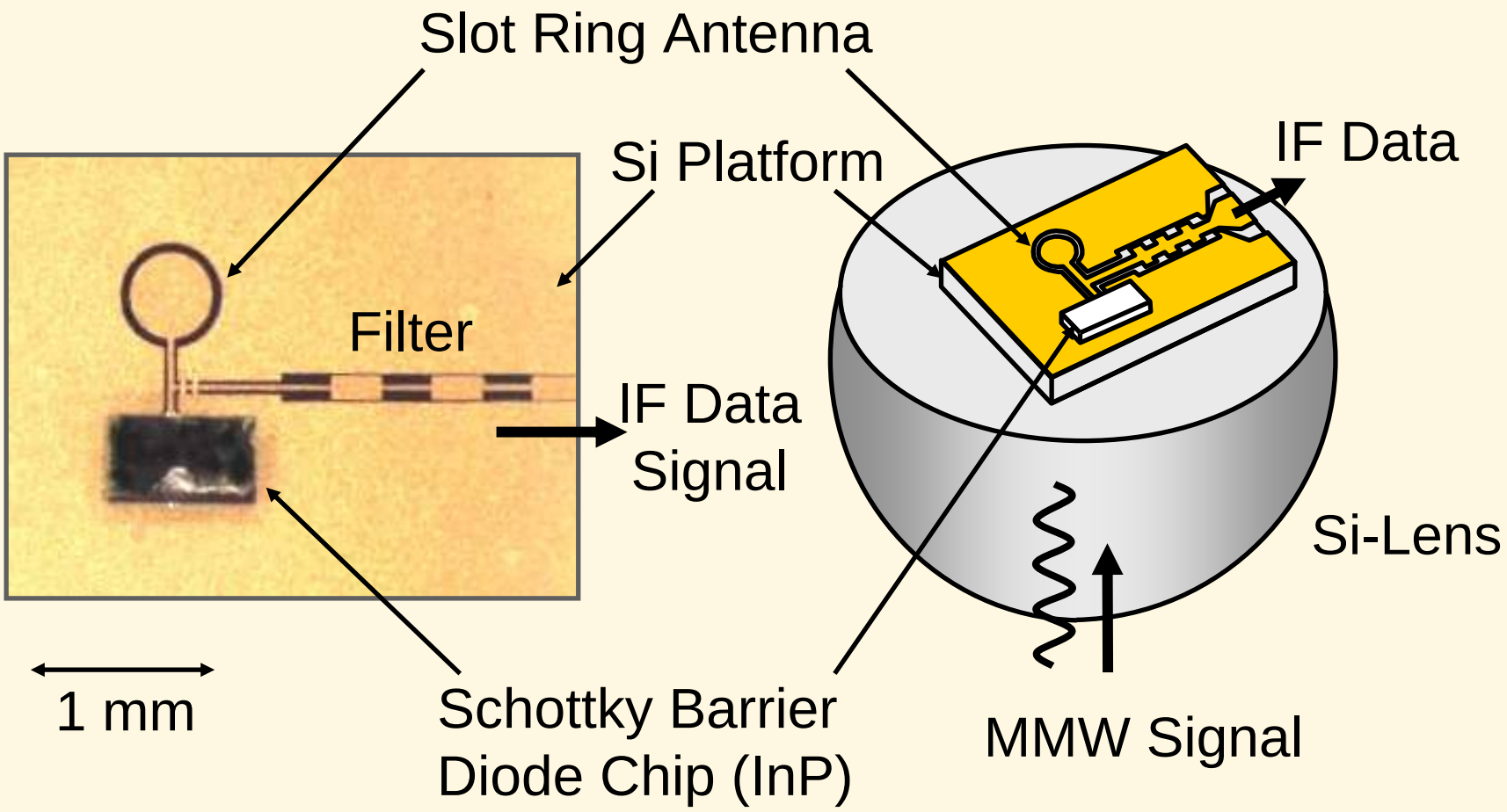
1 mm

Si Platform

Si-Lens

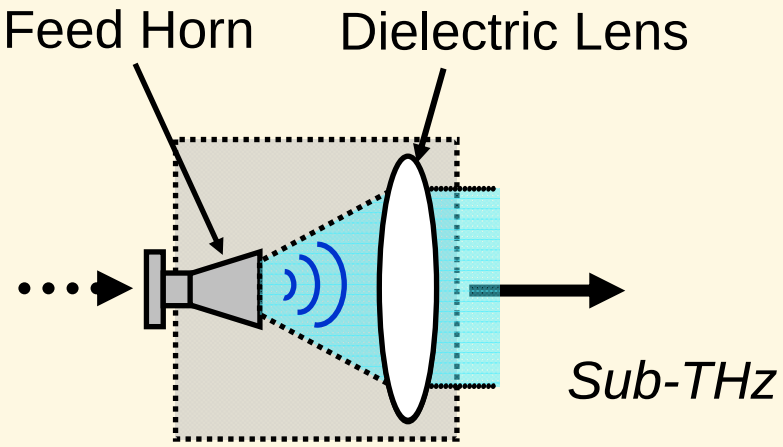
MMW Signal

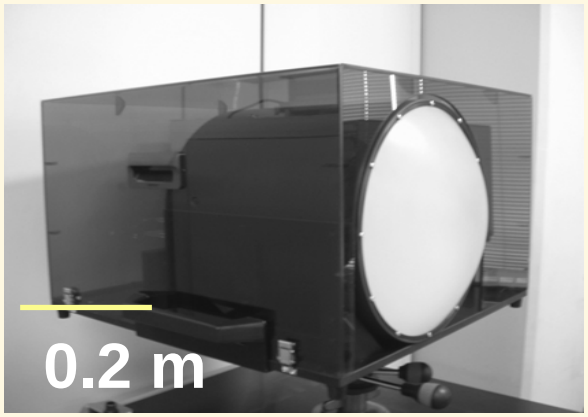
120-GHz Receiver for 10-Gbit/s



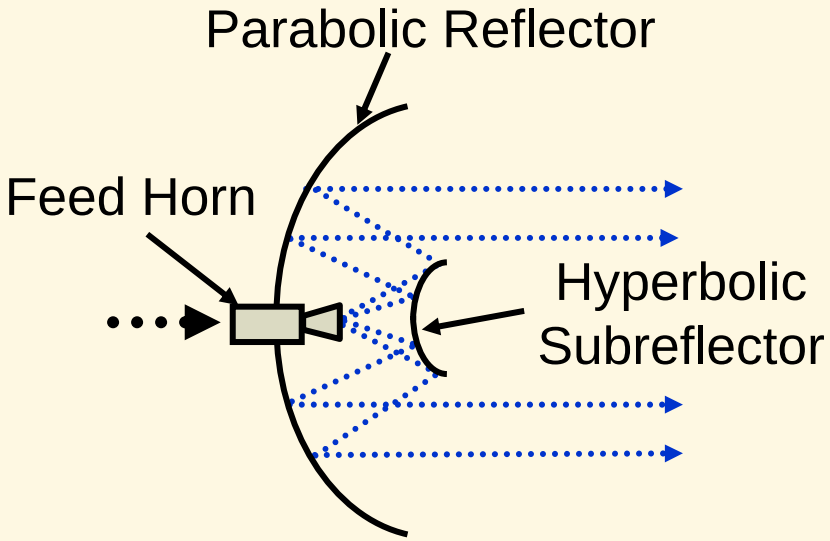
Antennas for Long Distance Link

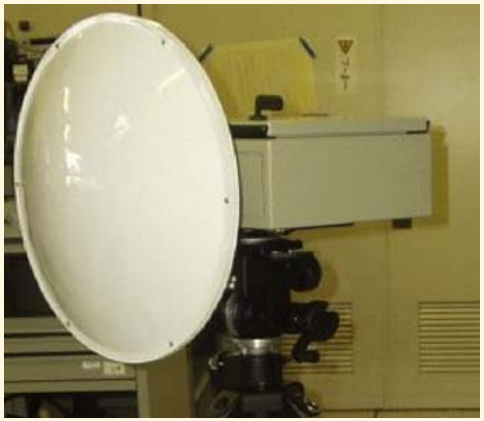
Lens Antenna





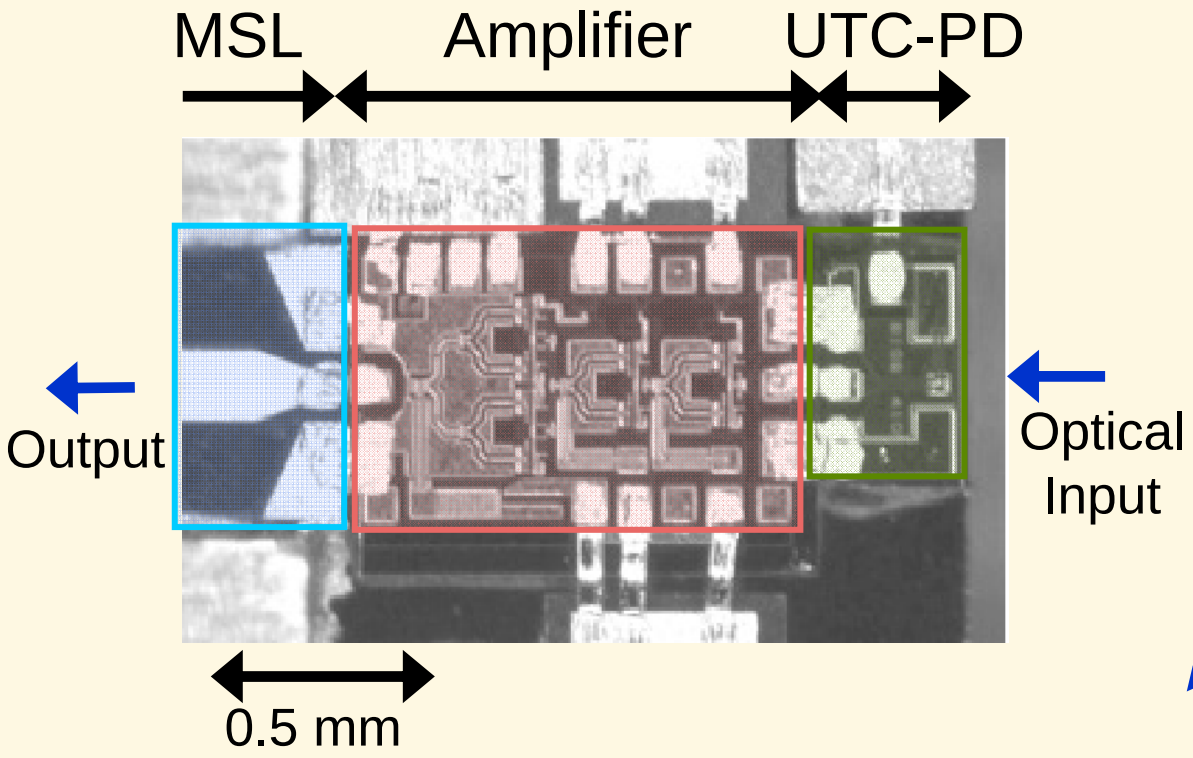
Cassegrain Antenna

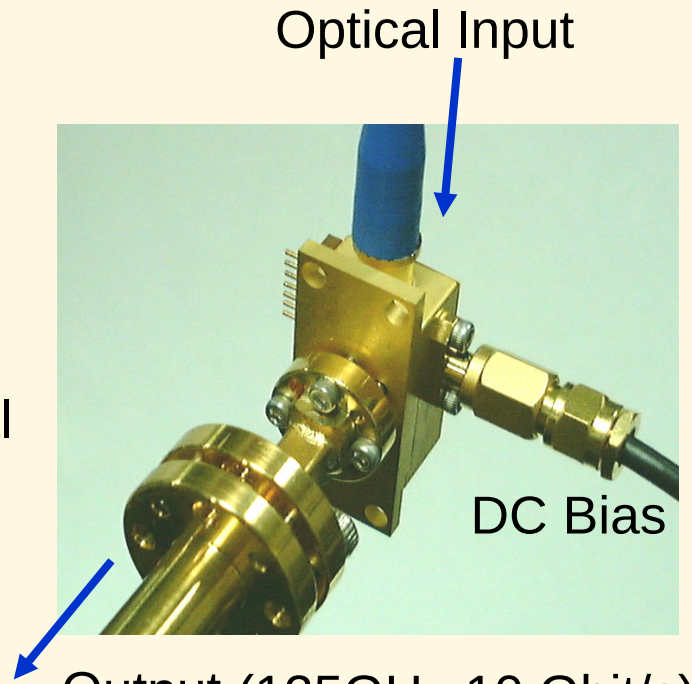




120-GHz Emitter for Long Link

Hybrid integration with butt-joint structure



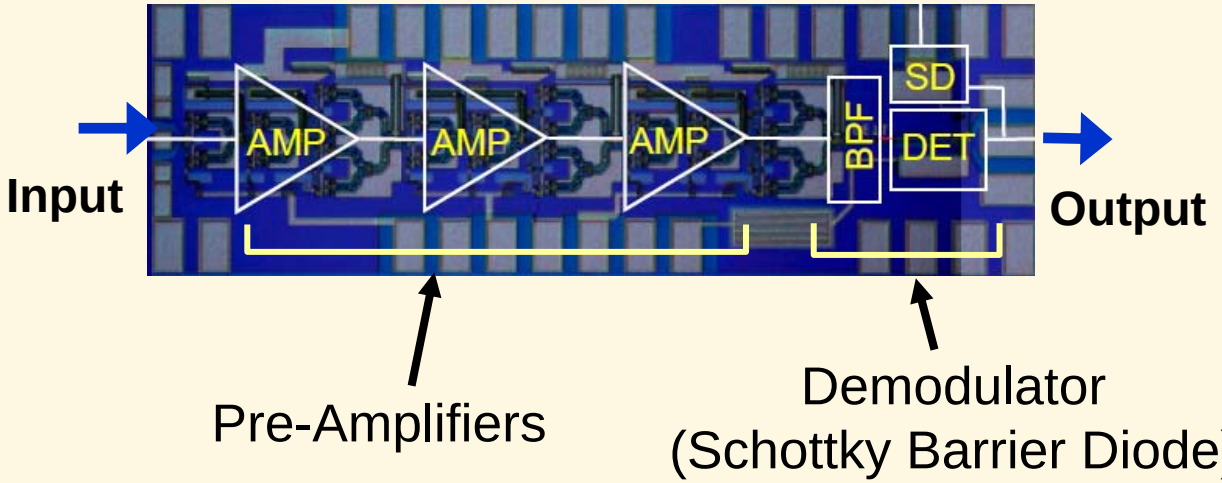


H. Ito et al., Electron. Lett., 41, pp. 360-362, 2005.

120-GHz Receiver for Long Link

Monolithic IC Receiver

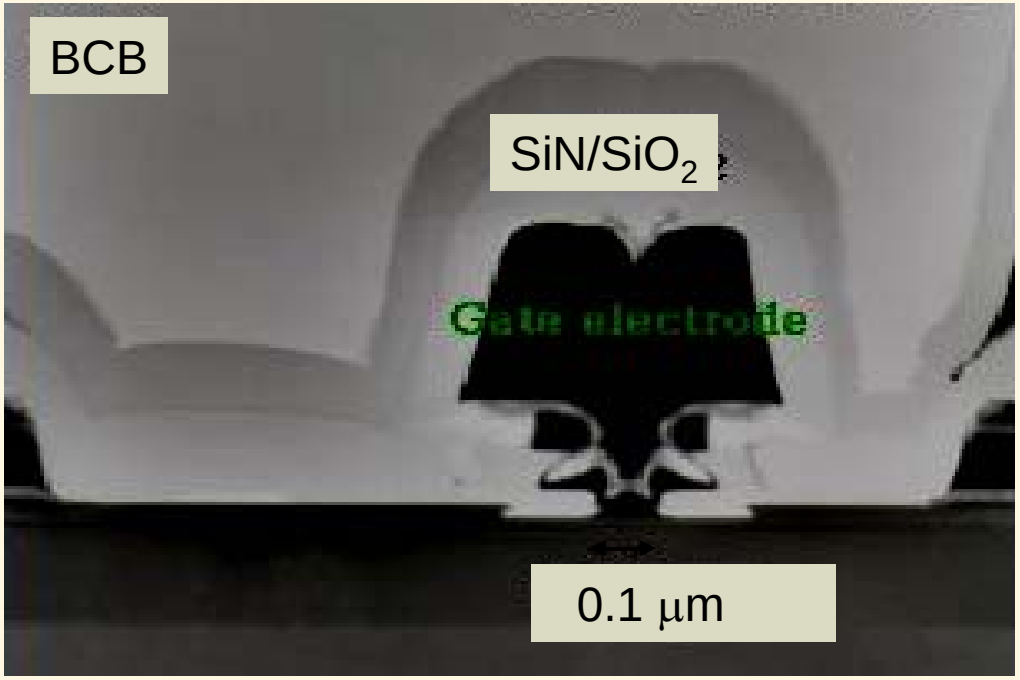
MMIC



Packaged Module

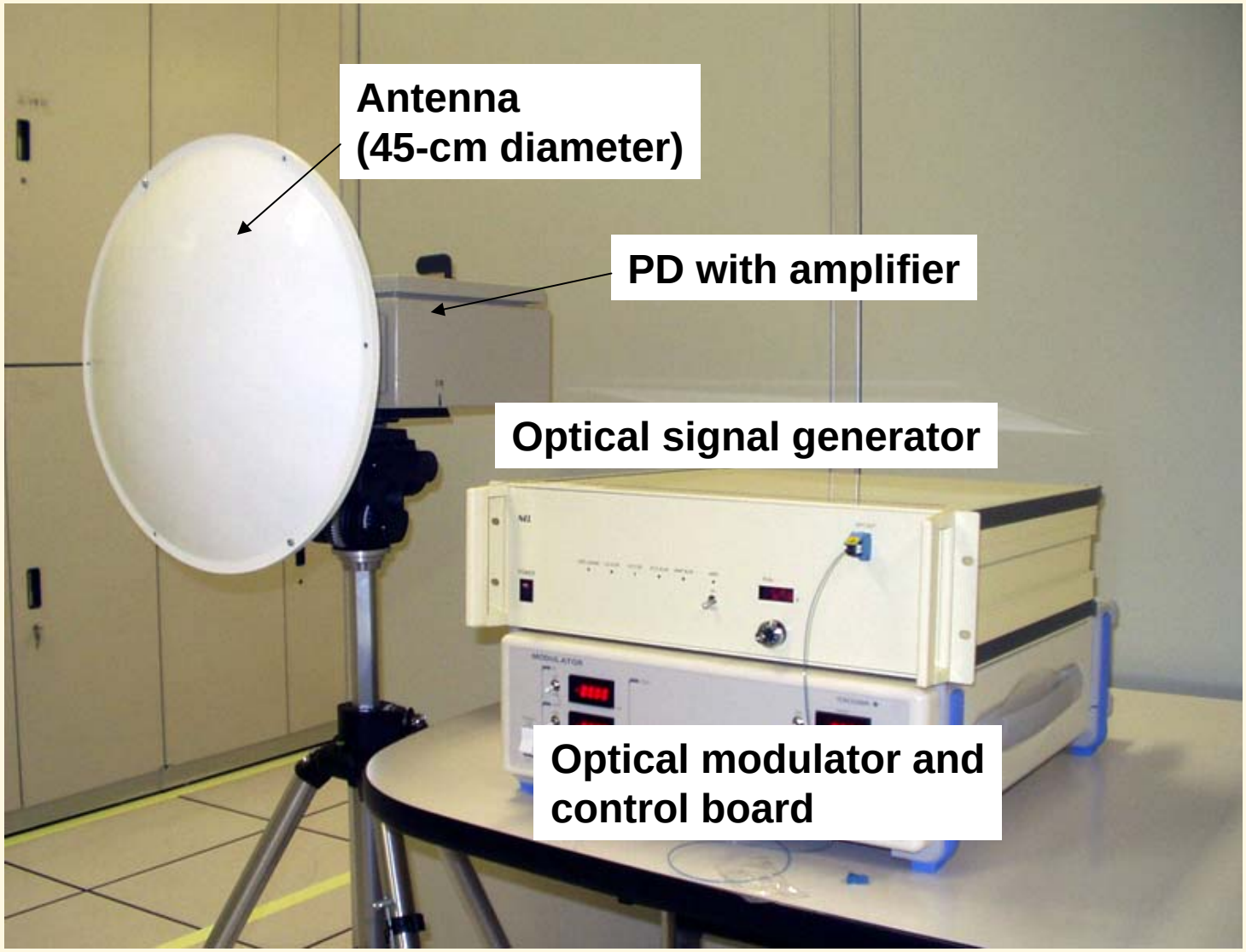
Electronic Devices: InP HEMT

- 0.1-μm-gate InAlAs/InGaAs HEMT
- g_m = 1.2 S/mm, f_t = 170 GHz, f_{max} = 350 GHz
- MIM capacitor, double-layer interconnection process with BCB



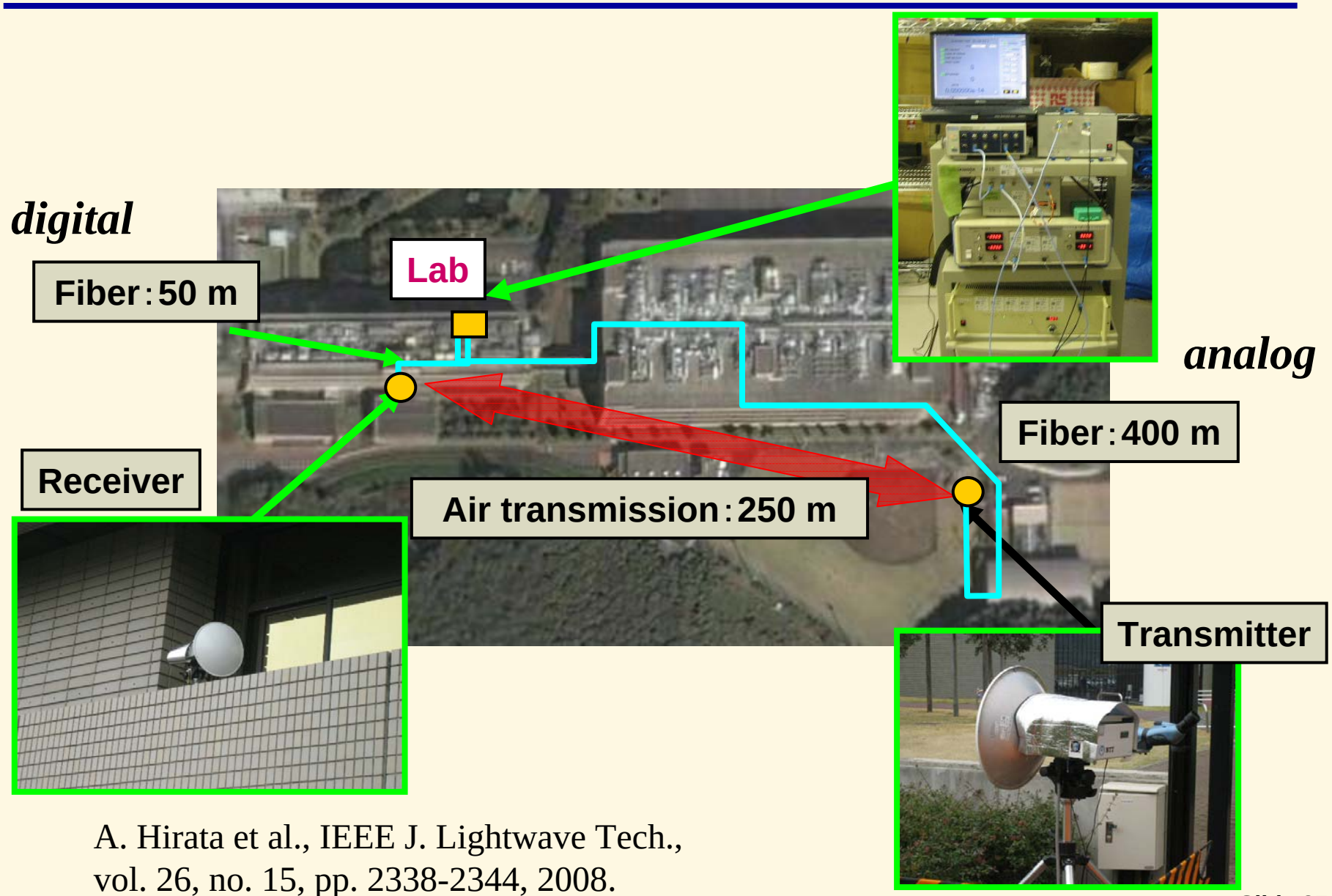
Fully matured production level technology (NTT Electronics)

120-GHz Band Transmitter



A. Hirata et al., IEEE Trans. Microwave Theory Tech., vol. 54, pp.1937-1944, 2006.

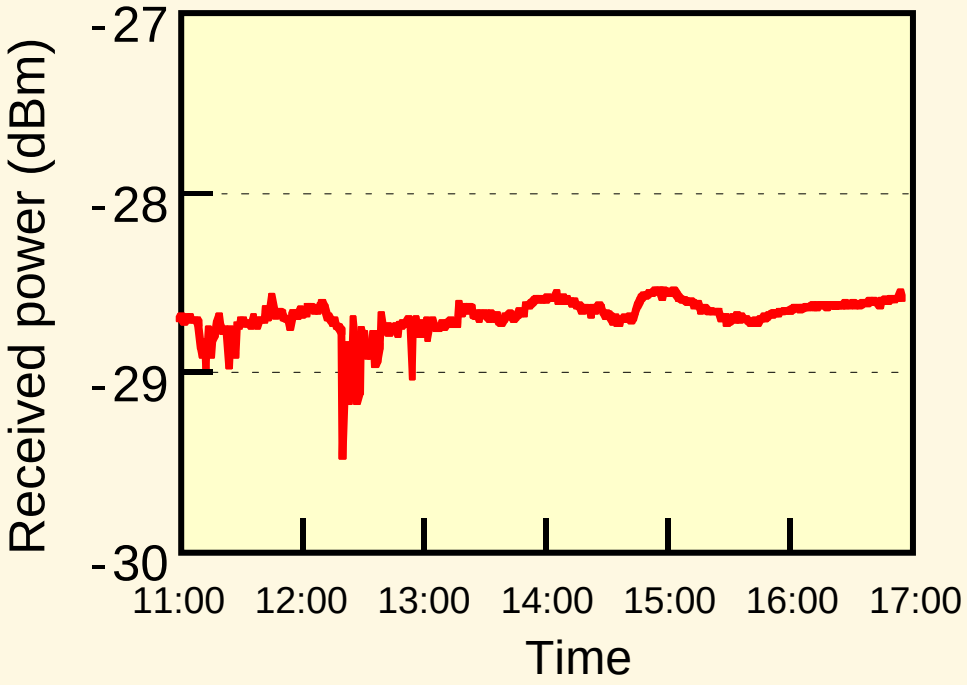
Setup for Field Test



A. Hirata et al., IEEE J. Lightwave Tech., vol. 26, no. 15, pp. 2338-2344, 2008.

Transmission Characteristics

Receiver power



Bit error rate (BER)

	Total number of bit errors	BER
1st day	3	$1X10^{-14}$
2nd day	5	$2X10^{-14}$
3rd day	13	$5X10^{-14}$

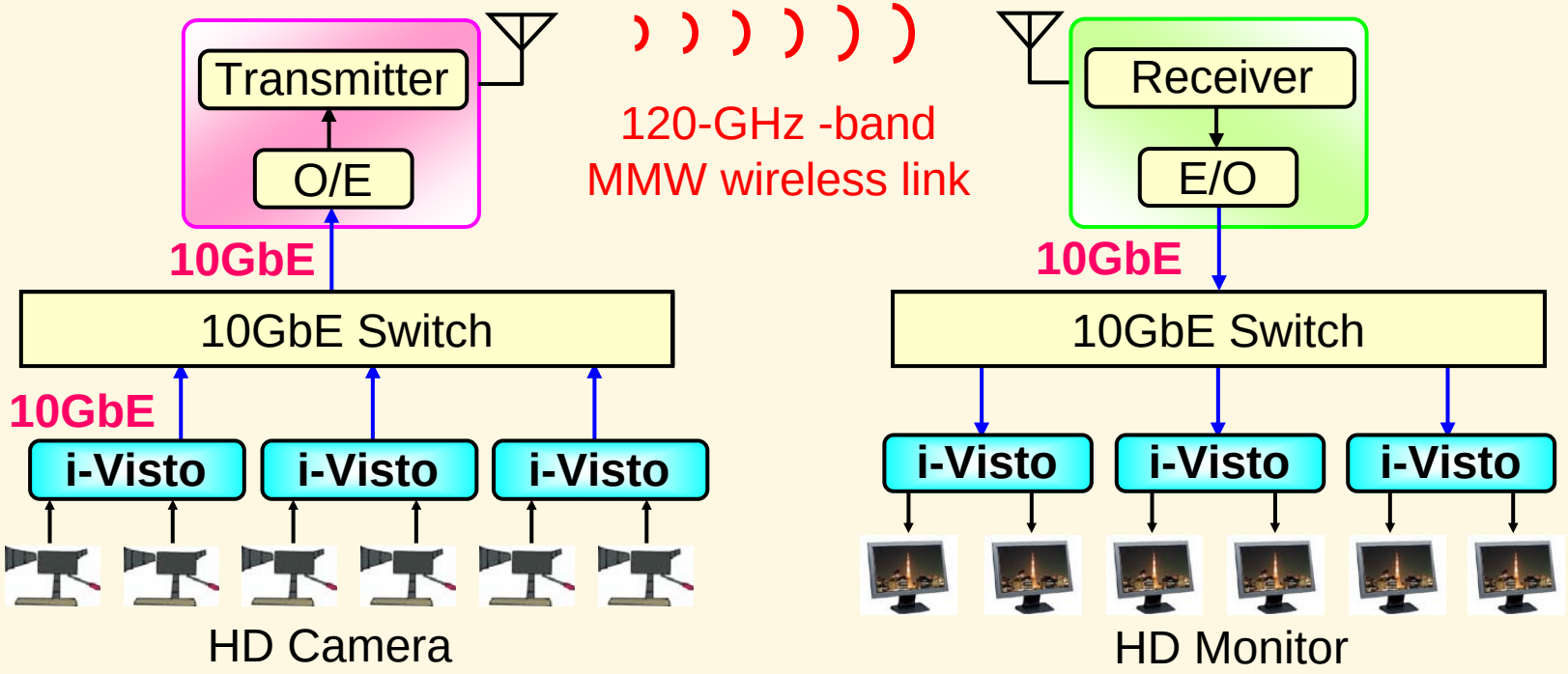
- Fluctuations in received power: < 1 dB for 6 hours
- BER of wireless link: < $1X10^{-13}$

→ Meets OC-192 and 10GbE standards

A. Hirata et al., IEEE J. Lightwave Tech., vol. 26, No. 15, pp. 2338-2344, 2008.

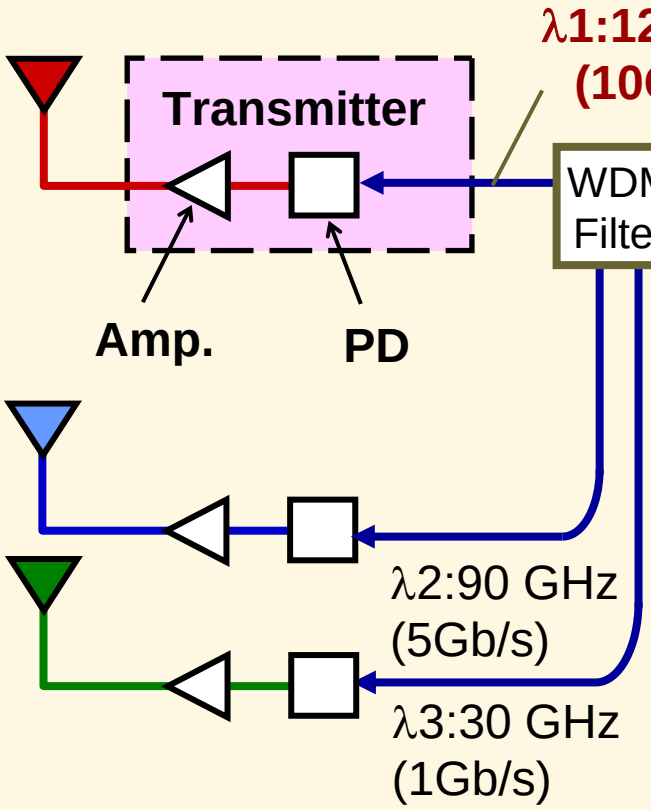
Multiplexed HDTV Wireless Transmission System

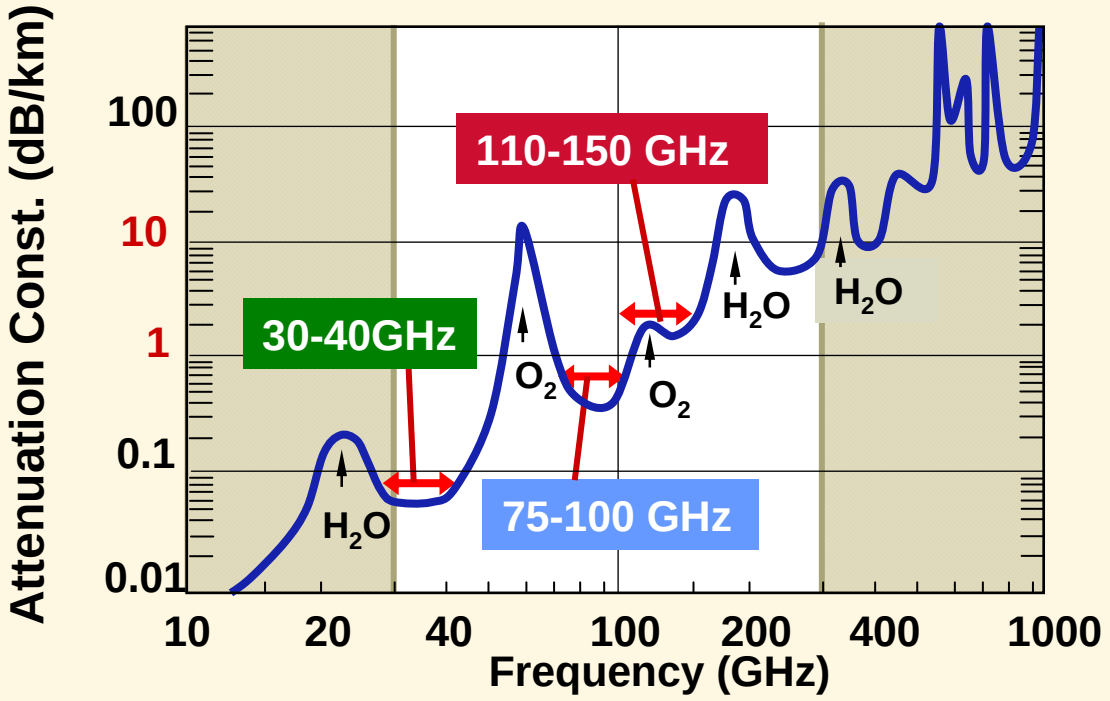
- "i-Visto gateway" converts two HDTV video streams into IP packets and then multiplexes the packets using the 10 Gigabit Ethernet protocol.
- Packets from three i-Visto are multiplexed by a 10GbE switch.
- Six channels of HDTV signals are transmitted as 10GbE signals over the 120-GHz-band wireless link.



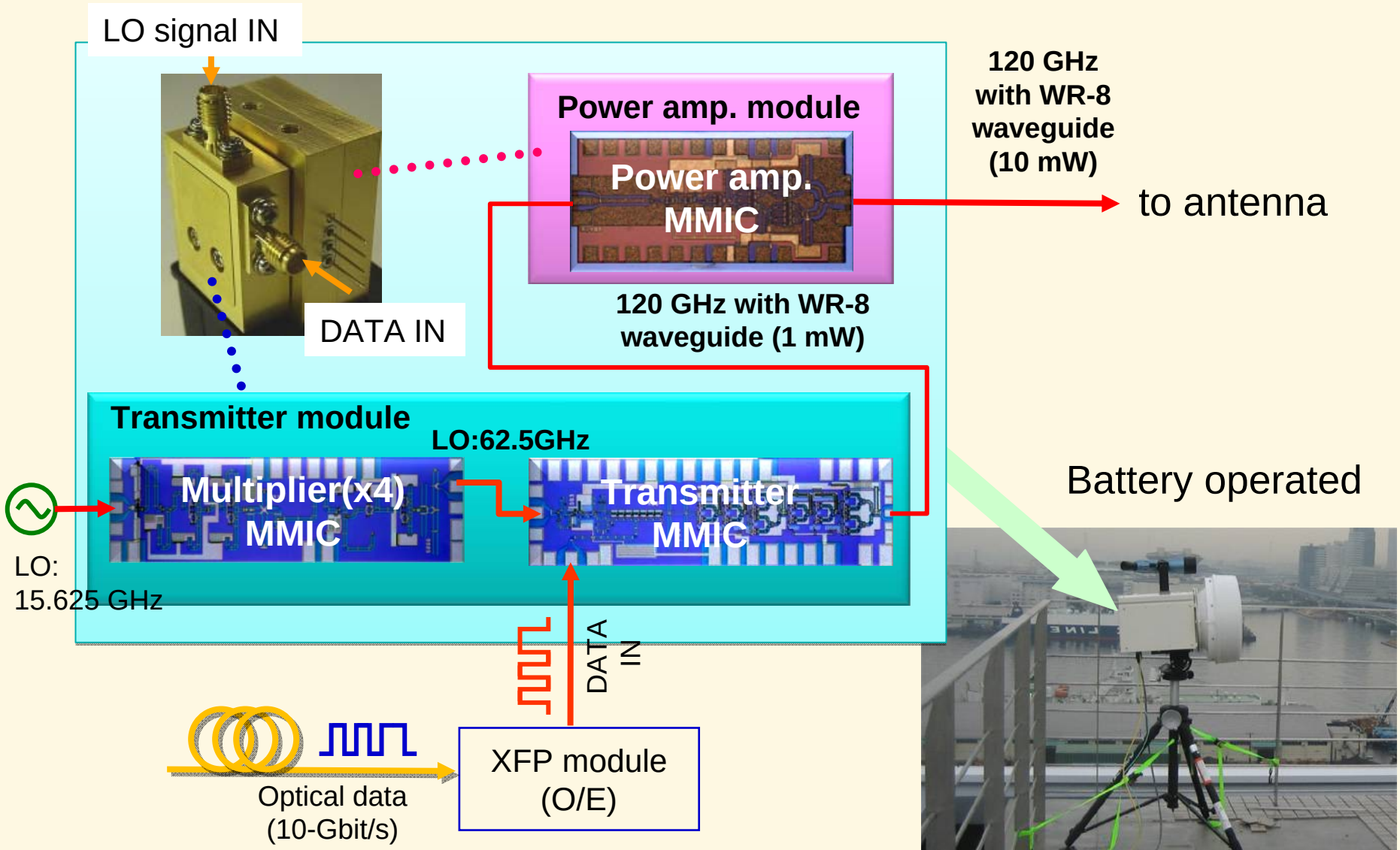
NTT Technical Review, vol. 4, no. 3, pp. 64-70, 2006.

Multi-band System with Optical WDM





120-GHz-band Transmitter with Electronics

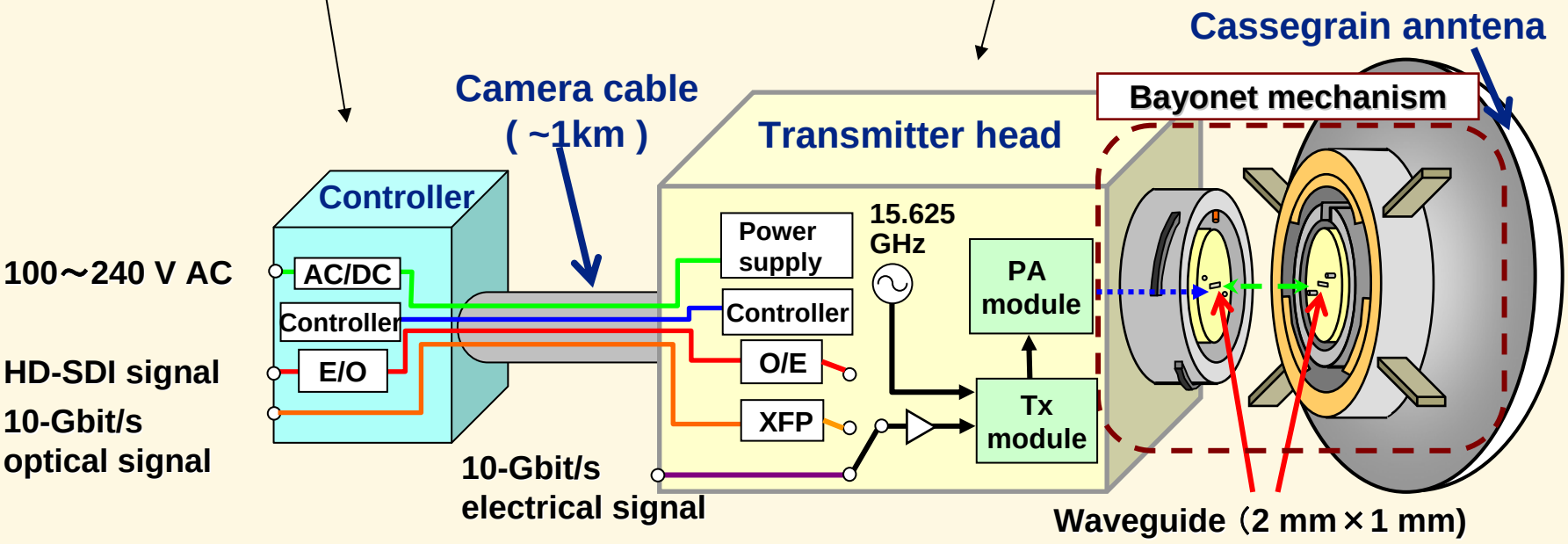


NTT Technical Journal, Vol. 19, No. 5, pp. 48–51, 2007 (in Japanese).

Advanced All-Electronics System

Controller

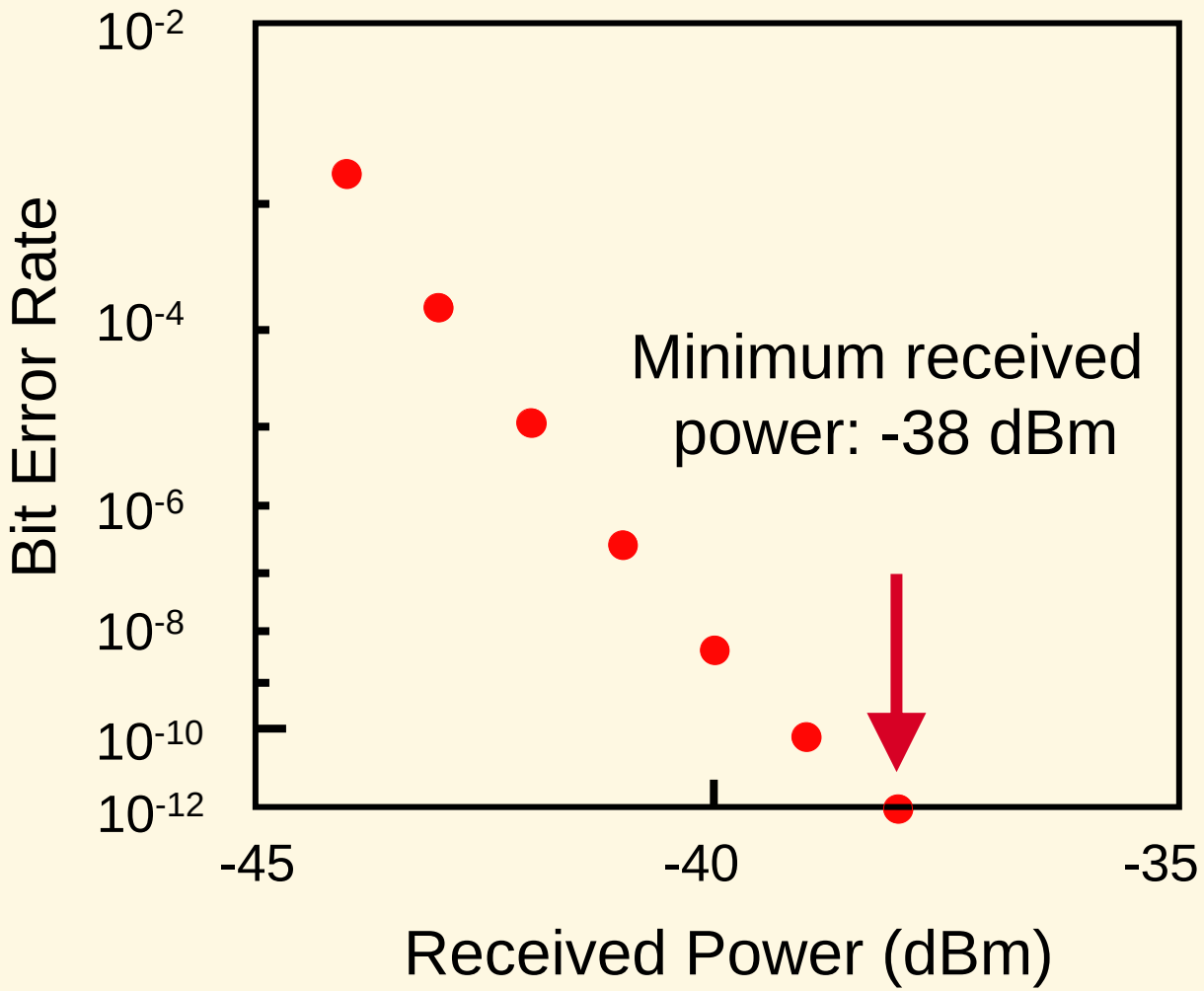
Tx Frontend



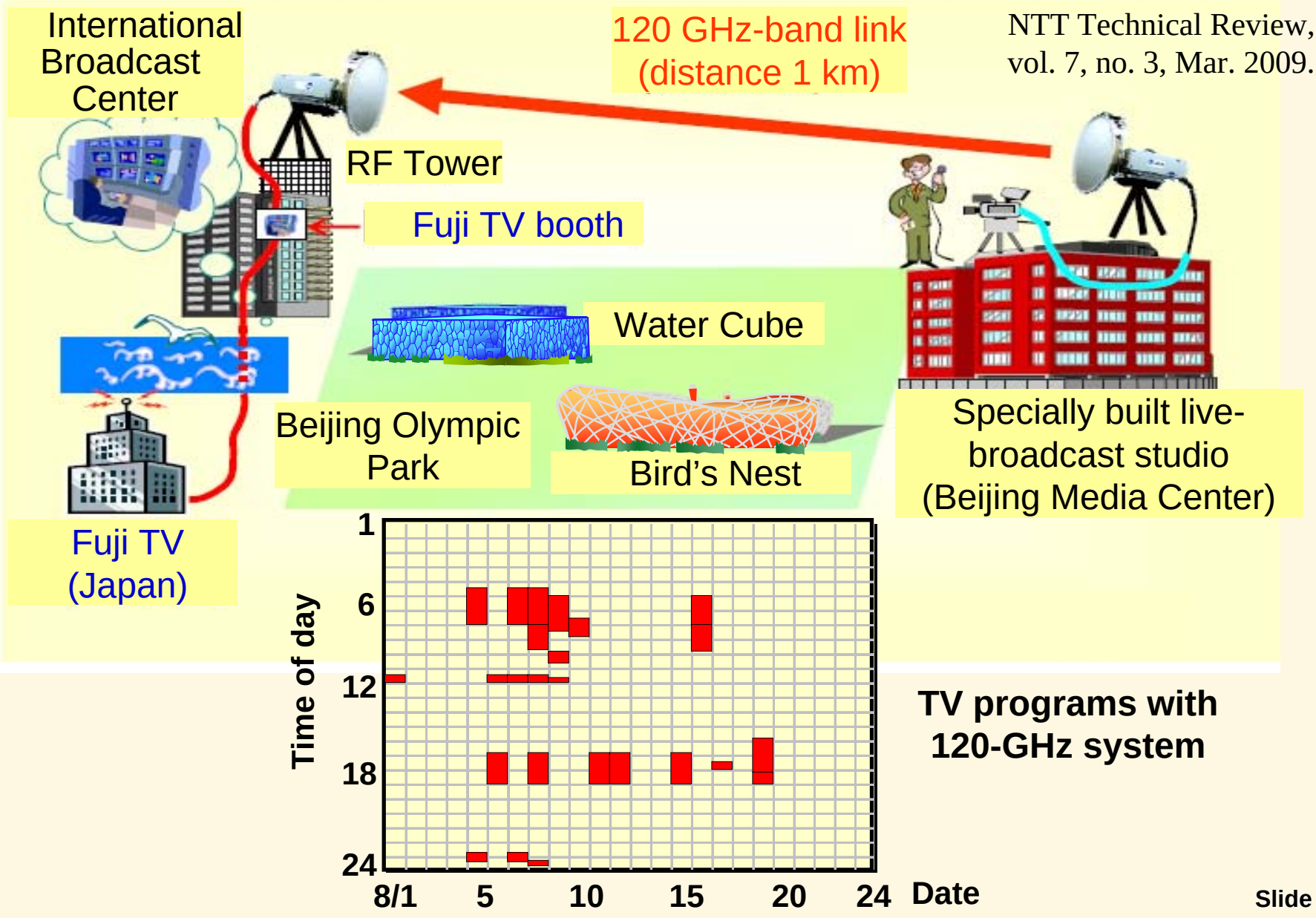
NTT Technical Review, vol. 7, no. 3, Mar. 2009

Typical Performance

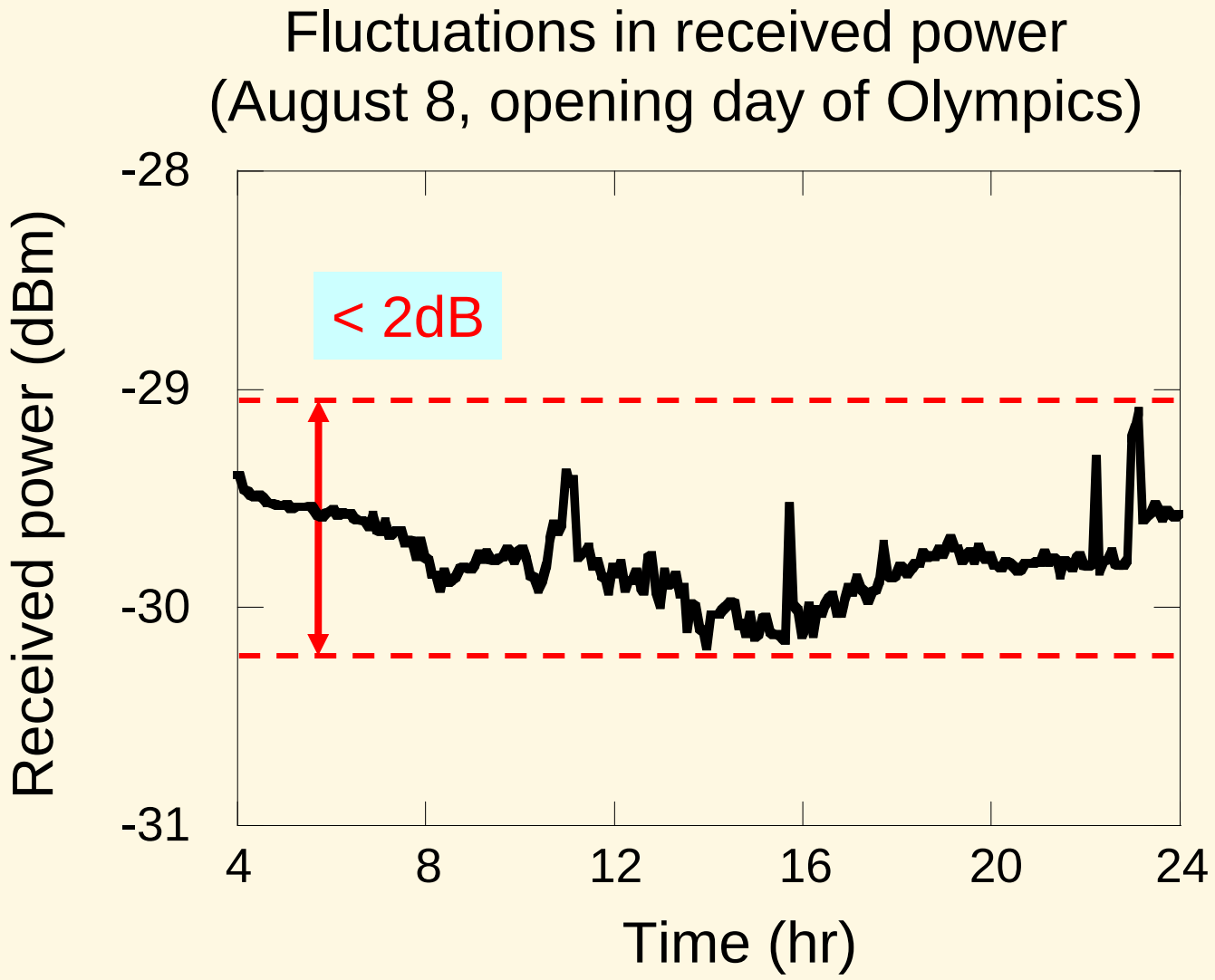
Data rate:10.3125 Gbit/s



Trials at Olympics: Configuration



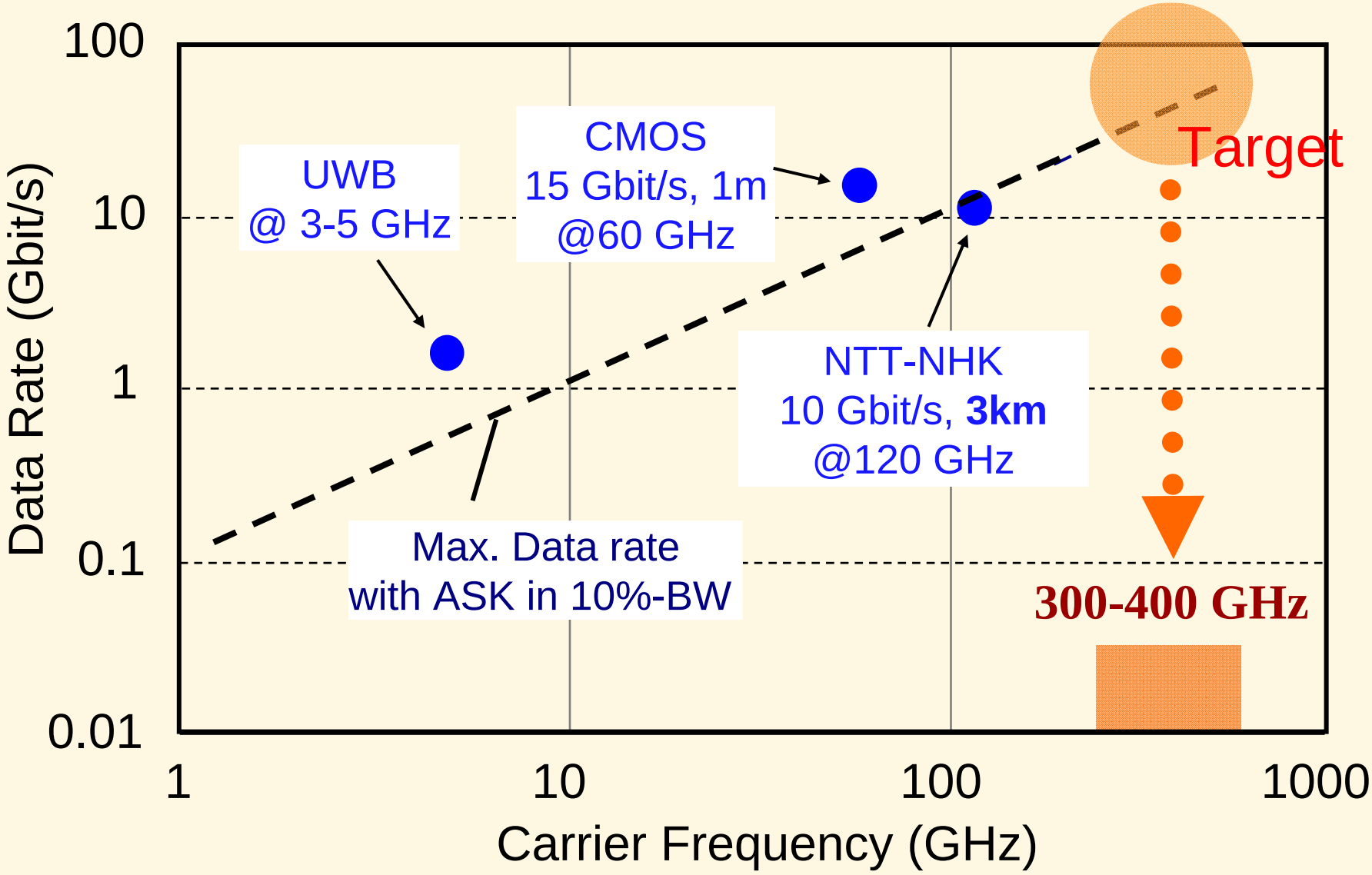
Trials at Olympics: Live-broadcasting



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

- Background & Needs
- 10-G wireless with 120-GHz Bands
- **Exploring 300-400 GHz Band**
- Summary

Carrier Frequency vs. Data Rate



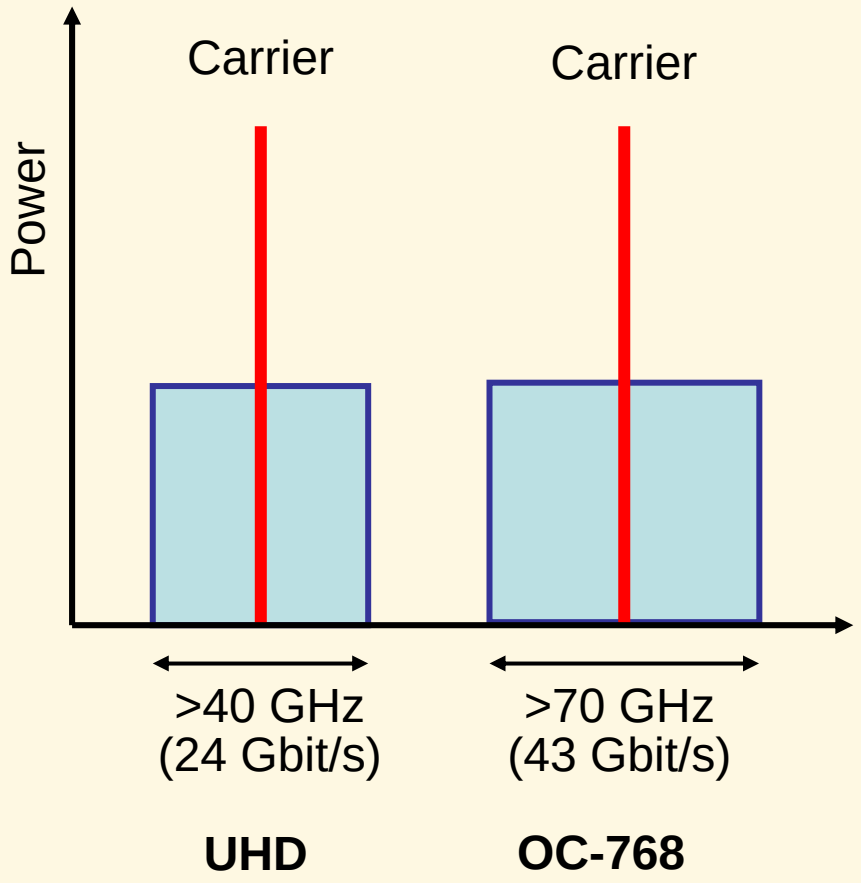
Objective of 300-GHz Band Wireless

- Examine “giga-bit” wireless link using full 300-400 GHz band
- Photonics-based transmitter as technology demonstrator
- Discuss possibility of >20-40 Gbit/s wireless

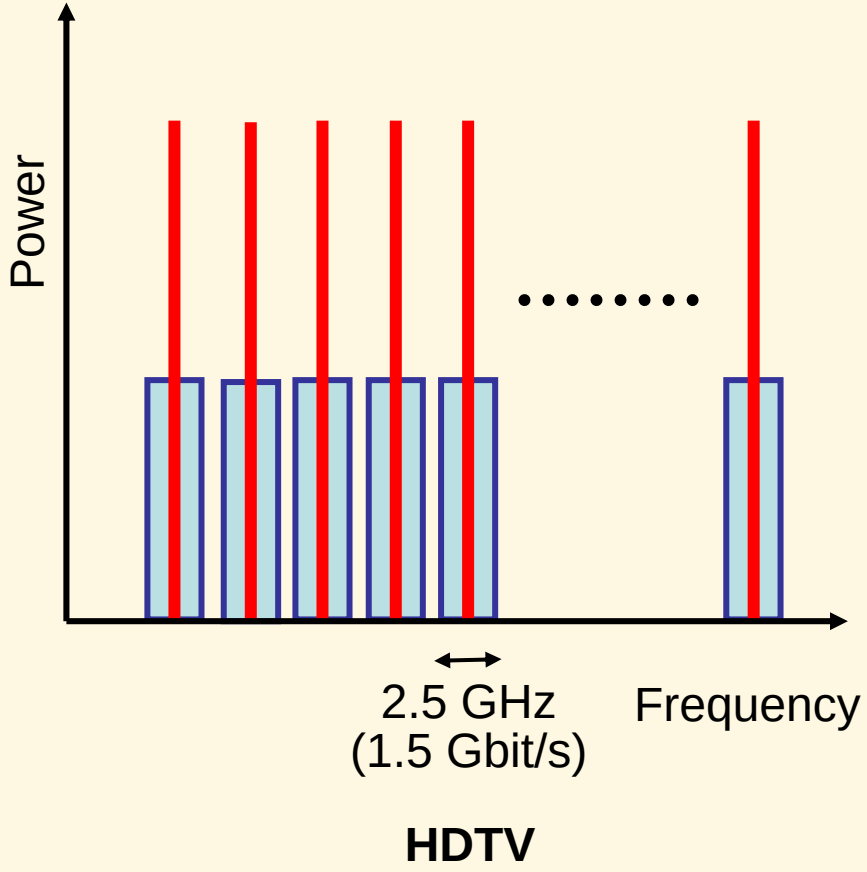
T. Nagatsuma et al., Tech. Dig. 2009 International Topical Meeting on Microwave Photonics, 15 October, Session Th.2.

Possible Utilization of 300-400 GHz

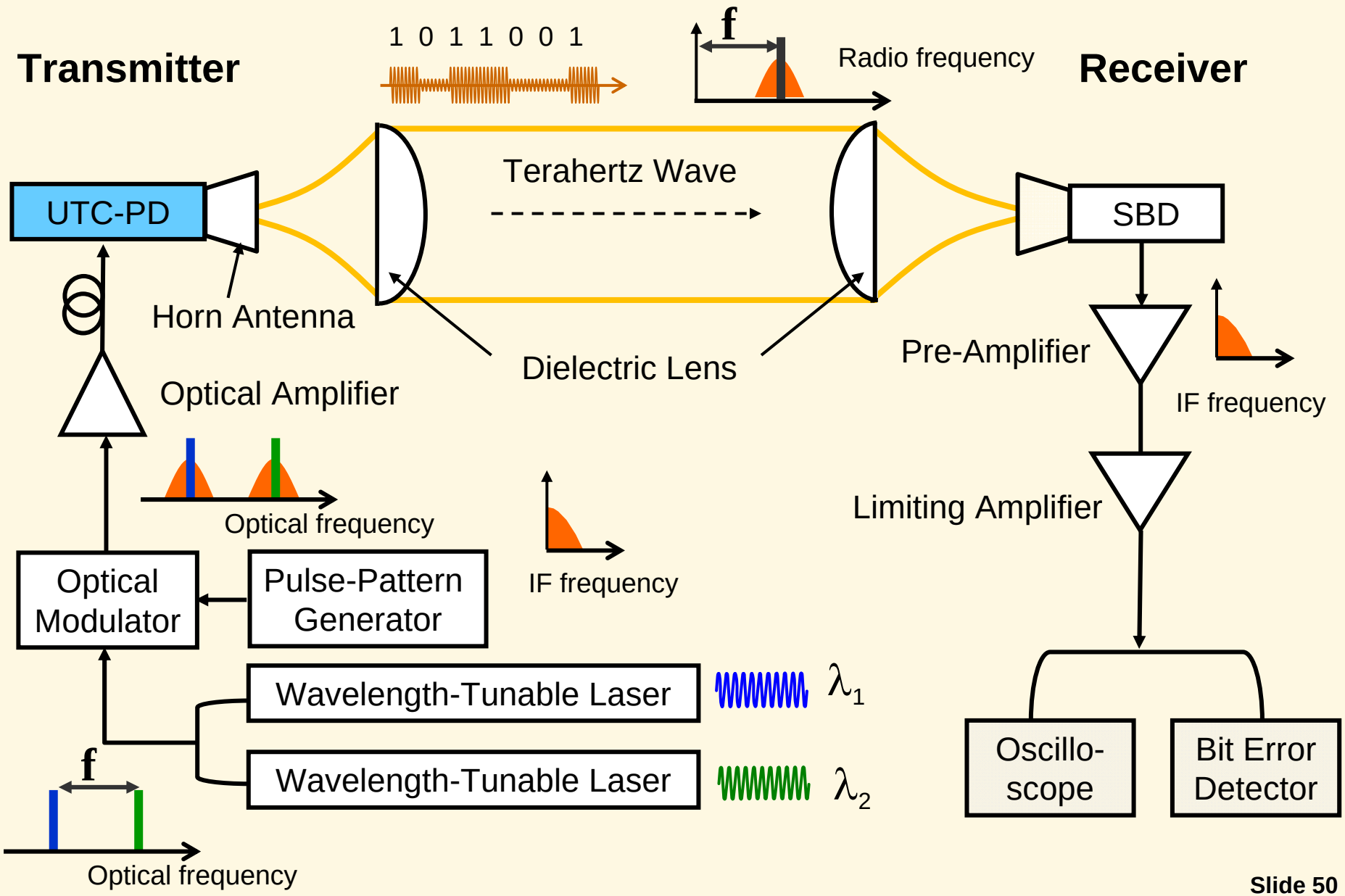
(a) Ultra-broadband channel



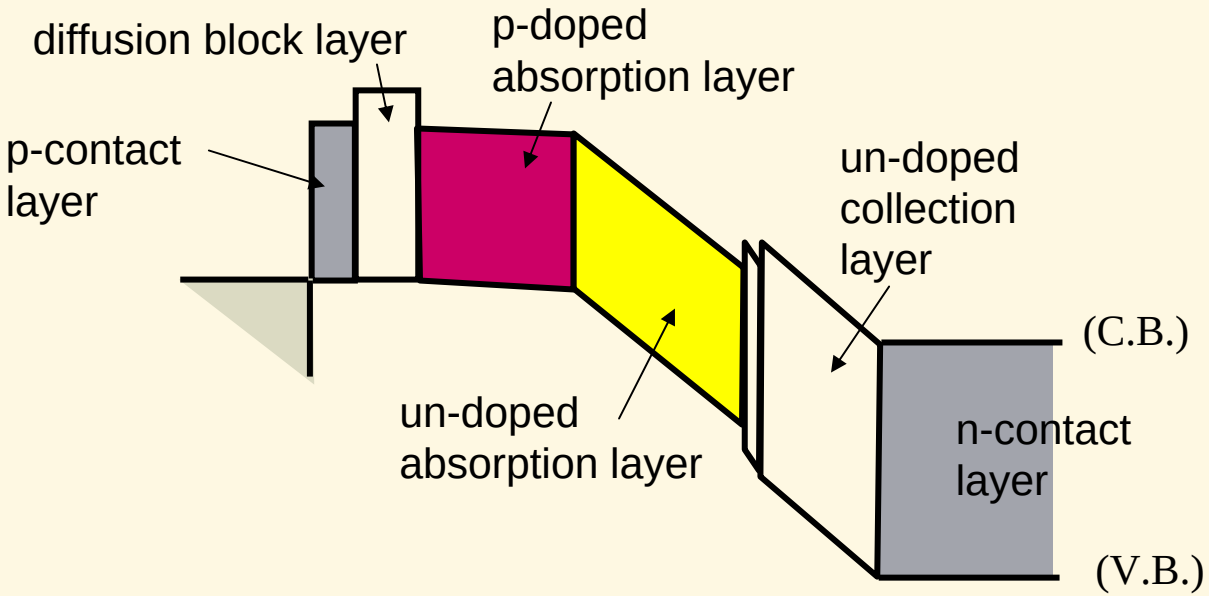
(b) Multiple giga-bit channels

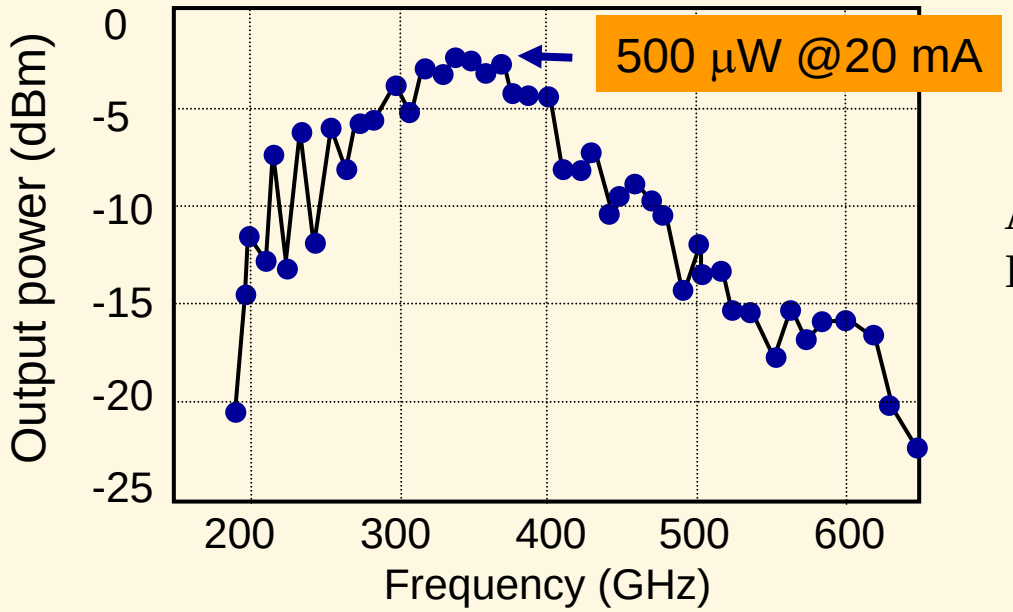


Experimental Wireless Link



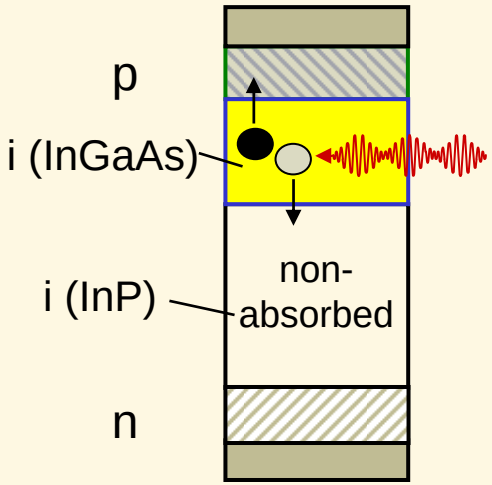
Modified UTC-PD (Composite Structure)



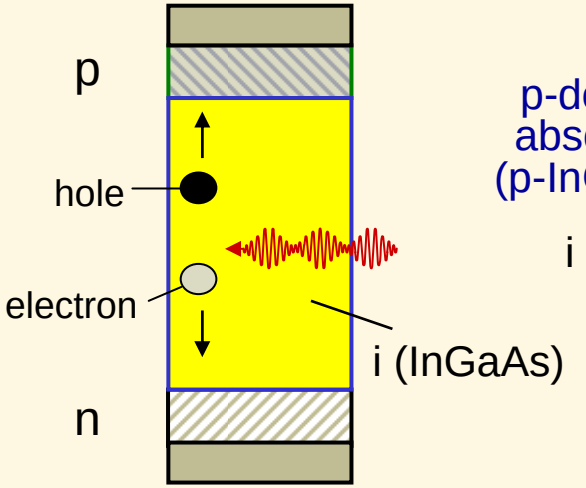


A. Wakatsuki et al.,
IRMMW-THz 2008.

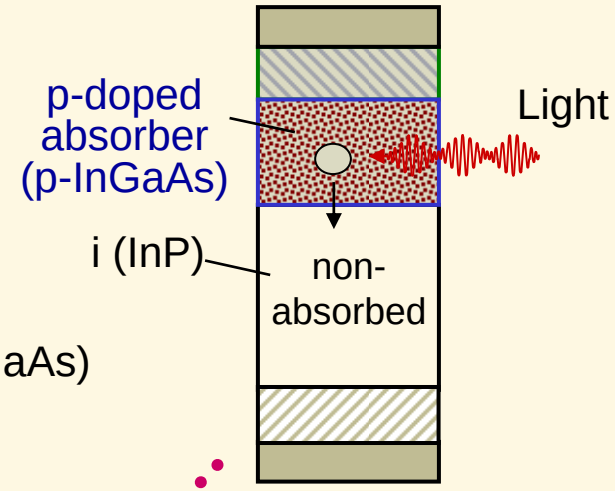
Menu of “Hamburgers”



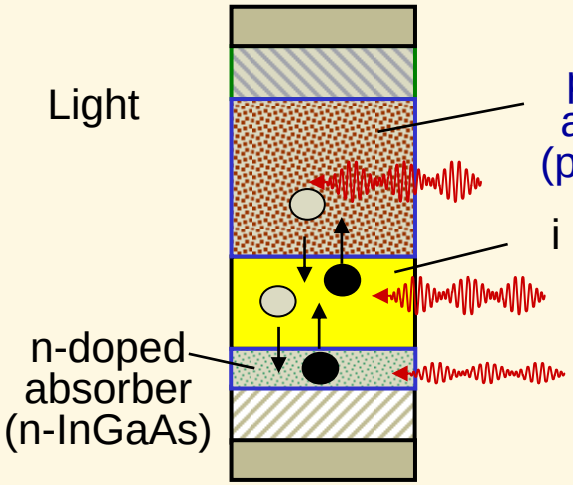
(a) Dual depletion pin



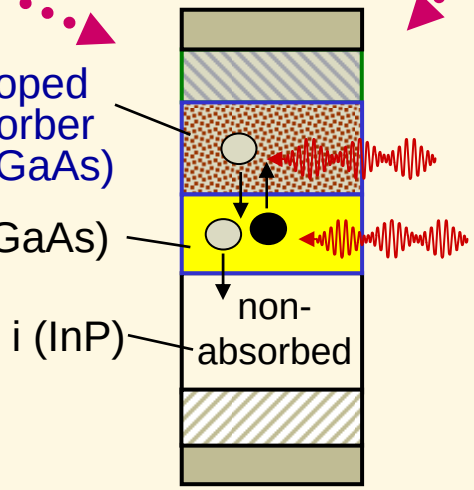
(b) Conventional pin



(c) UTC



(d) Partially doped absorber



(e) Modified UTC (composite)

Output Power at 300-400 GHz

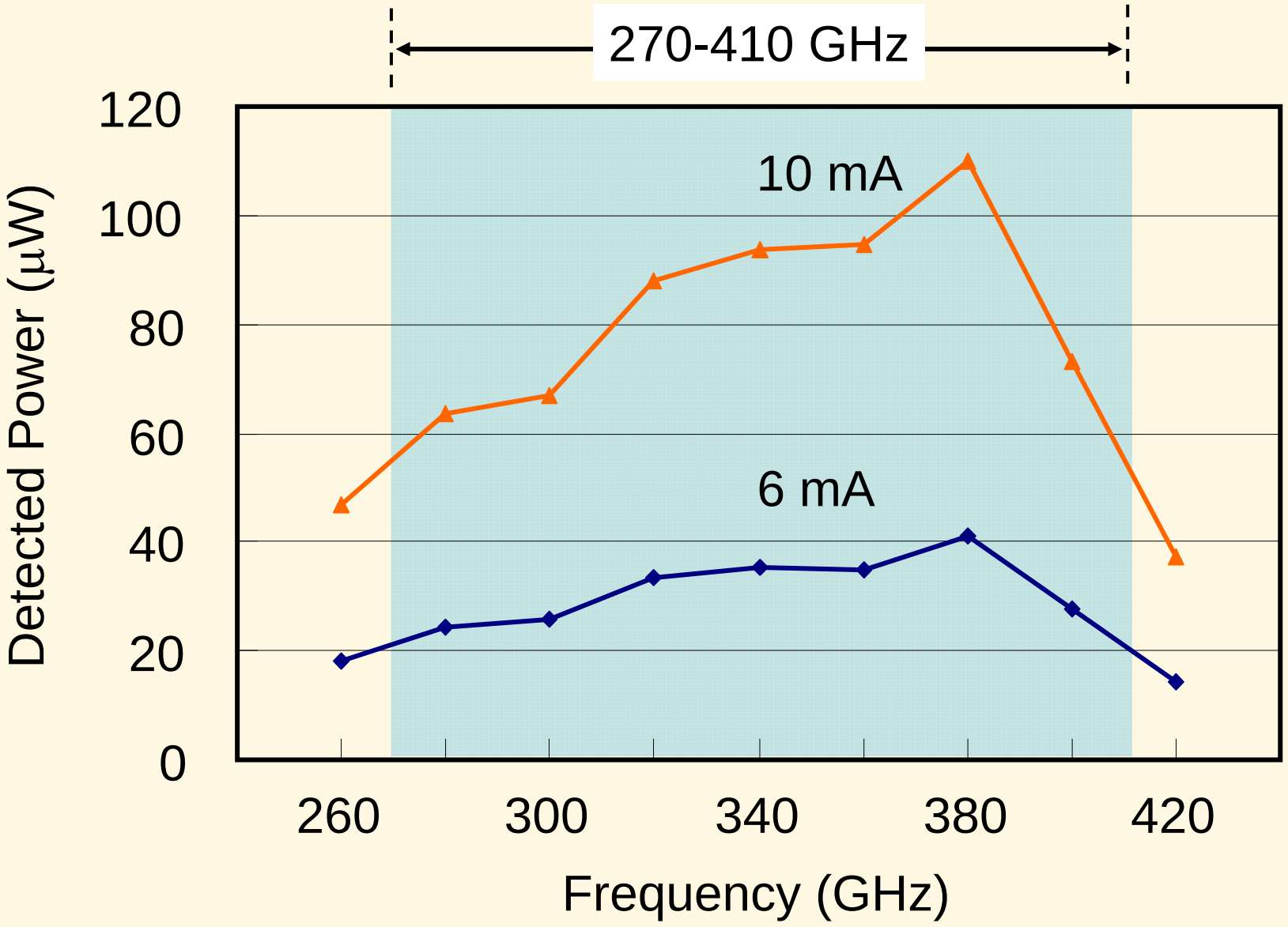
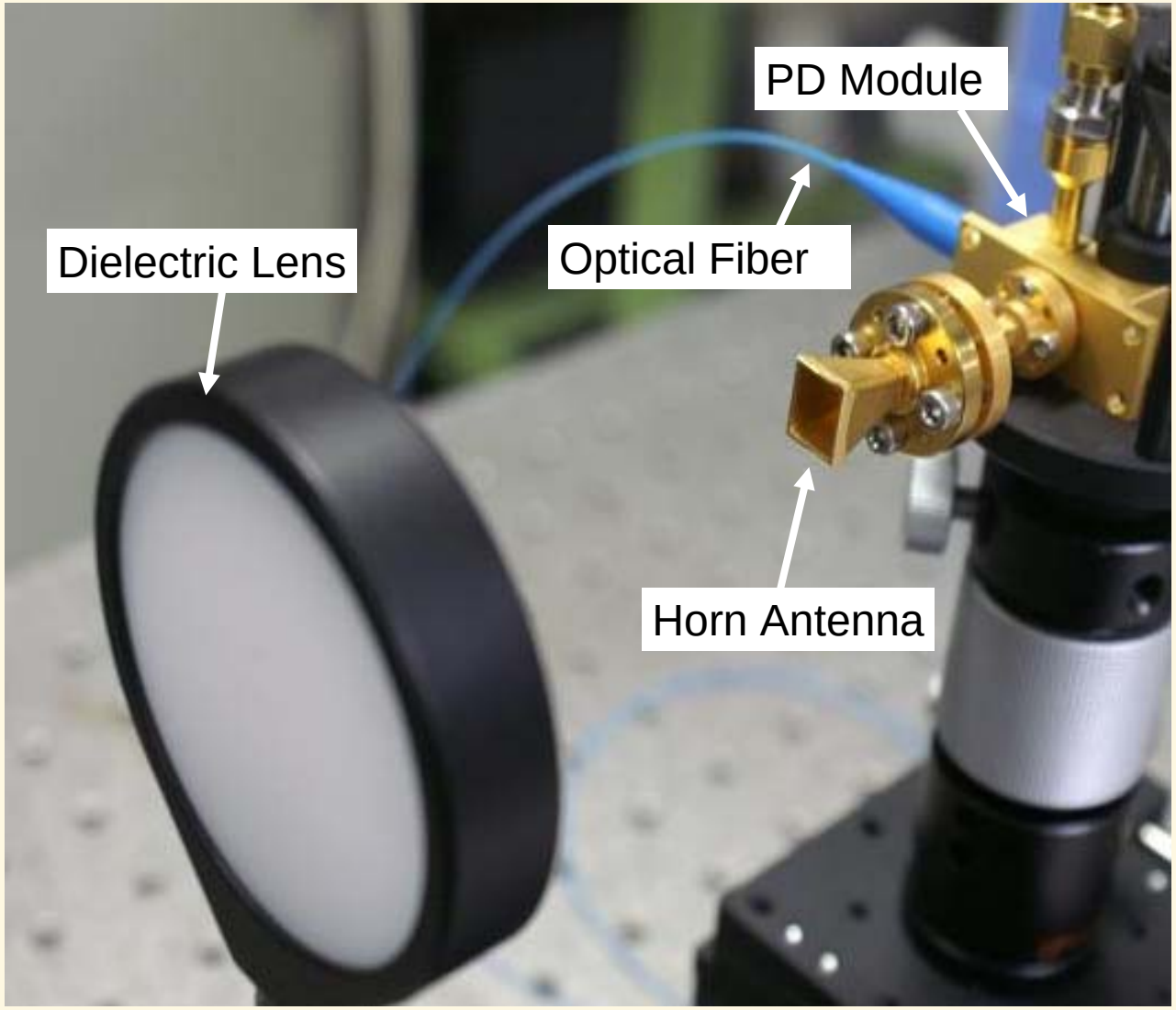
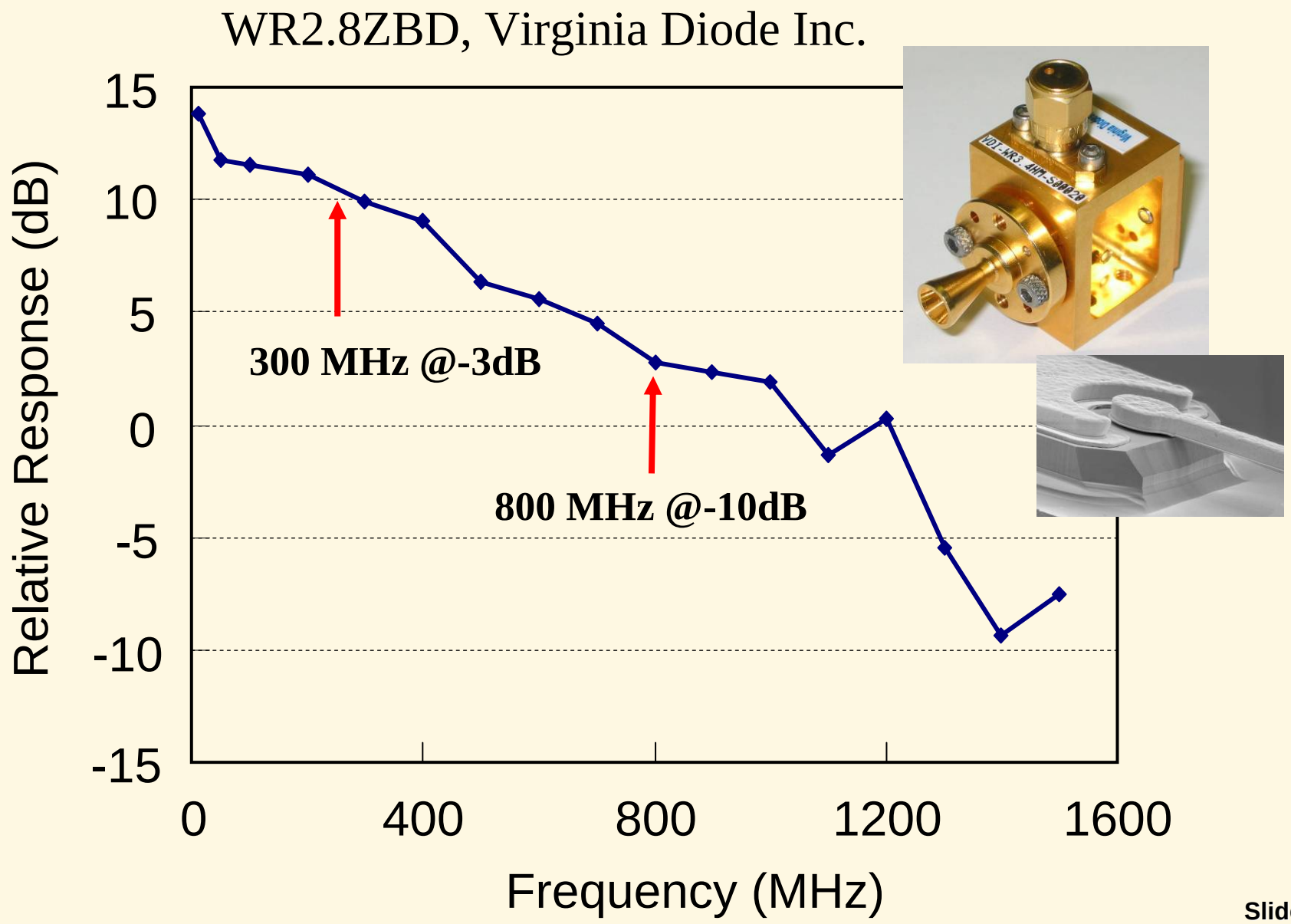


Photo of Transmitter



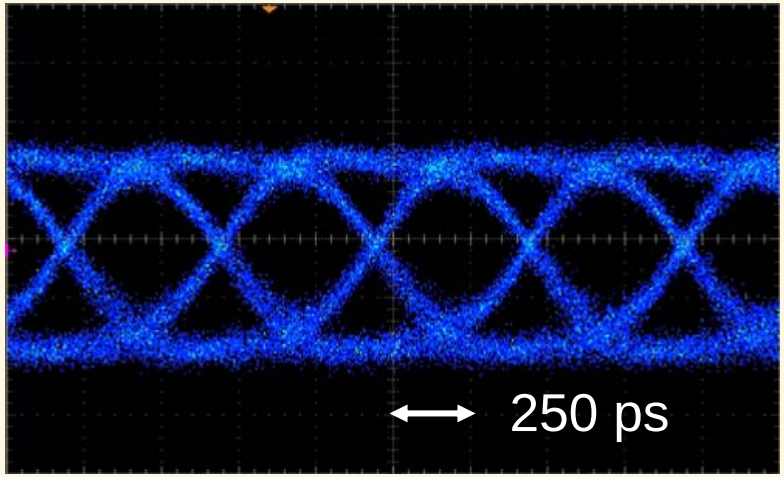
Receiver Bandwidth



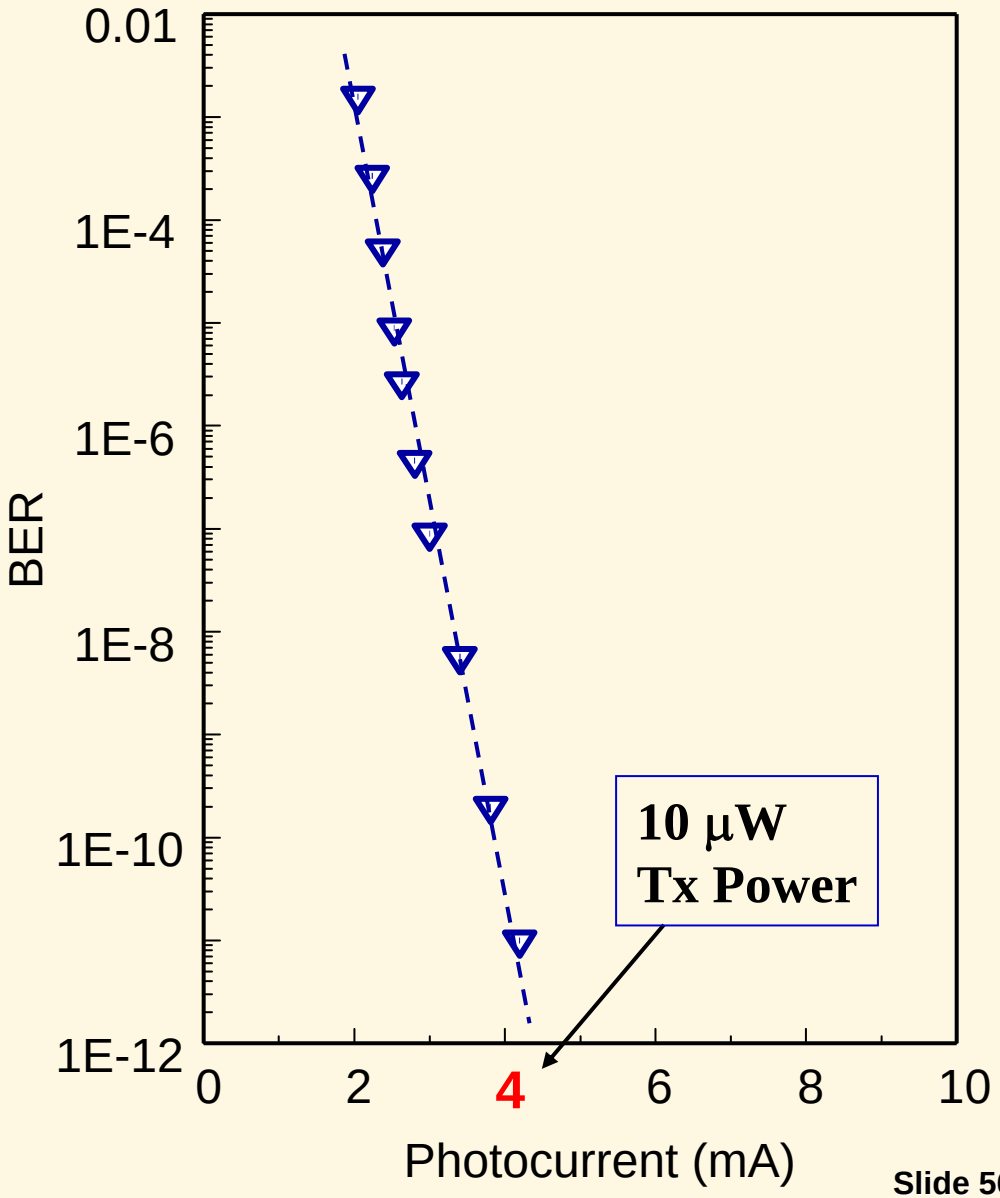
Transmission Characteristics (1)

2 Gbit/s

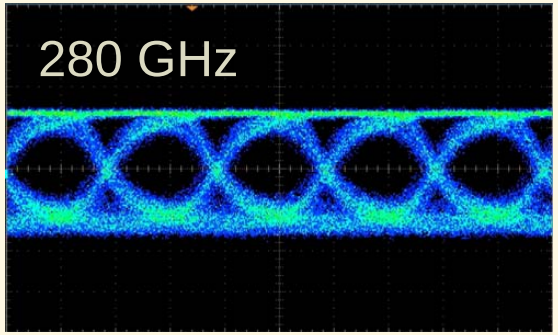
Distance: 50-100 cm



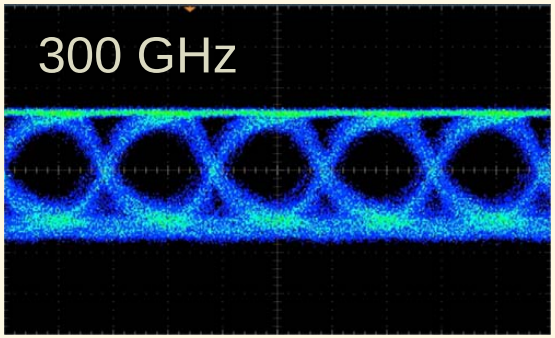
→ >20 Gbit/s
with >100 µW



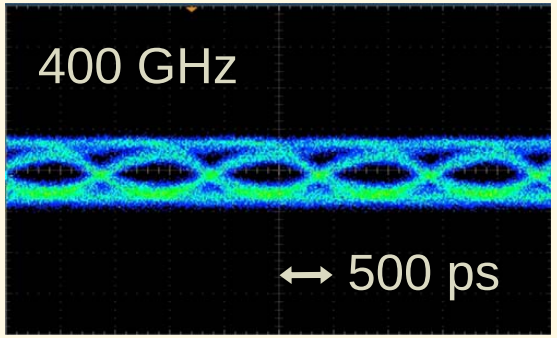
Transmission Characteristics (2)



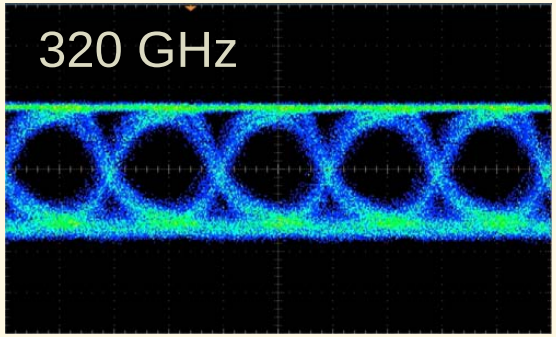
(a)



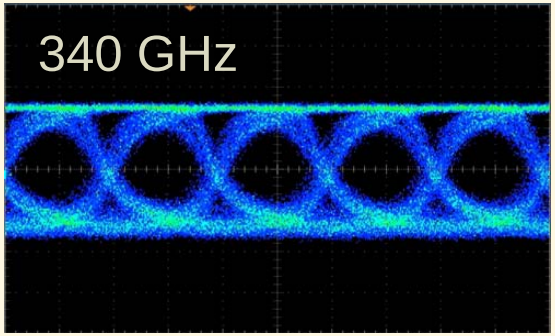
(b)



(g)

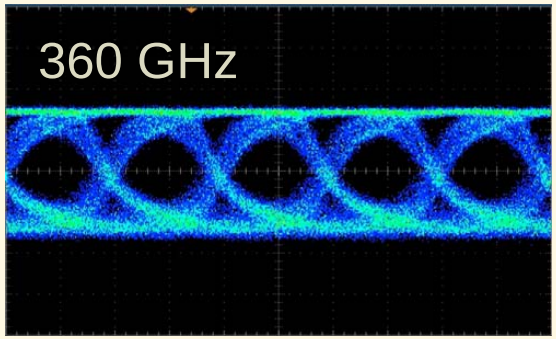


(c)

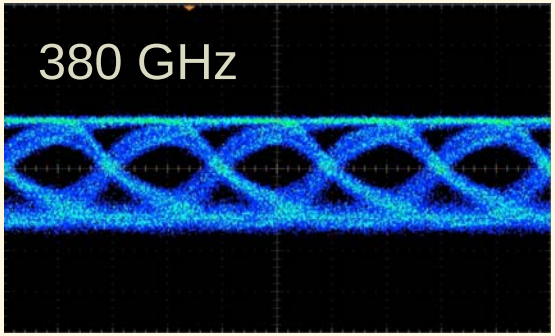


(d)

1 Gbit/s



(e)



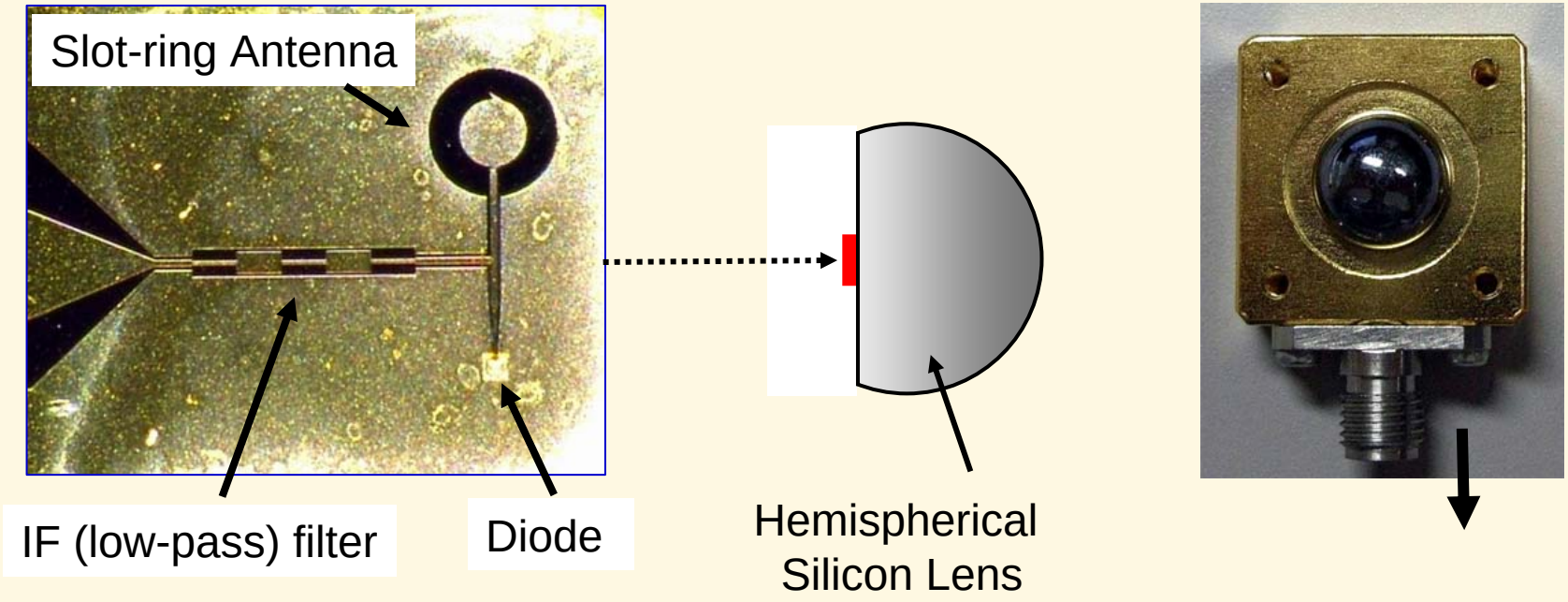
(f)

→40 ch. x 1 Gbit/s
with 200 μW

Increasing Bit Rate (1)

250-GHz Wireless Link with Integrated Receiver

H-.J. Song et al, IEE Electron. Lett., vol. 45, no. 22, October 2009.



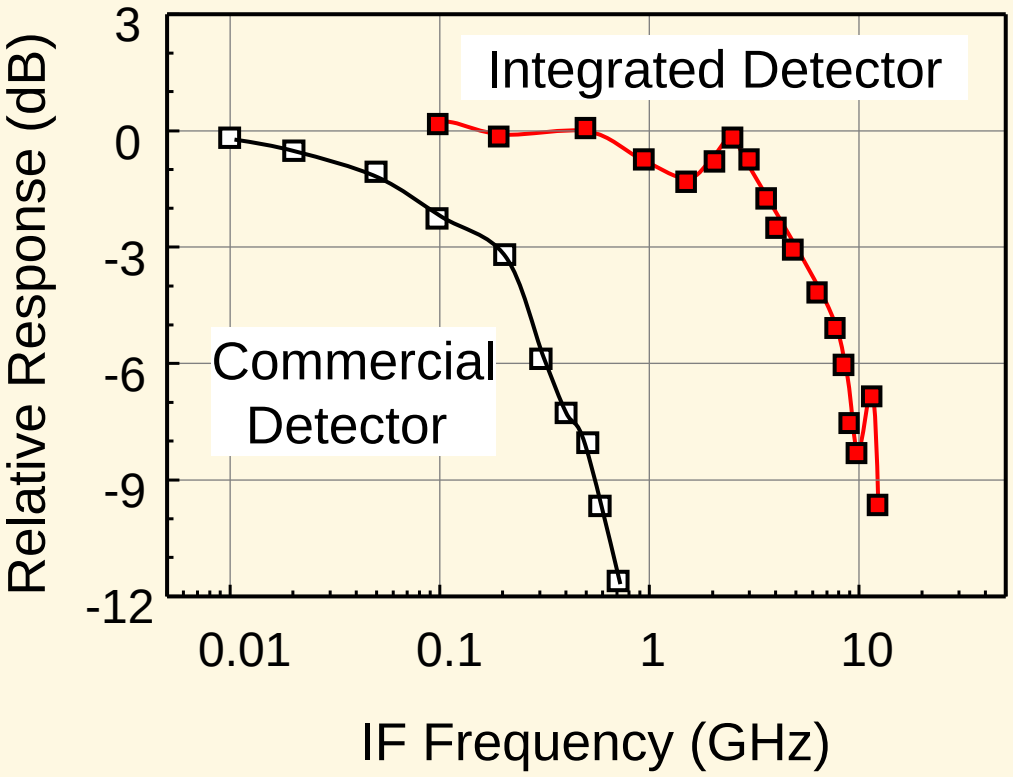
Receiver Chip

(1.5 x 2 mm^2)

Module

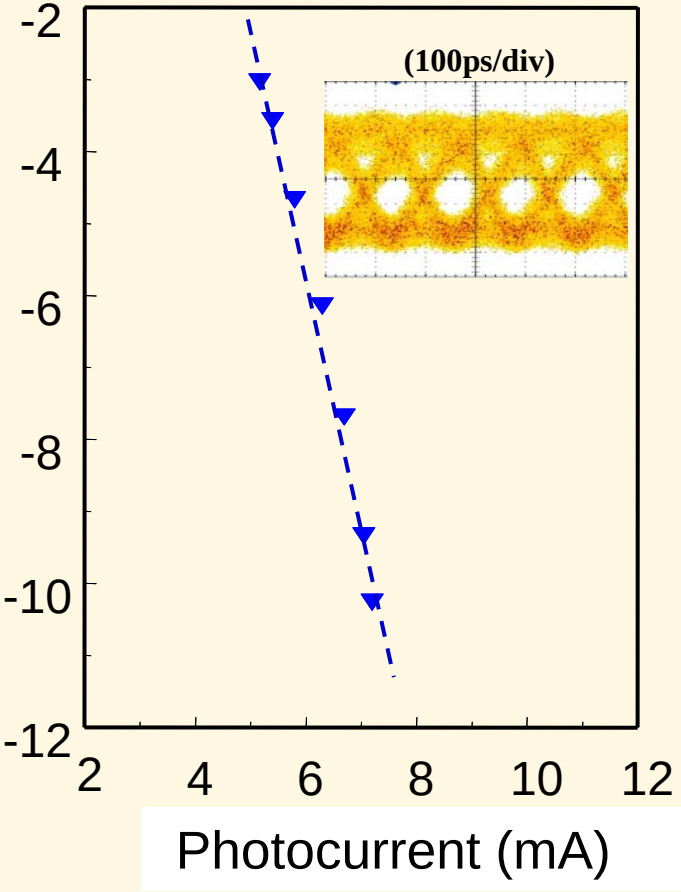
Increasing Bit Rate (2)

250 GHz



IF Bandwidth: ~4.5 GHz

8 Gbit/s



10 µW Tx Power

Summary

- **Established 120-GHz band system with 10-Gbit/s**
- **First demonstration of giga-bit wireless at 300-400 GHz band using photonics-based transmitter**
- **Error-free transmission at 1-Gbit/s from 280 to 400 GHz**
- **Max rate (2 Gbit/s) was limited mainly by bandwidth of receiver**
- **>20 Gbit/s is feasible by increasing a receiver IF bandwidth with the same photonics-based transmitter**