TeraHertz: New opportunities for industry

February 11, 2013

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Swissto12

Present and Future of Terahertz Communications

Tadao Nagatsuma

Osaka University

My First "THz"

J. Appl. Phys. 54 (6), pp.3302-3309 **(1983) .**

Flux-flow type Josephson oscillator for millimeter and submillimeter wave region

T. Nagatsuma, K. Enpuku, and F. Irie

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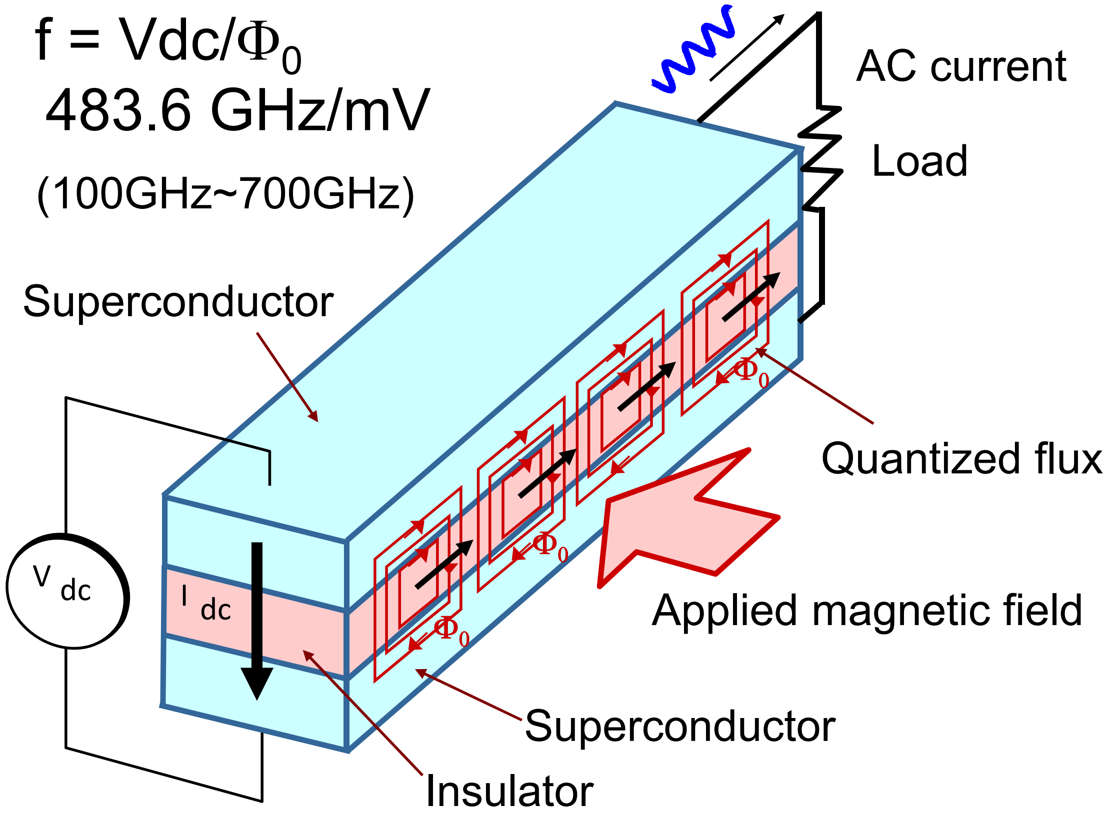
(Received 15 November 1982; accepted for publication 3 February 1983)

An oscillator which utilizes the effect of the vortex motion in long Josephson tunnel junctions, i.e., flux flow, has been presented in millimeter and submillimeter wave region. An electromagnetic wave generated by the oscillator is detected with a small tunnel junction as a detector with a refined coupling configuration. Quantitative evaluation of the detected power showed that the detected power attained the value of 10^{-6} W in the frequency range between 100 and 400 GHz, which is far superior to previous results. Frequency and magnetic field dependences of the present system were also measured, which showed that the output power was able to be controlled by the dc magnetic field. The present oscillator will be promising as the local oscillator in the integrated Josephson receiver systems.

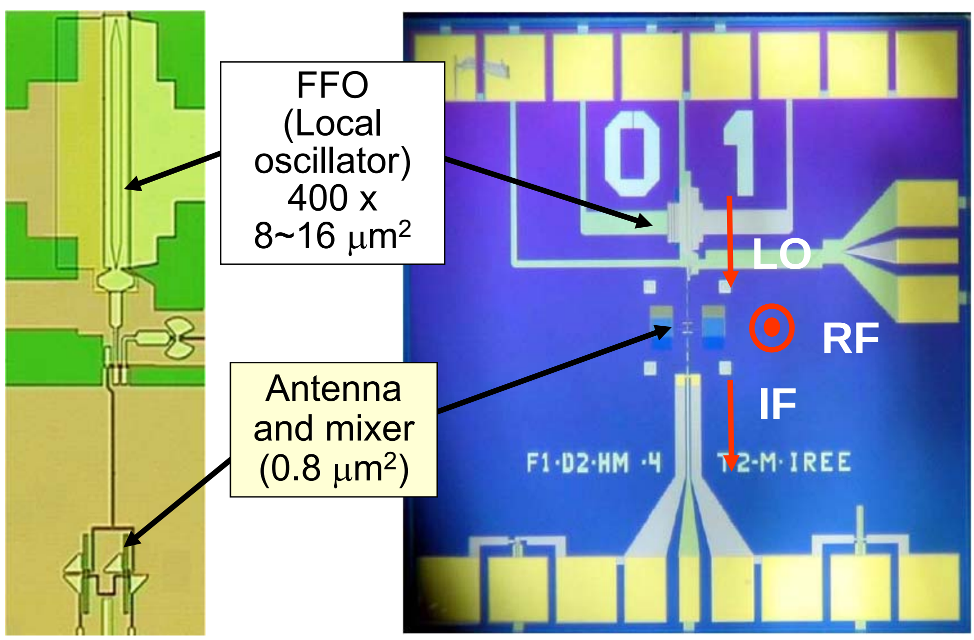
PACS numbers: 74.50. + r, 85.25. + k

Flux-Flow Oscillator (FFO)



"FFO"-Integrated MMW/THz Receivers

Integrated superconducting receiver for atmosphere monitoring
at 500-650 GHz (TELIS project: TErahertz and submm LImb Sounder)



ISEC 2007 "Integrated Receivers for Space" by V. Koshelets

Outline

- Background and motivation
  needs for high-speed wireless
  why THz?
  who pays for THz wireless?
- Enabling Technologies
  photonics vs. electronics (reviewing 120GHz band wireless)
- Photonics-base approach
  direct detection
  coherent detection
- Electronics-based approach
- Future issues
- Summary

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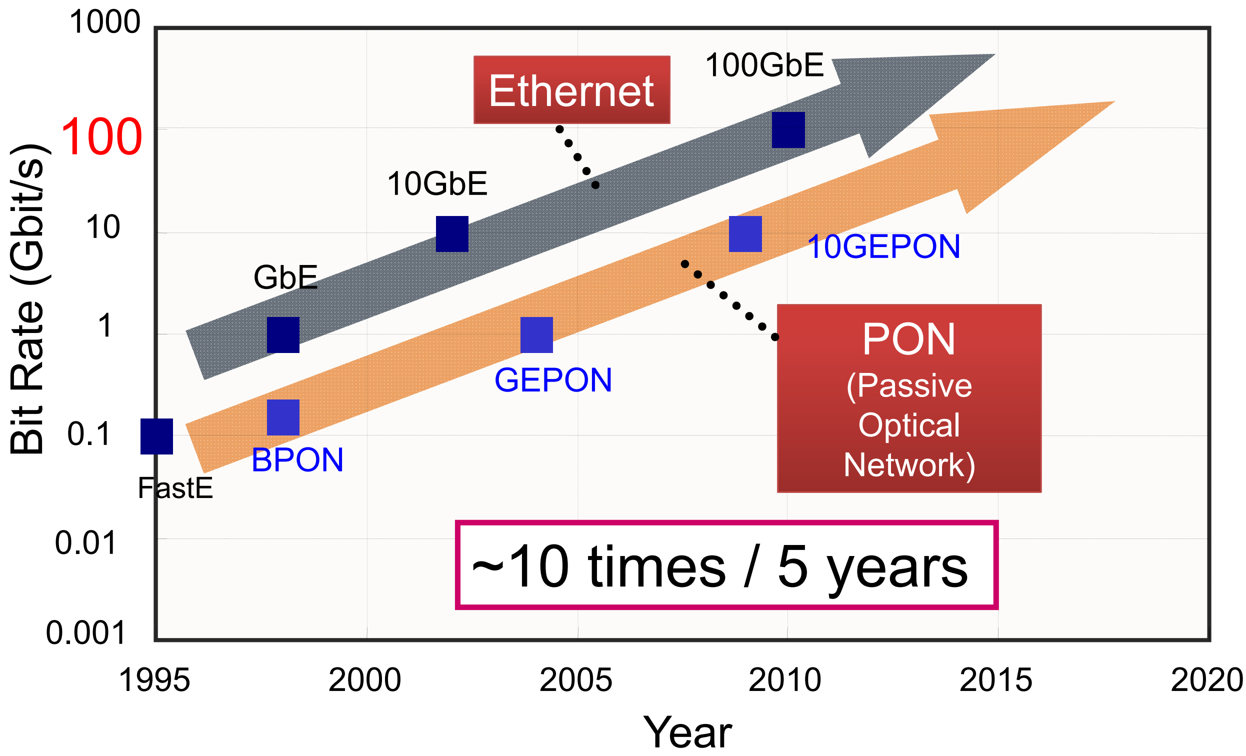
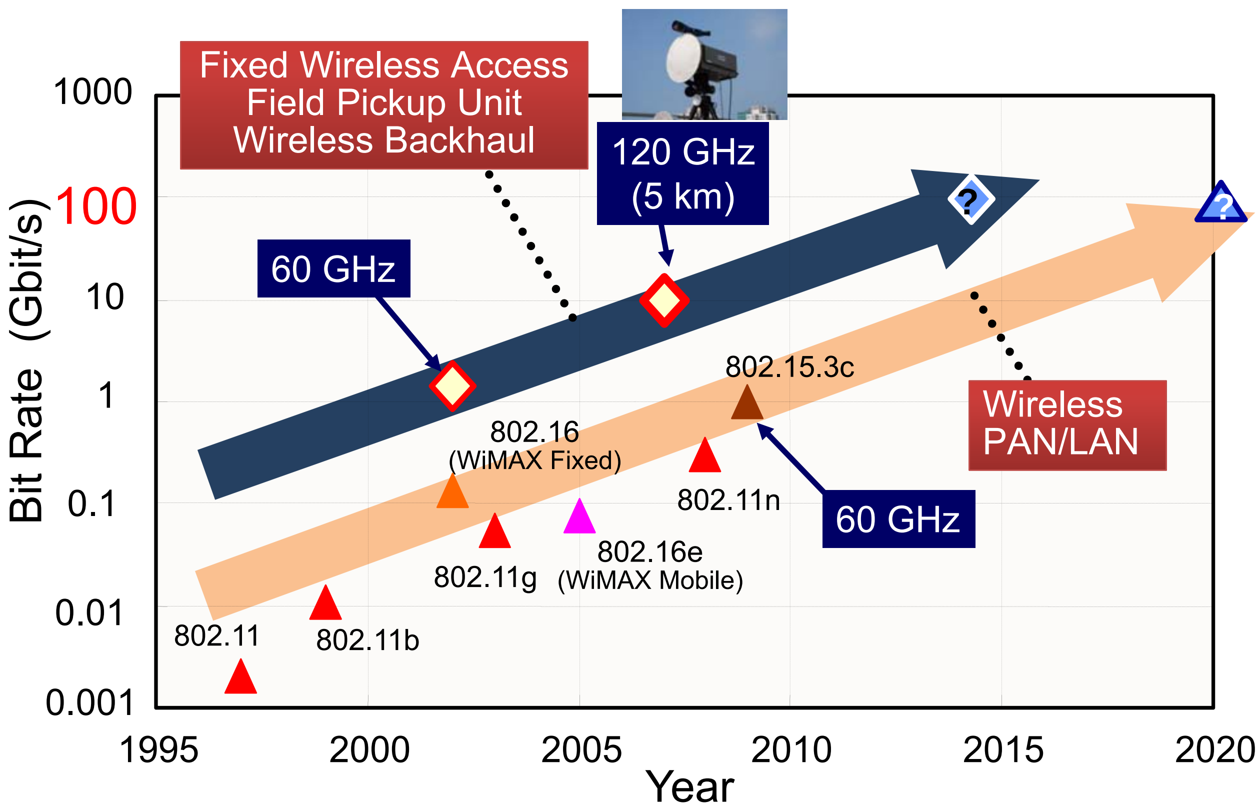
Trends in Wired Line



Trends in Wireless



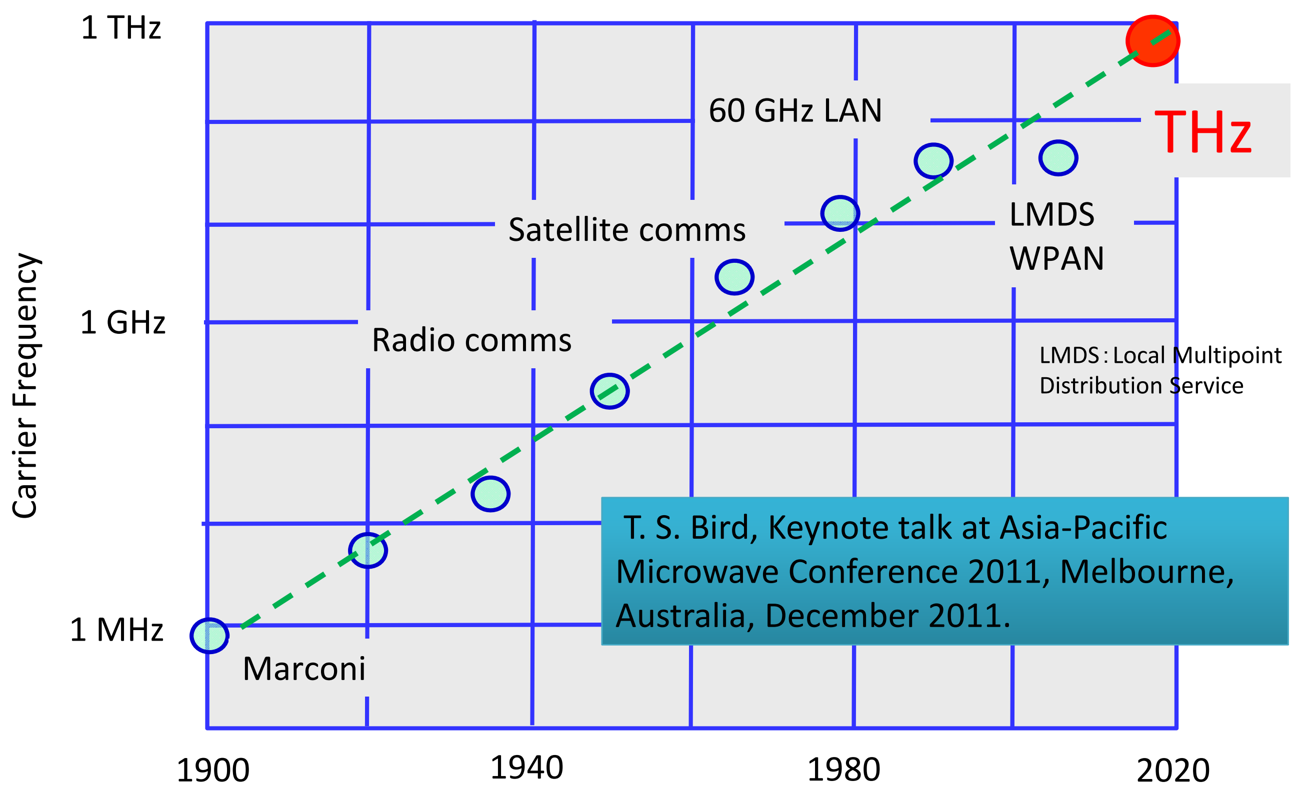
Approaches to Enhancing Speed

1) Improvement of the spectral efficiency with use of multi-value modulation or MIMO (multiple input multiple output) at microwave and millimeter-wave frequencies such as 60 GHz/90 GHz

2) Free-space optical link possibly with WDM technologies, which have already been established in the fiber-optic communications technologies

3) Use of terahertz carrier frequency with simple modulation format like ASK (amplitude shift keying), PSK (phase shift keying), and FSK (frequency shift keying)

Developing Higher Carriers



Different Way of Radio Use

Increasing power, complexity and cost

Shannon theory
R (bit/s) = **B** (Hz) $\log_2$ (1 + S/N)

VS.

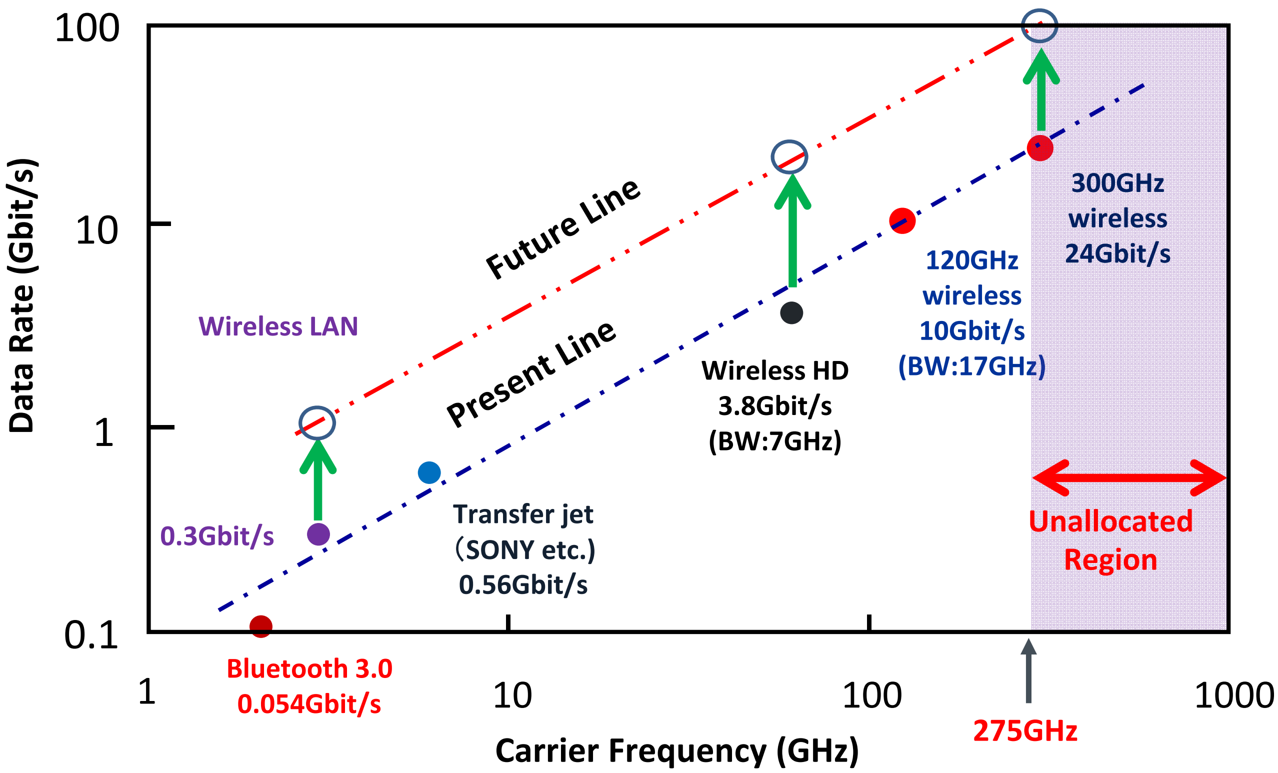
Energy efficient, cost effective, and ….

Frequency
= Space

Microwaves

THz waves

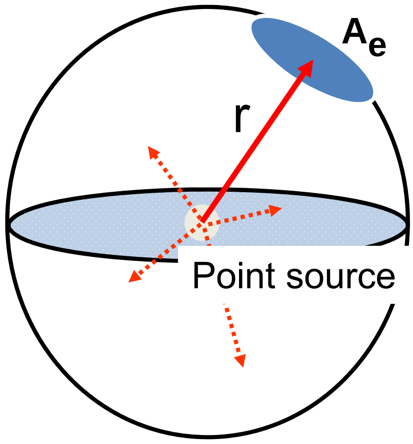
Carrier Frequency vs. Data Rate



Free-Space Loss (1)

$$\Gamma = \left(\frac{4\pi r}{\lambda}\right)^2 = \left(\frac{4\pi f r}{c}\right)^2$$

Loss increases in proportion to square of distance, r, and frequency, f.



Loss $\propto$ $4\pi r^2/A_e$

A_e: Antenna aperture $= \lambda^2 Ga/4\pi$

G_a: Antenna gain

The above formula is obtained when Ga = 1 (0 dBi).

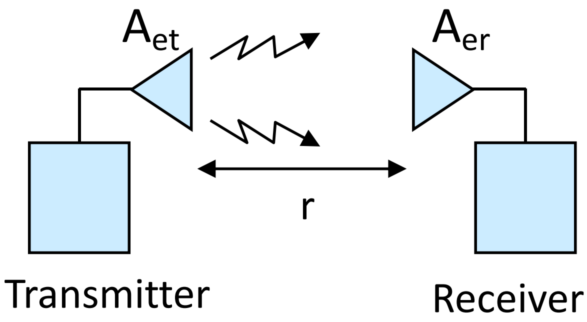
Free-Space Loss (2)

P_r (Rx power) = P_t (Tx power)
+ G_t (Tx antenna gain)
+ G_r (Rx antenna gain)
- 20 log ($4\pi rf/c$) ← Free-space loss

In case of point-to-point link, free-space loss can be compensated with antenna gain, which increases with square of frequency.

【Example】
Free-space loss = 134 dB for 1 km at 120 GHz (λ = 2.5 mm),
And it becomes 34 dB with 50-dBi antennas for Tx & Rx.

Friis' Formula



$$P_r = P_t\,(A_{et}\,A_{er})\,/\,(r\lambda)^2 \quad \propto \; f^{\,2}$$

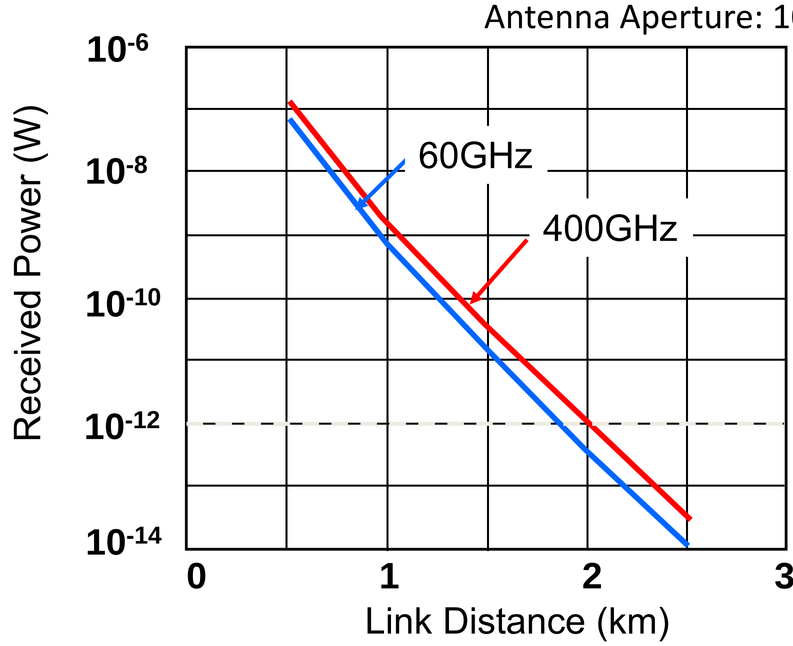
- A_{et} : Effective area of Tx antenna
- A_{er} : Effective area of Rx antenna
- P_r : Transmitted power
- P_t : Received power
- r : Link distance
- λ : Wavelength

Assuming the same antenna size, the received power increases with frequency, resulting in lower transmitted power required.

Case Study: 60GHz vs. 400GHz

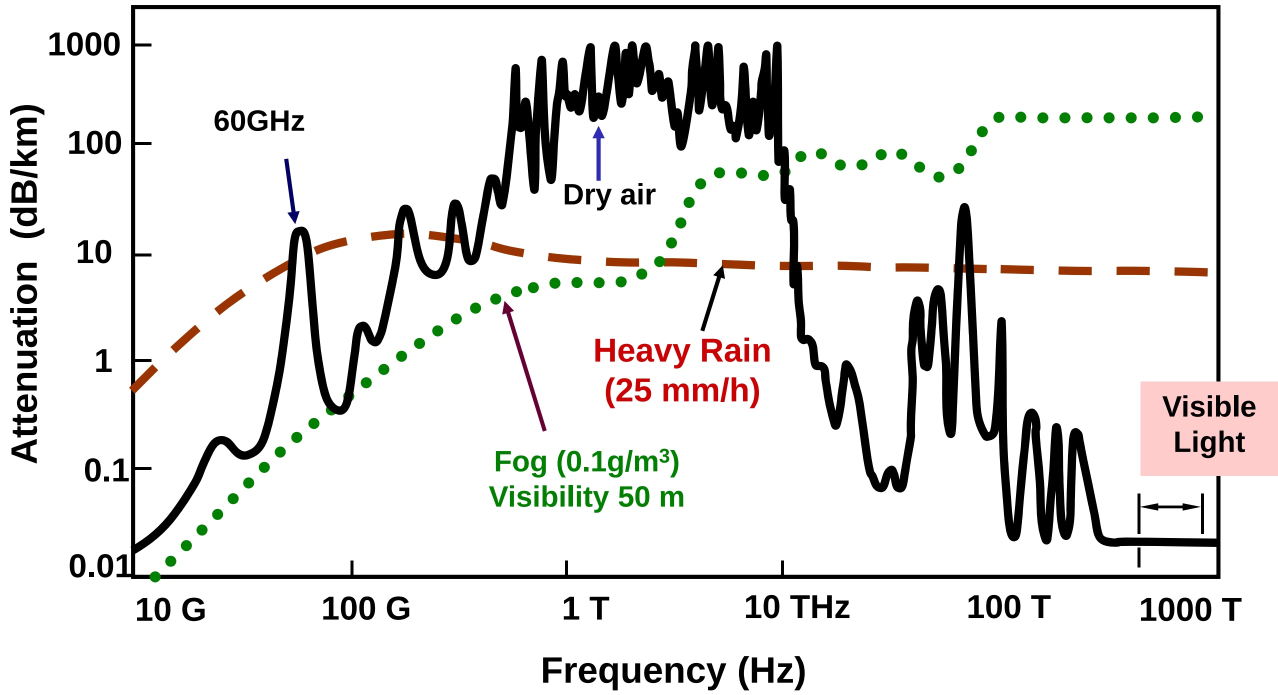
	60GHz	400GHz
Loss due to atmospheric/rain(25mm/h)/fog	27dB	26dB
Transmitted power	100mW	4 mW

Antenna Aperture: 10cmx10cm

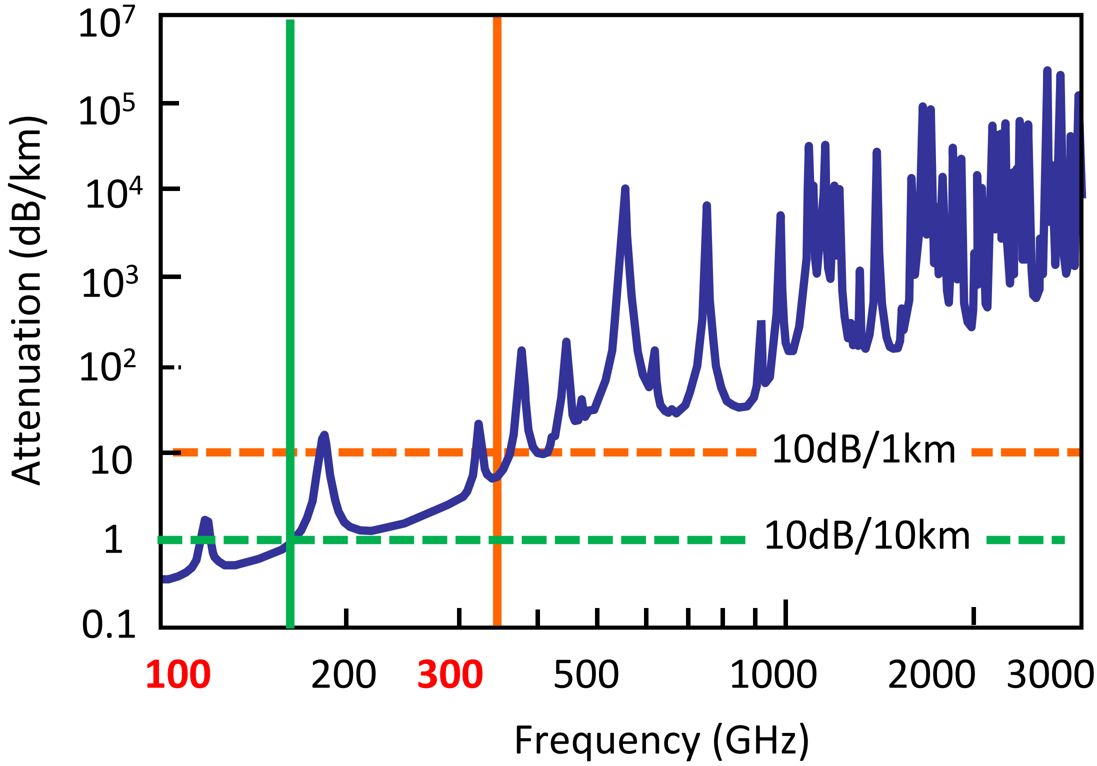


C. M. Mann, in "Terahertz sources and systems", Kluwer, 2001, p. 261.

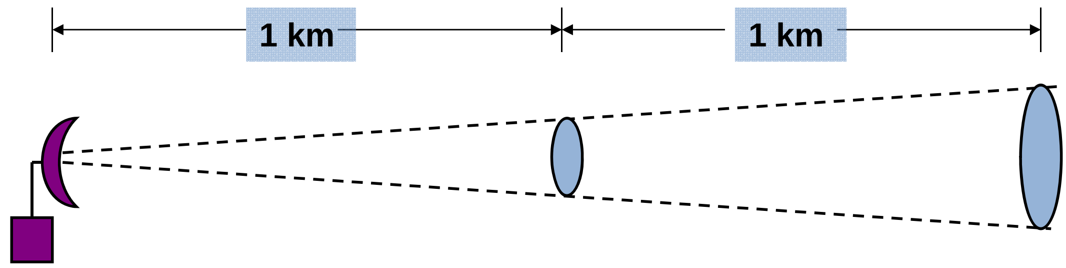
Attenuation by Air/Rain/Fog



Atmospheric Attenuation: Mid. Distance



Impact of Attenuation by Rain

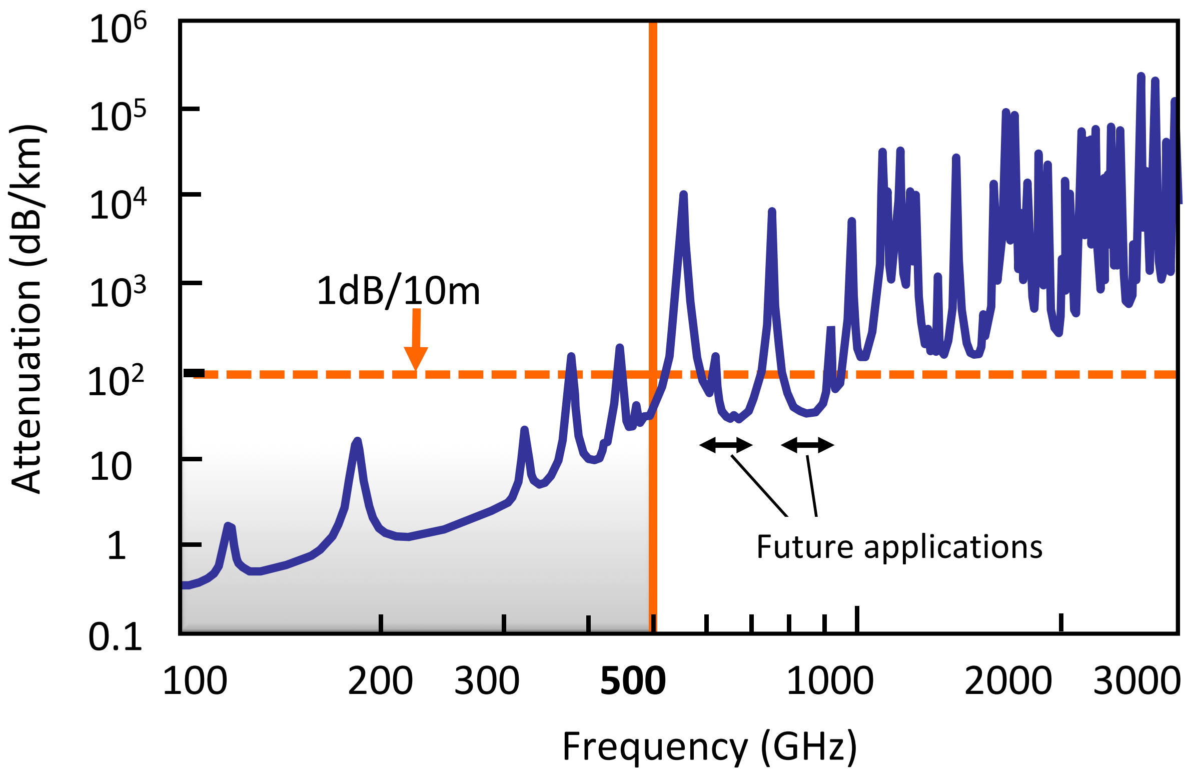


Fair condition	100 μW	25 μW (inversely proportional to square of distance)
Rain atten.: 10dB/km	10 μW	250 nW
Rain atten.: 20dB/km	1 μW	2.5 nW
Rain atten.: 30dB/km (=60dB/2km)	100 nW	25 pW

3 orders

6 orders

Atmospheric Attenuation: Short Distance

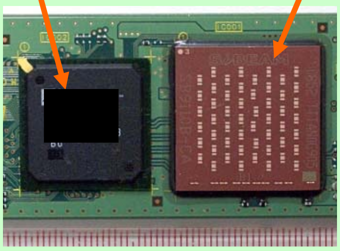


60 GHz vs. 300 GHz

60GHz band

LSI for Baseband Signals

Array Antenna

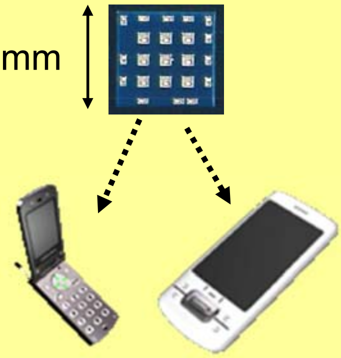


25mm

300GHz band

Reduction of size: 1/5 (area: 1/25)

2~5mm



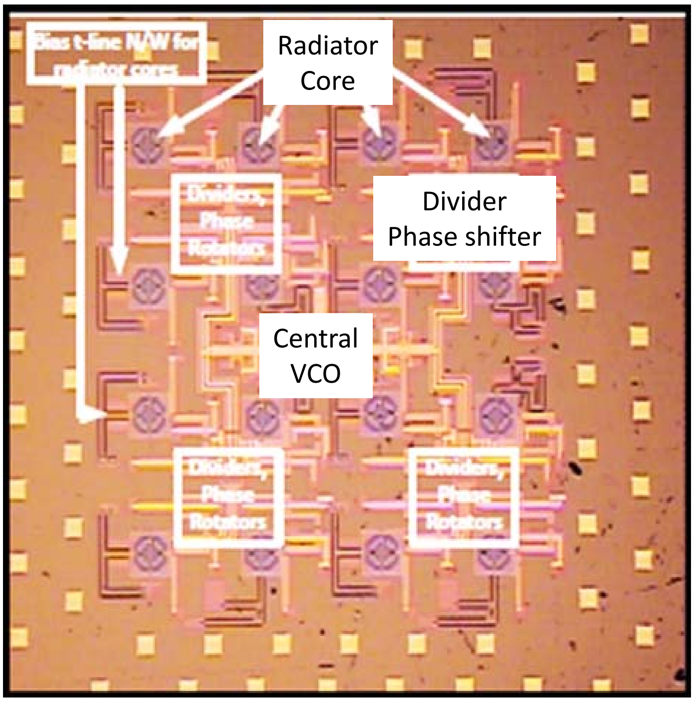
Possible to use for consumer devices
→market opportunity

Usage and Requirements

Usage	Environment	Distance	Condition	Beam Positioning
Fixed wireless access (FWA)	Backbone NW link Fixed/outdoor	100 m~ a few km	Line of sight Air attenuation	Highly Directive/ Manual
THz nanocell	Mobile NW In/outdoor	<100m	Line of sight Non-LOS (dynamically changed)	Automatic positioning required
WLAN/WPAN	Link to access point Mainly indoor	<10~100 m	Same as above	Same as above
Kiosk download	Indoor/mobile	<0.1~1 m	LOS Tx/Rx Multiple reflection	Same as above (manual is OK)
Short distance device connection	Indoor Mainly on desk	<0.1 m	LOS Multi-pass	Same as above
Board-to-board connection	In computers/ instruments	<0.1 m	Same as above	Almost fixed

Example of Beam Steering Techniques

K. Sengupta and A. Hajimiri (Caltech), ISSCC 2012



45 nm CMOS
4x4 array
2.7mm x 2.7mm
BW: 276-285 GHz
Beam angle: 80 degree
Output power: 190 μW

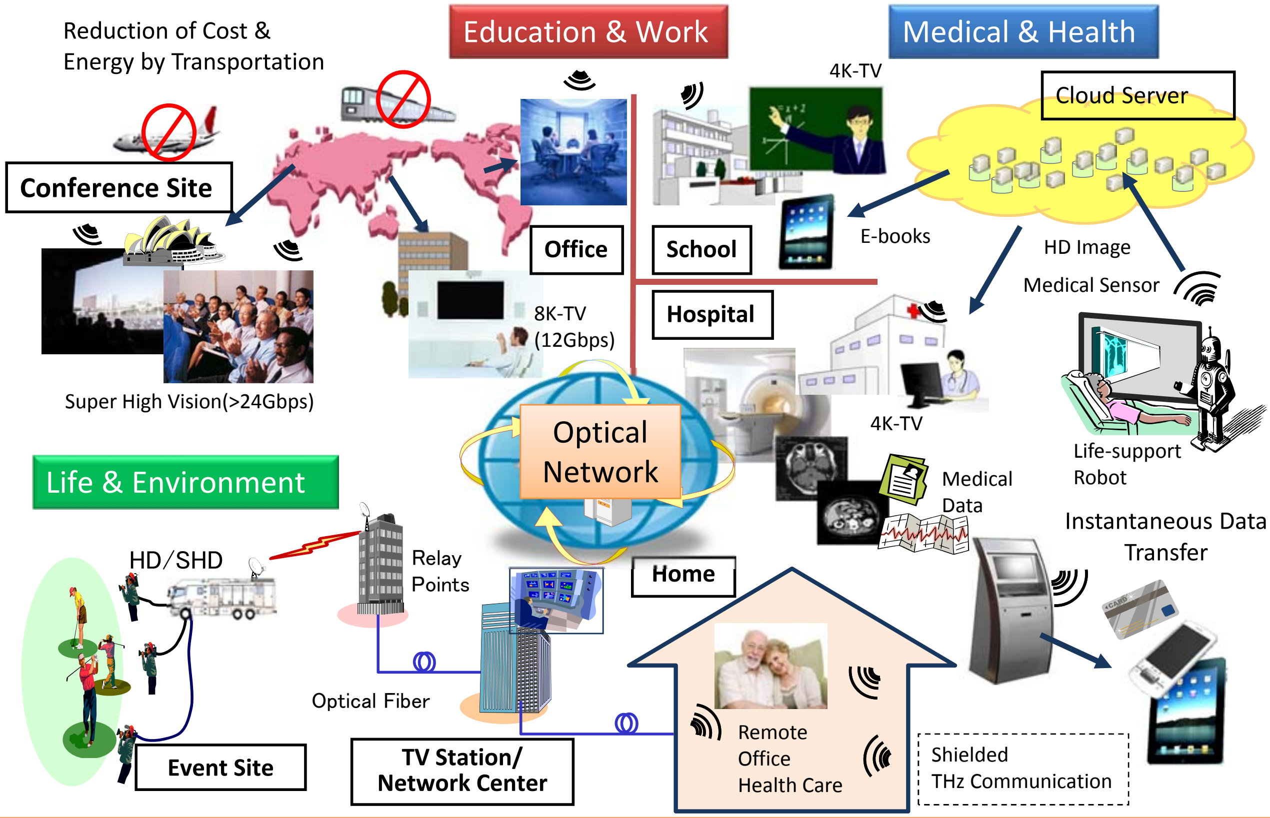
Who pays for THz Com. ??

1) **Broadcasting**
uncompressed HD x N:1.5 Gbit/s x N
uncompressed UHD (SHV): 24 Gbit/s, 42, 72…
uncompressed 3D w/ HD or UHD → >100 Gbit/s

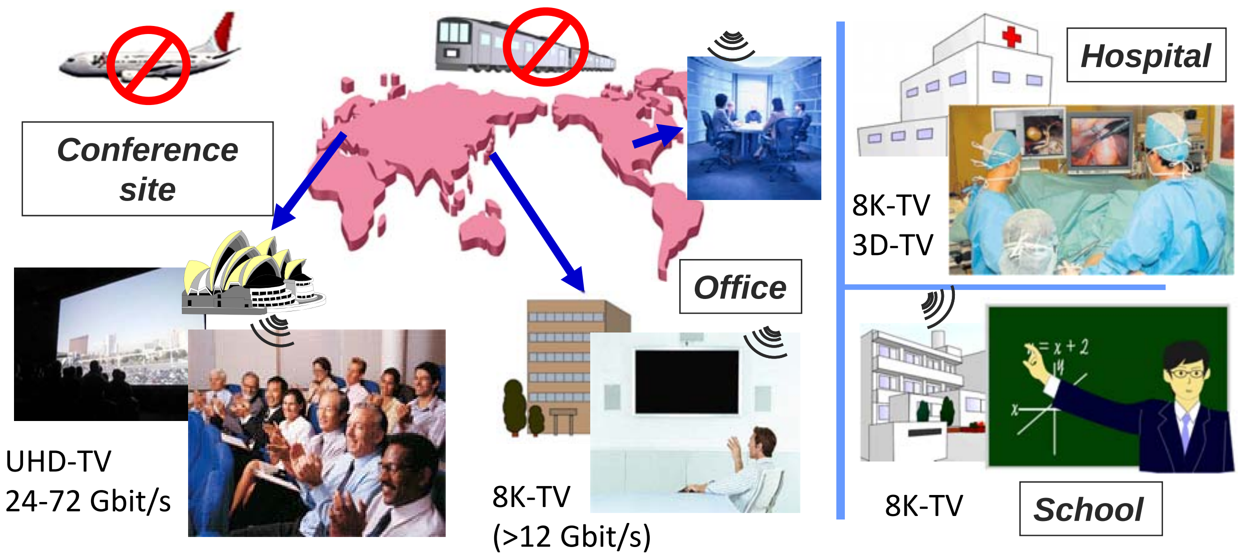
2) **Medical**
more reality in color and increased resolution for diagnosis
huge image data handled at real time for surgery
wireless data transfer required in surgery rooms
no latency for remote medicine

3) **General consumer** ??
cheaper and smaller

Expected Applications



Big Wall Displays Change Our Life

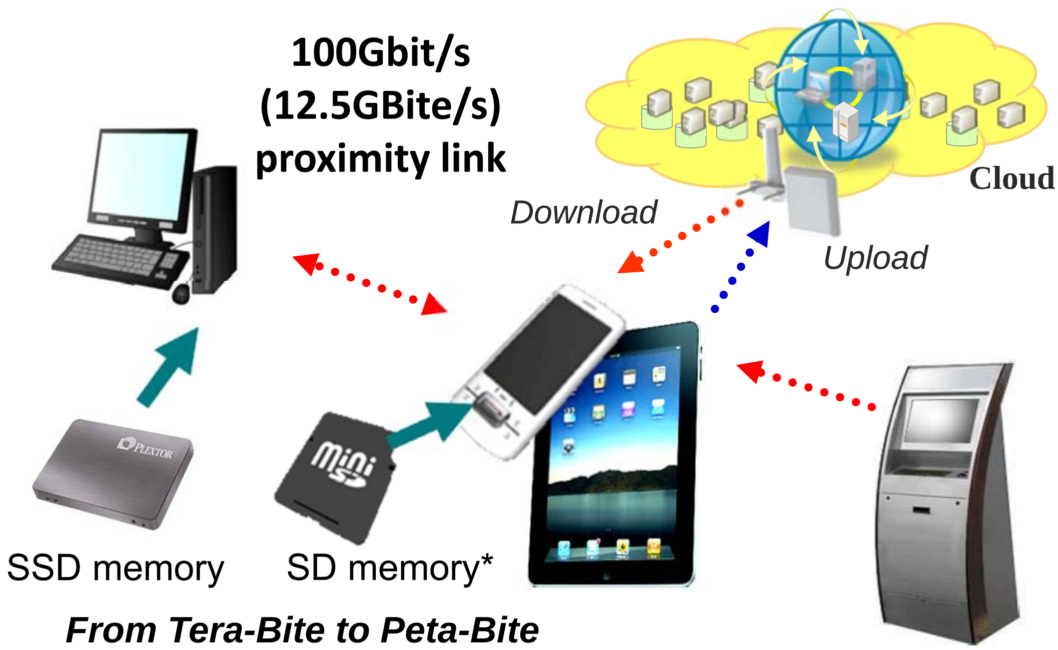


Big wall-displays provide highly realistic-sensation remote communications, and a wireless will be truly user's demand.

Smart Phone with Wall Displays

Courtesy of David Britz, AT&T

Big Data: from Store to Circulation



From Tera-Bite to Peta-Bite

We will carry only "smart phone" with huge memory, when instantaneous wireless transfer of big data becomes possible

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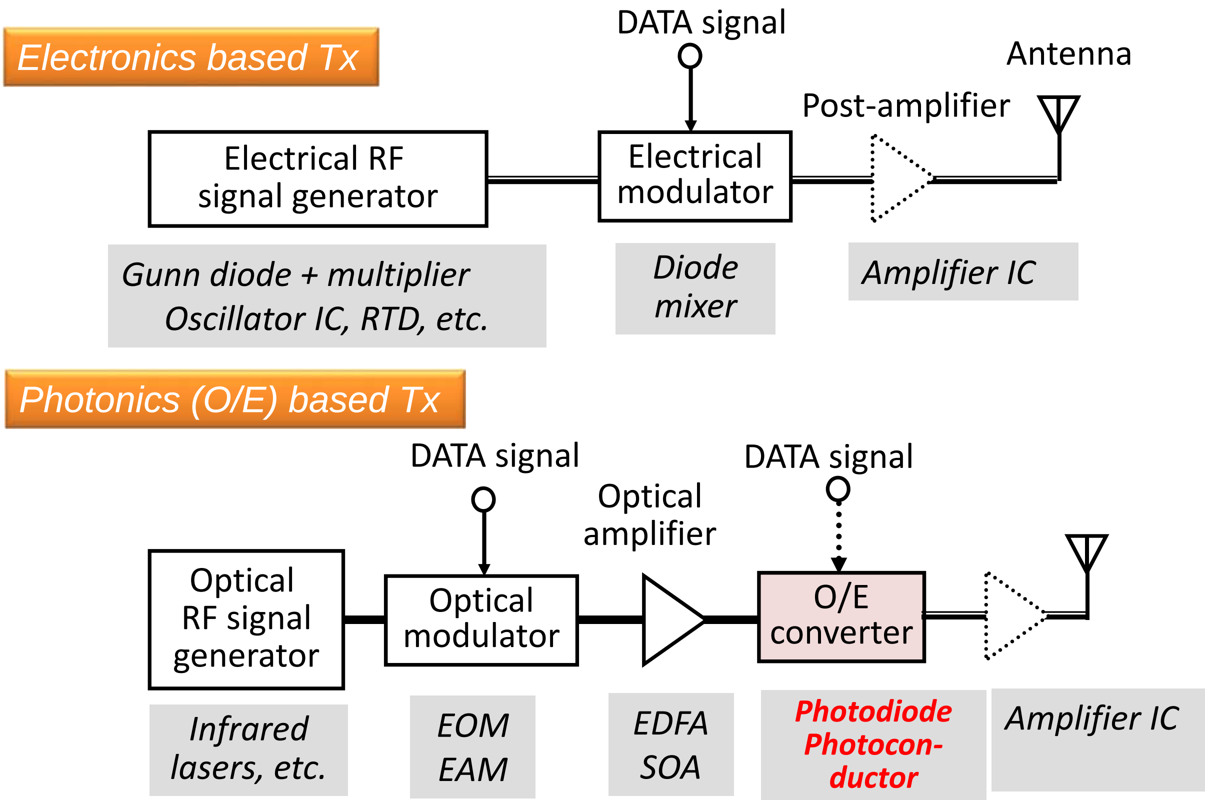
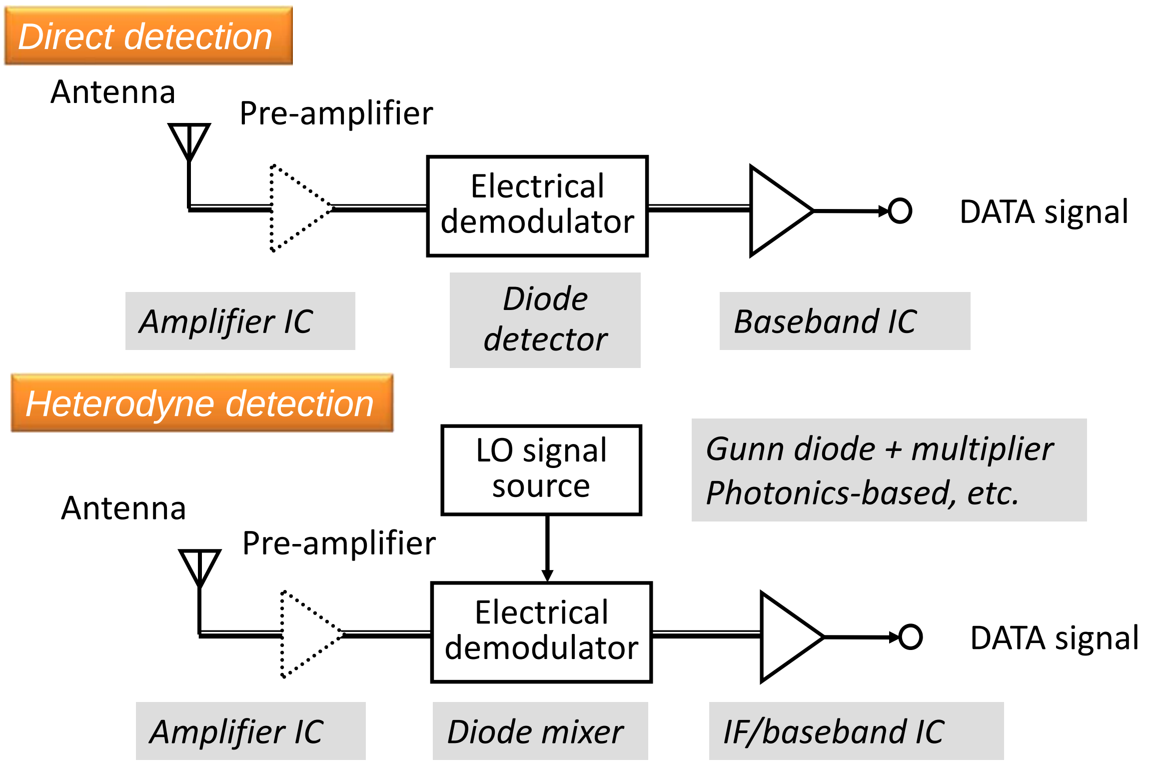
Enabling Technologies: Tx



Enabling Technologies: Rx



Recent Developments(1)

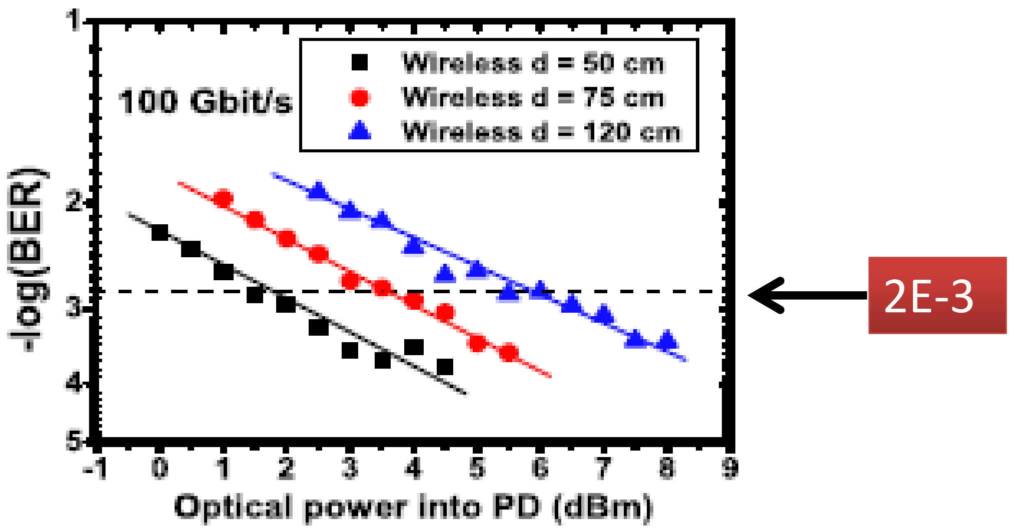
Carrier Frequency	Technology		Max. Bit rate **(Error free)**	Affiliation
	Tx	Rx		
120 GHz	Photonics-based	MMIC(InP) (direct det.)	10 Gbit/s	NTT
120 GHz	MMIC(InP)	MMIC(InP) (direct det.)	20 Gbit/s (with pol.MUX)	NTT
120 GHz	MMIC(CMOS)	MMIC(CMOS) (direct det.)	9 Gbit/s	Hiroshima U.
146 GHz	Photonics-based	Disc. comp. (heterodyne det.)	1 Gbit/s	UCL III-V Lab UC3M
200 GHz	Photonics-based	Disc. comp. (heterodyne det.)	1 Gbit/s	IEMN
220 GHz	MMIC(GaAs)	MMIC(GaAs)	~15 Gbit/s	Fraunhofer IAF
250 GHz	Photonics-based	Disc. comp. (direct det.)	8 Gbit/s	NTT Osaka-U

Recent Developments(2)

Carrier Frequency	Technology		Max. Bit rate **(Error free)**	Affiliation
	Tx	Rx		
300~400GHz	Photonics-based	Disc. comp. (direct det.)	24 Gbit/s	Osaka-U NTT
300 GHz	Frequency multiplier	Disc. comp. (heterodyne det.)	~100 Mbit/s	TU Braun-schweig
300 GHz	Frequency multiplier	Disc. comp. (heterodyne det.)	~1.5 Gbit/s	ETRI
300 GHz	Resonant-tunneling diode	Resonant-tunneling diode	2.5 Gbit/s	Rohm Osaka-U
542 GHz	Resonant-tunneling diode	Disc. comp. (direct det.)	1~2 Gbit/s	Tokyo Inst. Tech
625 GHz	Frequency multiplier	Disc. comp. (direct det.)	2.5 Gbit/s	NJ IT Bell Lab

100 Gbit/s Wireless Reported, But…

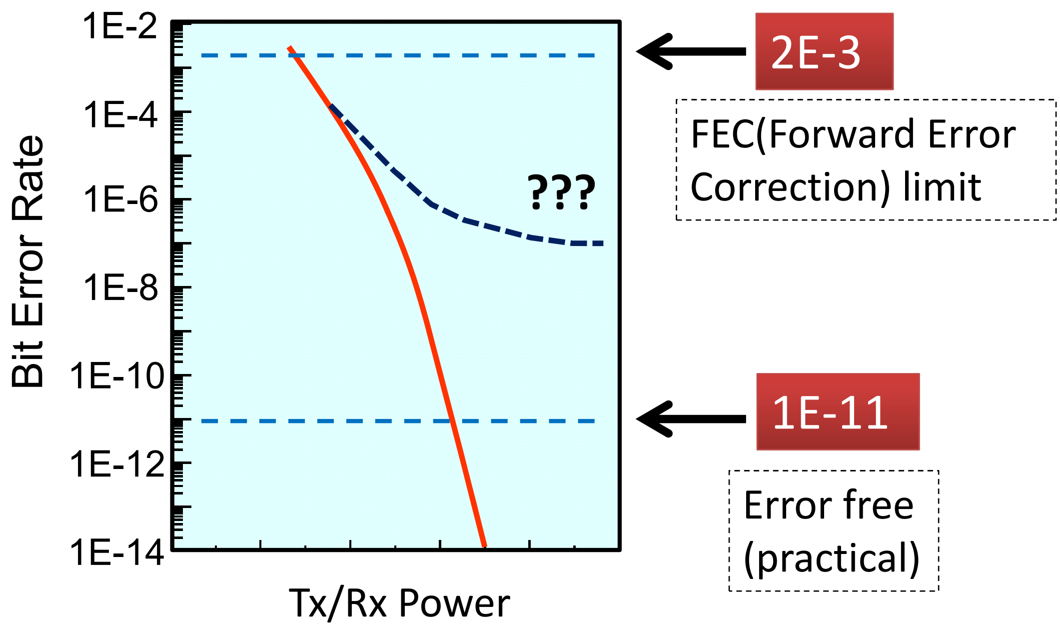
"NOT" error-free result; use of FEC was assumed.
BER was estimated by off-line signal processing.



Multi-level modulation (16QAM) and pol. MUX using W-band (75GHz-110GHz)
X. Pang et al., OPTICS EXPRESS, Vol. 19, No. 25, 24945(2011).

Pursuing "Error Free"

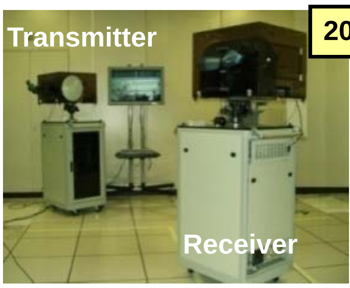
Bit Error Rate (BER) =
number of errors / total number of bits sent

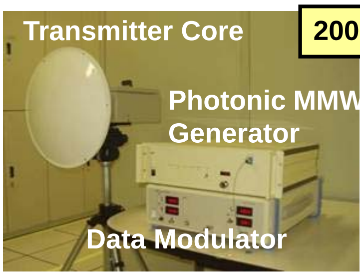


BER Movie

120 G: Hardware Evolution in 10 years

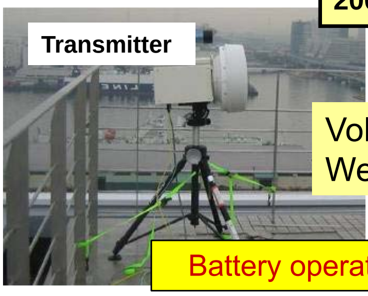
Photonics-based Transmitter





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

Electronics-based Transmitter

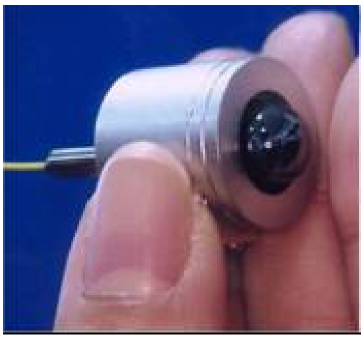


Volume: 1/6
Weight: 1/2

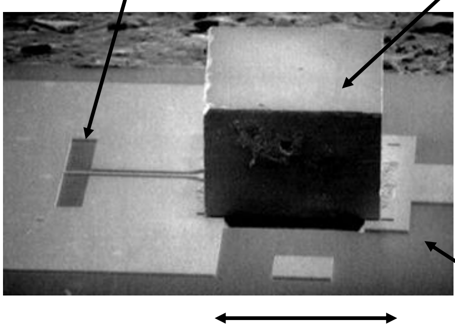
- Output power：10 mW, 2.2 km
- Power consumption：60 W

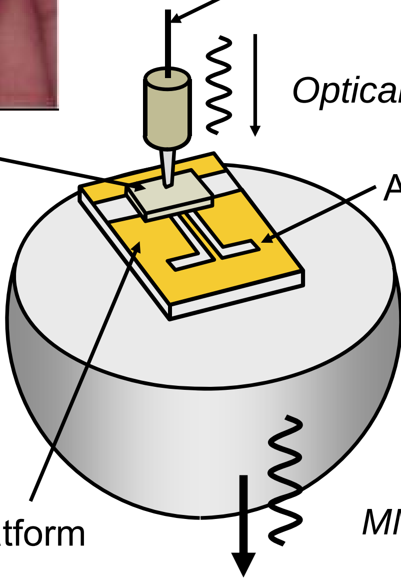
Easy set-up system

Initiated by Photonics



Microwave Photonics 2000

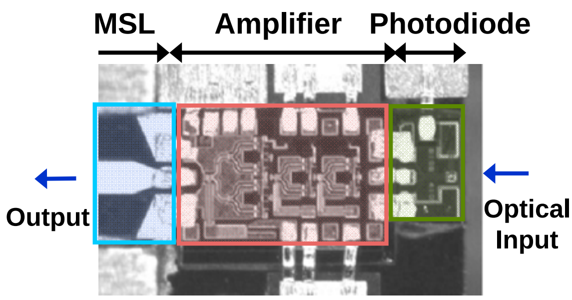




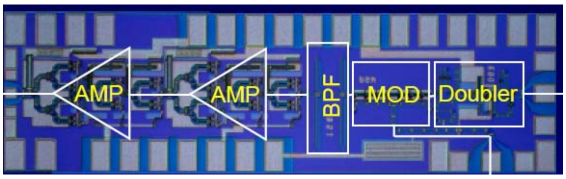
Powered by MMICs

Transistors and amplifiers change the world

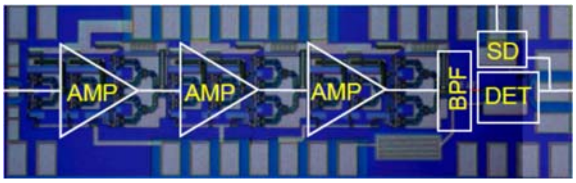
Transmitter (photonics based)



Transmitter MMIC

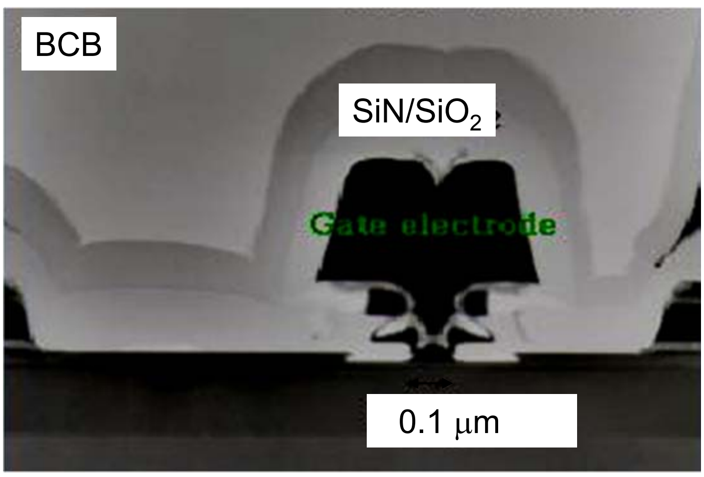


Receiver MMIC



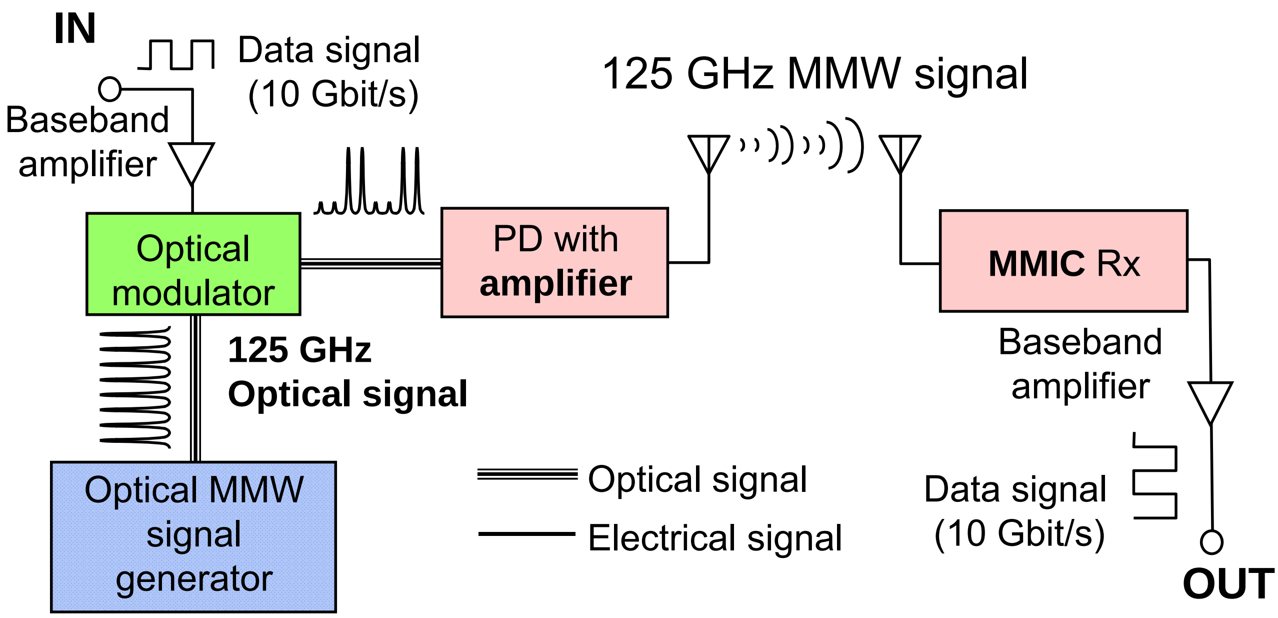
Electronic Devices: InP HEMT

- 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



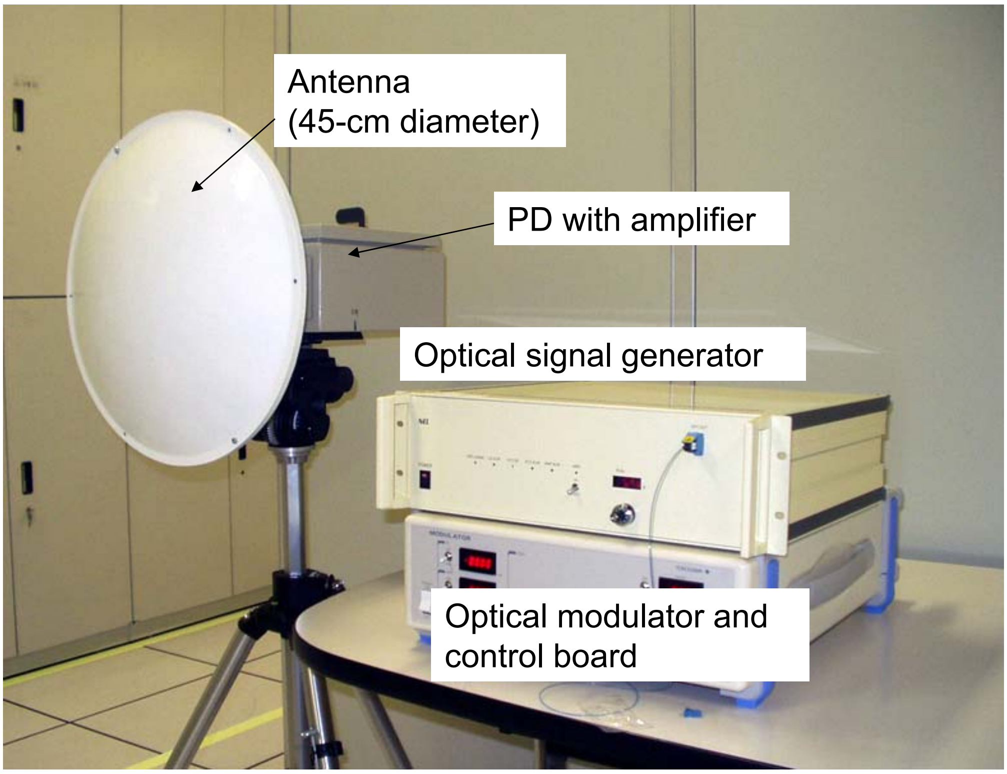
Fully matured production level technology (NTT Electronics)

120-GHz-band System with Photonic Tx



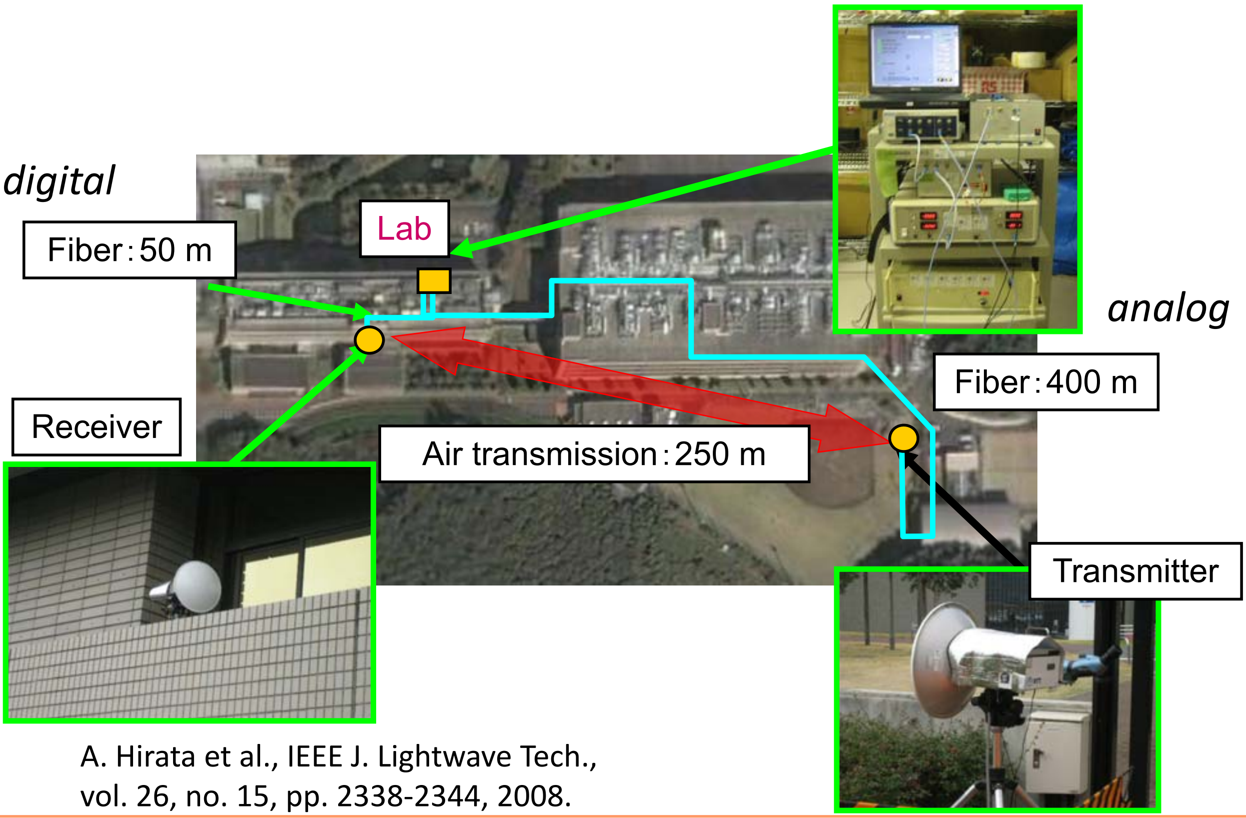
A. Hirata et al., IEEE Trans. Microwave Theory Tech., vol. 54, pp.1937-1944, 2006.

120-GHz Band Transmitter



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

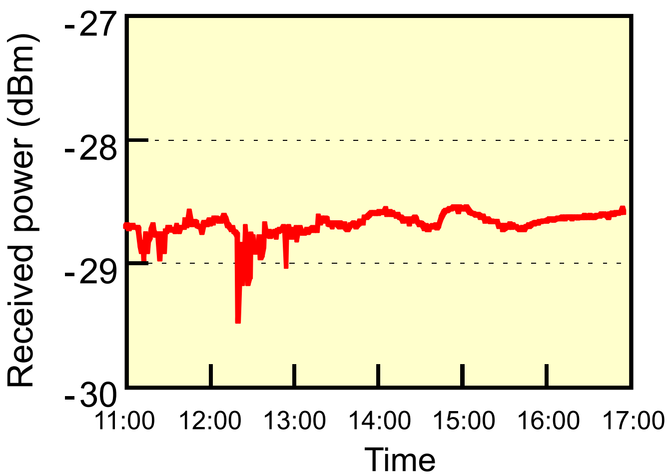
Setup for Field Test



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

Transmission Characteristics

Receiver power



Bit error rate (BER)

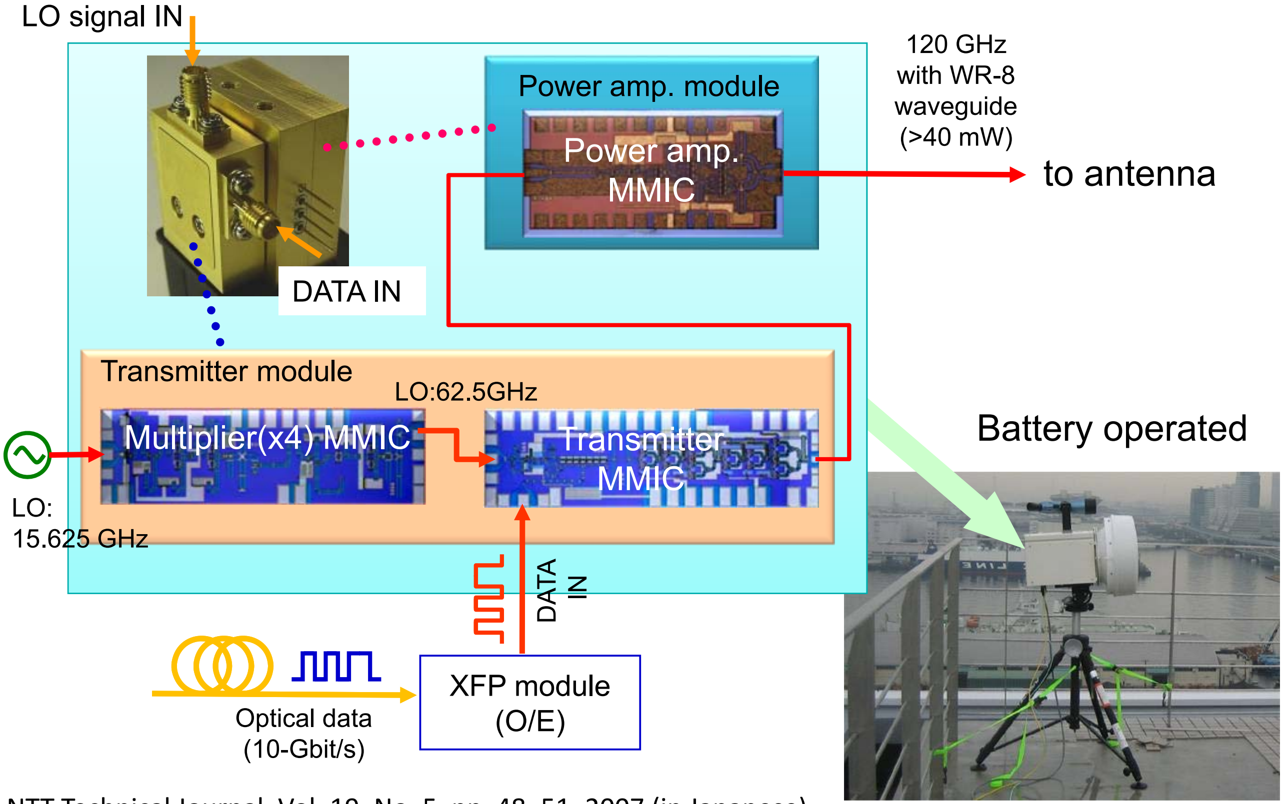
	Total number of bit errors	BER
1st day	3	$1X10^{-14}$
2nd day	5	$2X10^{-14}$
3rd day	13	$5X10^{-14}$

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

→ Meets OC-192 and 10GbE standards

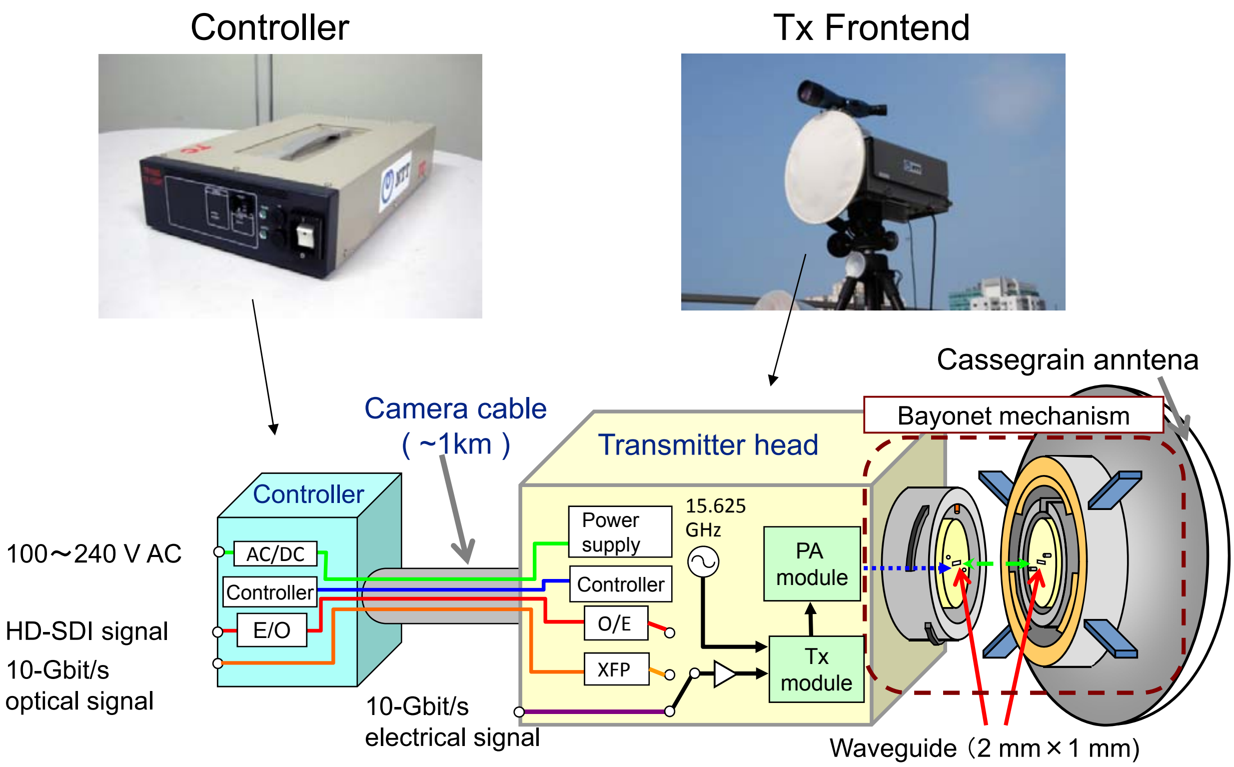
A. Hirata et al., IEEE J. Lightwave Tech., vol. 26, No. 15, pp. 2338-2344, 2008.

120-GHz-band Transmitter with Electronics



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

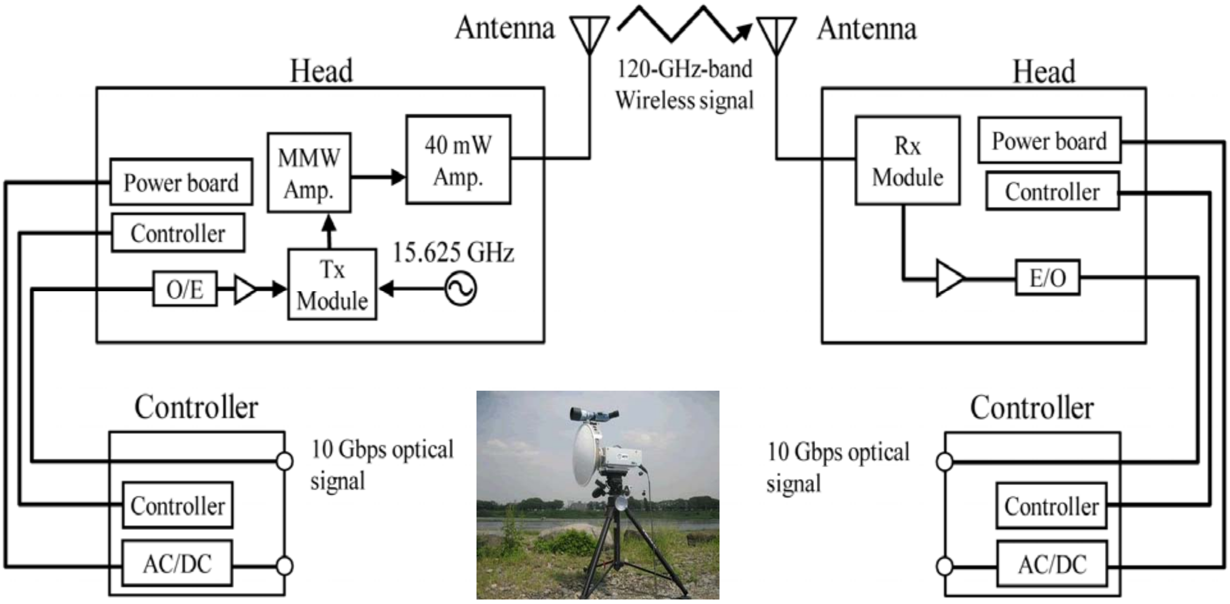
Advanced All-Electronics System



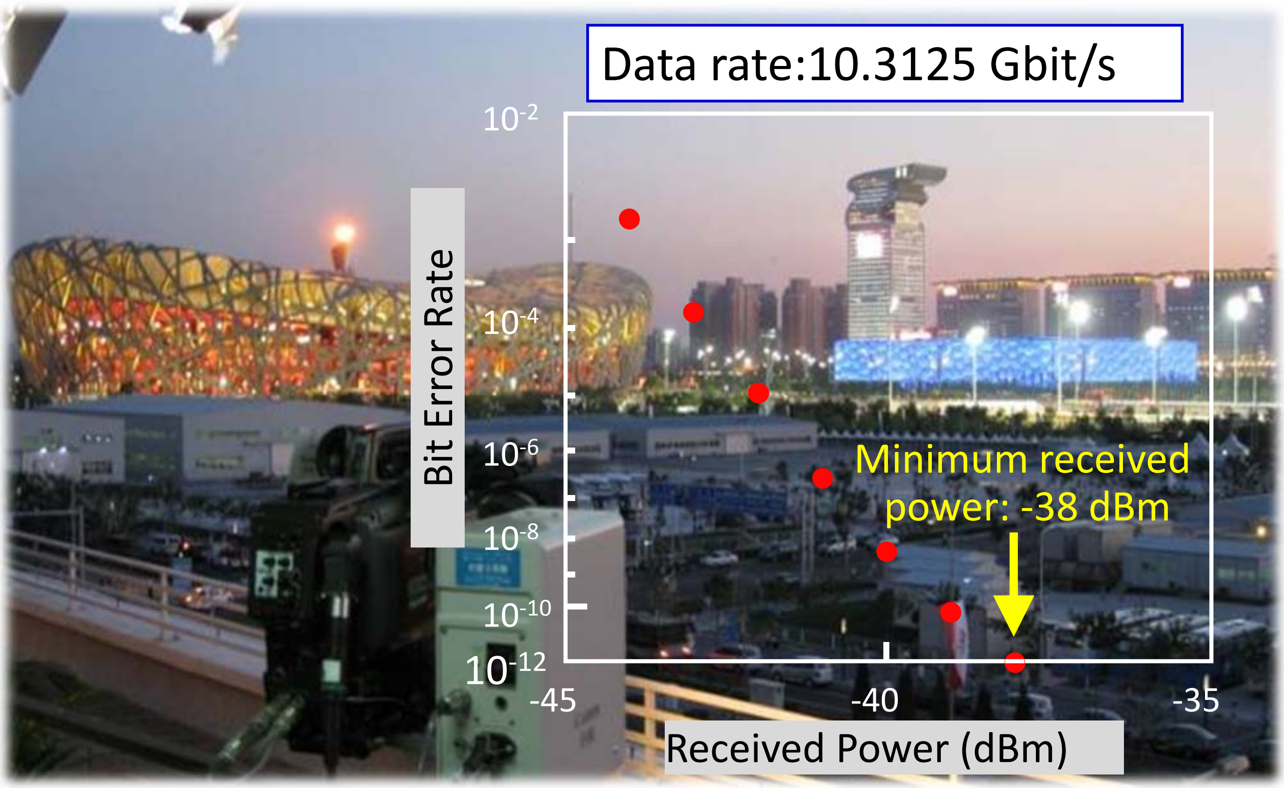
NTT Technical Review, vol. 7, no. 3, Mar. 2009

120 G: Now

10 Gbit/s, >5 km, InP-HEMT MMIC with FEC
Bidirectional with polarization multiplex



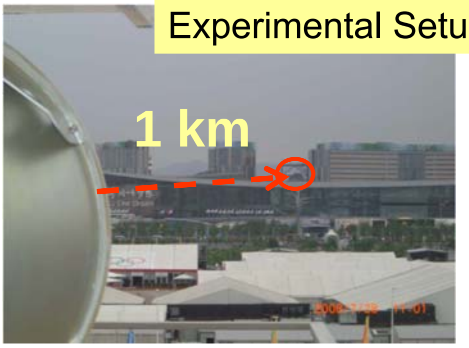
120 G @ Beijing Olympic

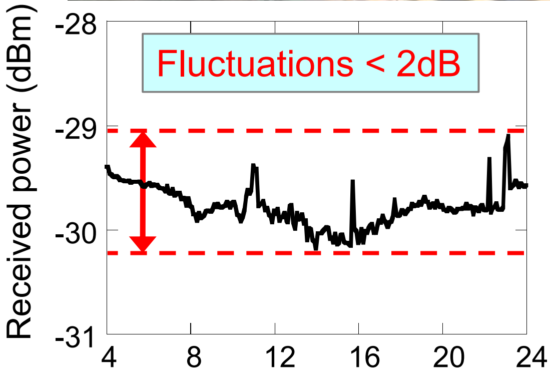


Results of 120 G @ Olympic

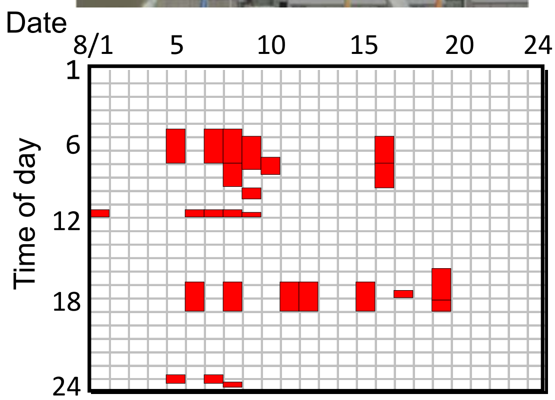
View from BMC

Experimental Setup



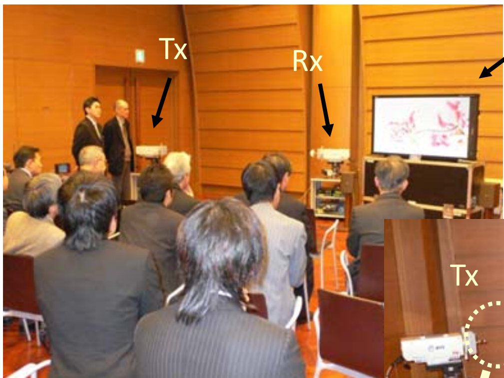


Received power on August 8
(Opening day of Olympics)



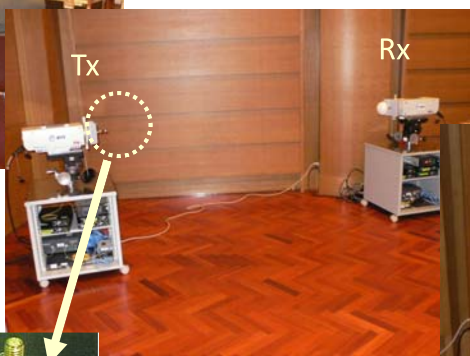
TV programs with 120-GHz system

Indoor 4-K Digital TV Transmission (<10 m)

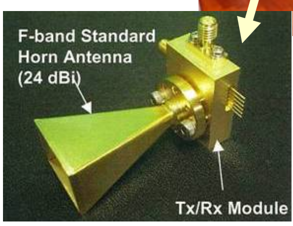


4-K Display

Link Distance < 10 m

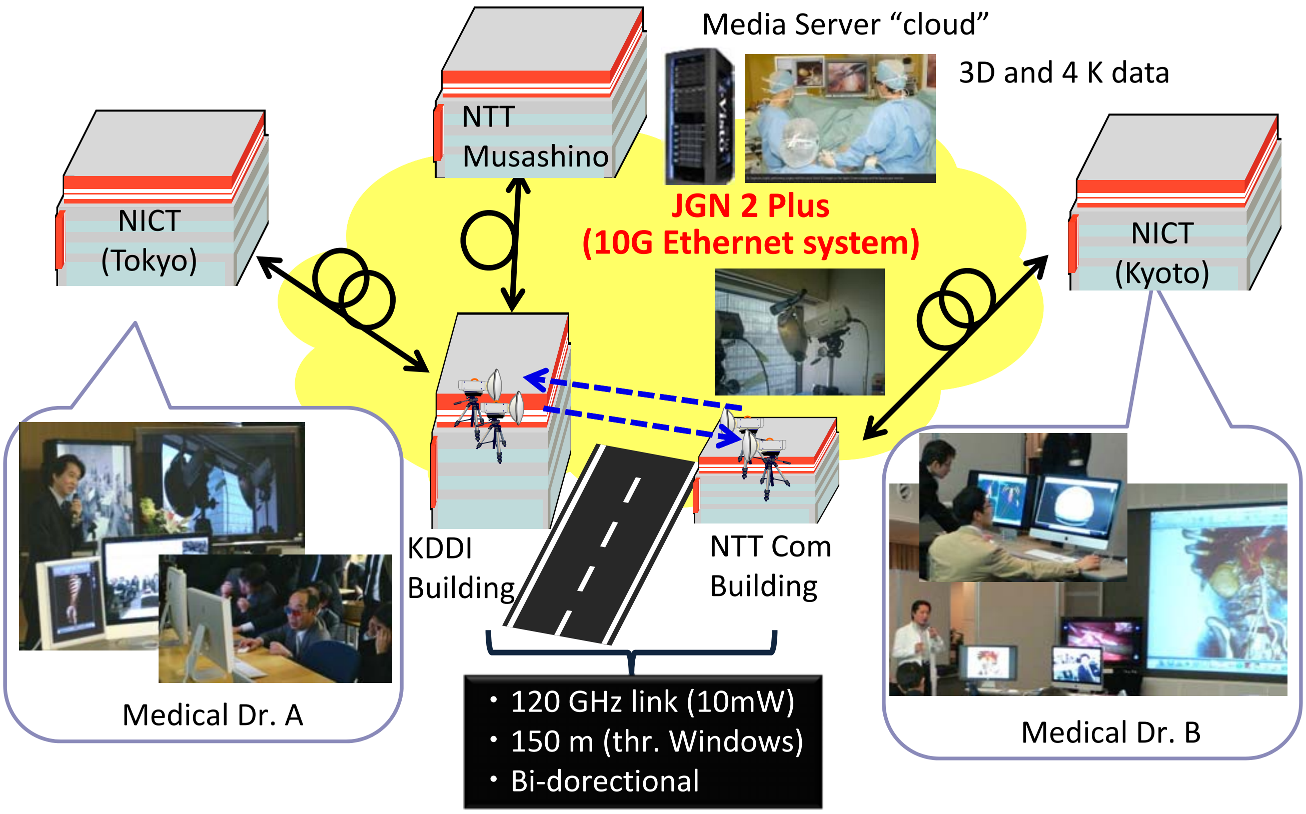


"Small Antenna"



30 mm

Teleconference with 10-G Wired & Wireless



Outline

- Background and motivation
  needs for high-speed wireless
  why THz?
  who pays for THz wireless?
- Enabling Technologies
  photonics vs. electronics
- Photonics-base approach
  direct detection
  coherent detection
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- Future issues
- Summary

Photonics-based Tx & Direct Detection

Seamless between fiber-optic and wireless

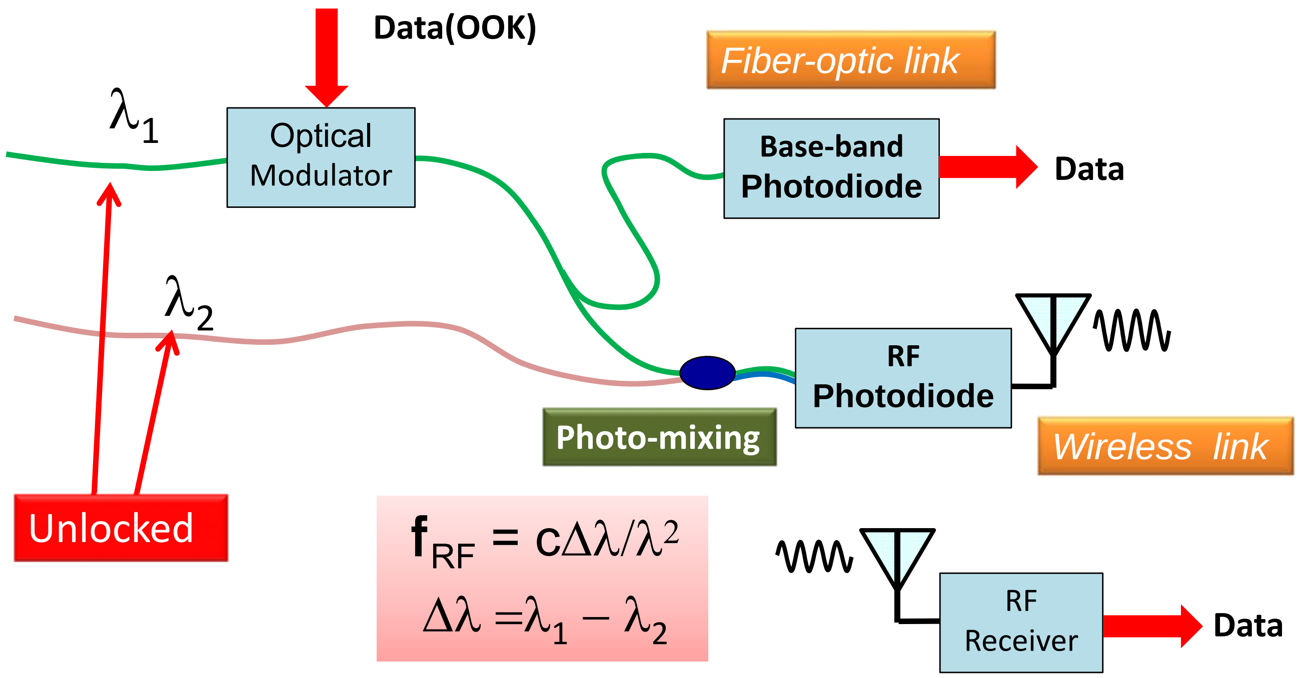
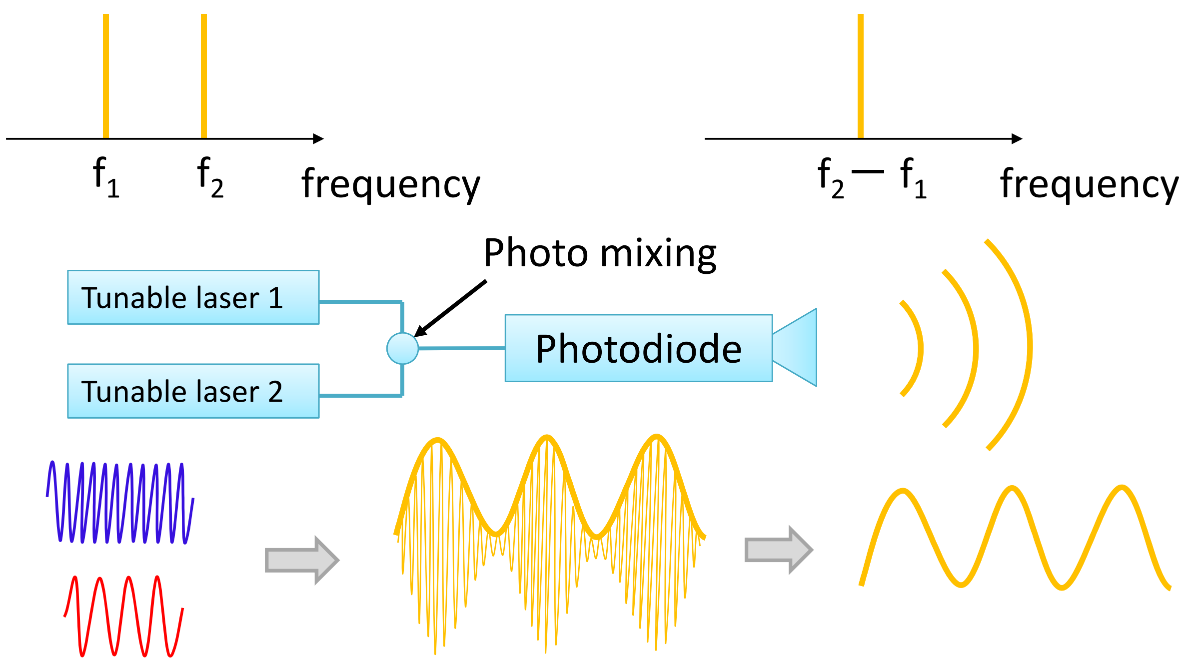


Photo-mixing



300-GHz Band Experiment

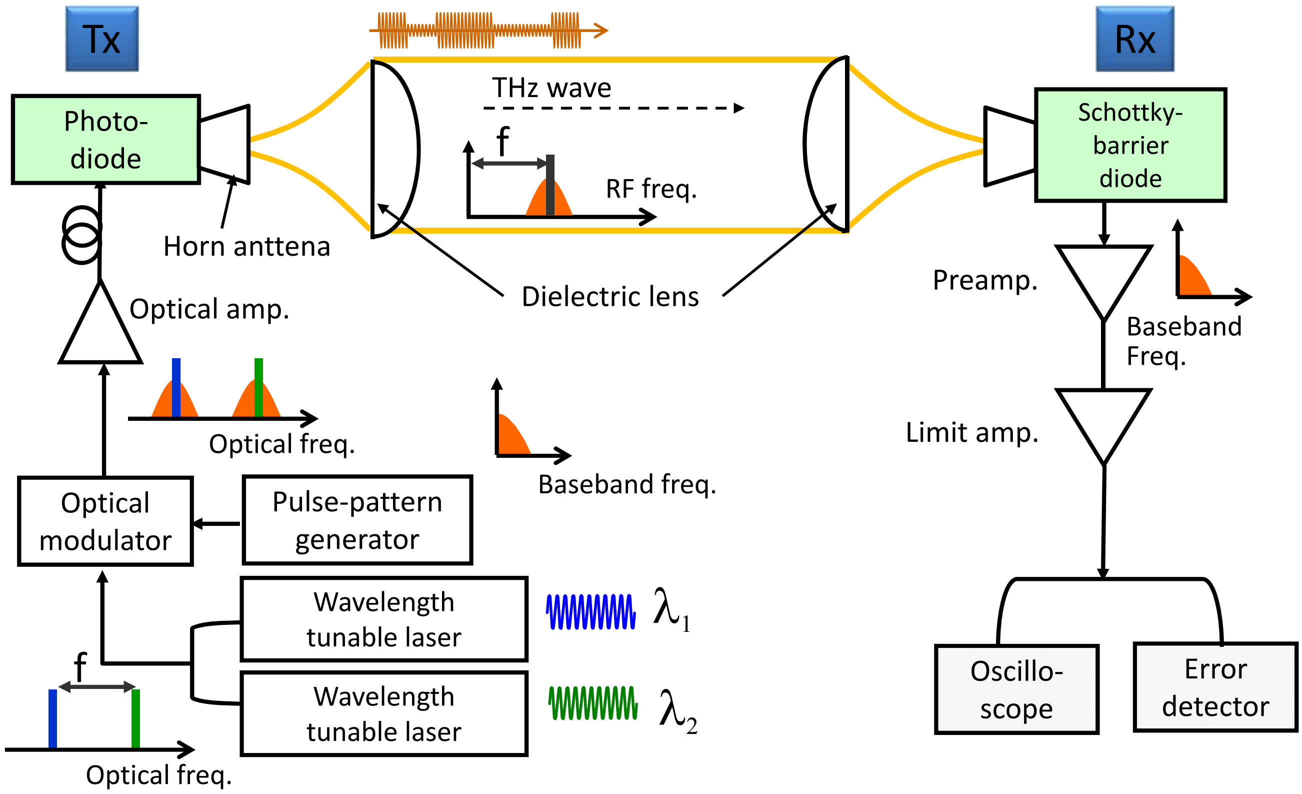
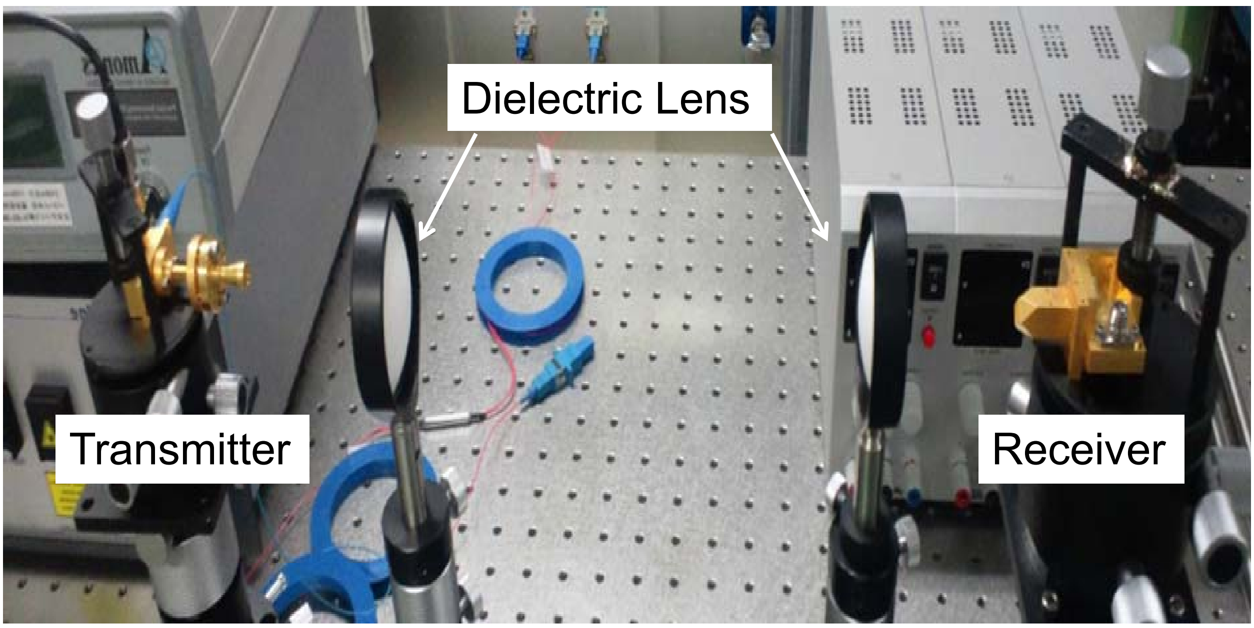
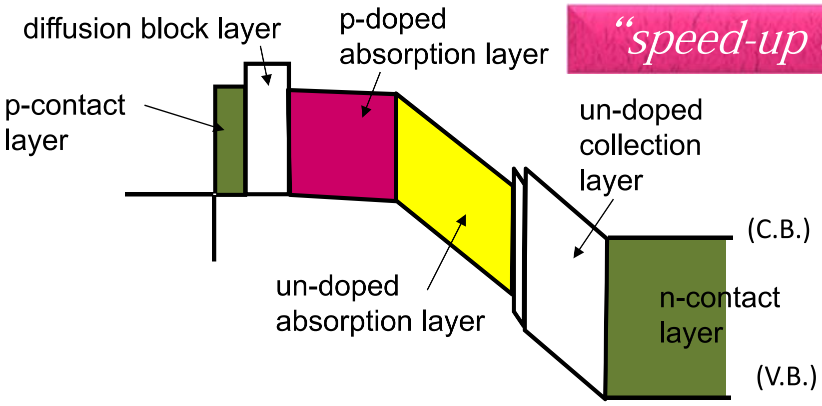


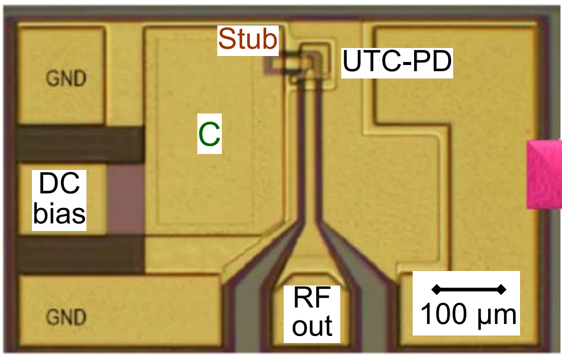
Photo of Setup



Fast Photodiode Technology

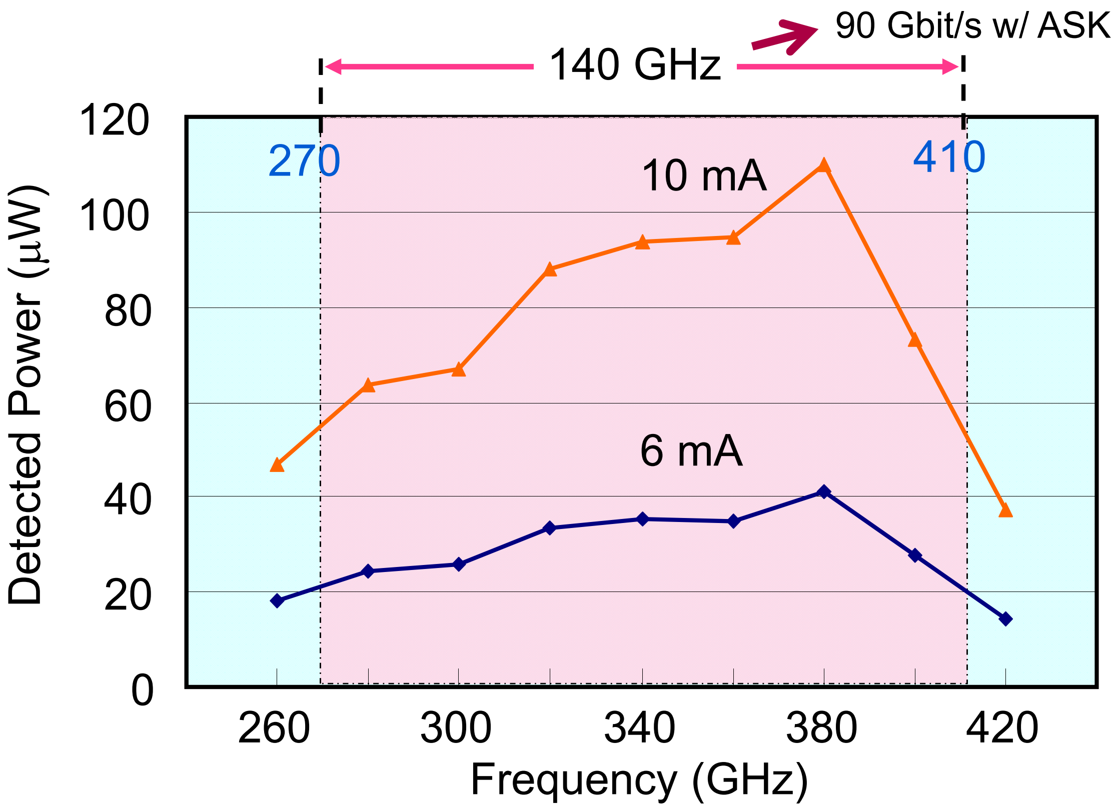


"speed-up carrier transit"



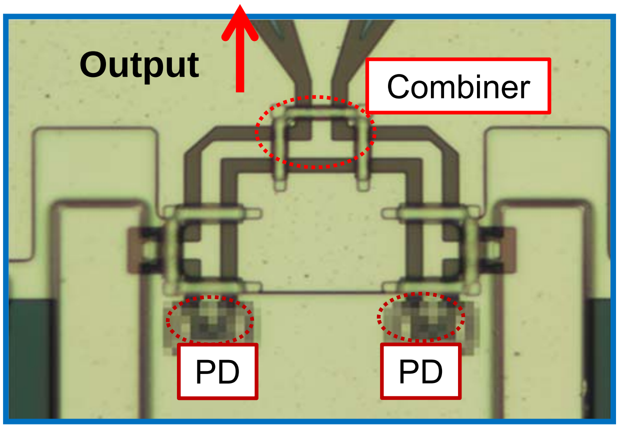
"relax CR time constraint"

Output Power at 300-400 GHz



Increasing Output Power

Chip Structure



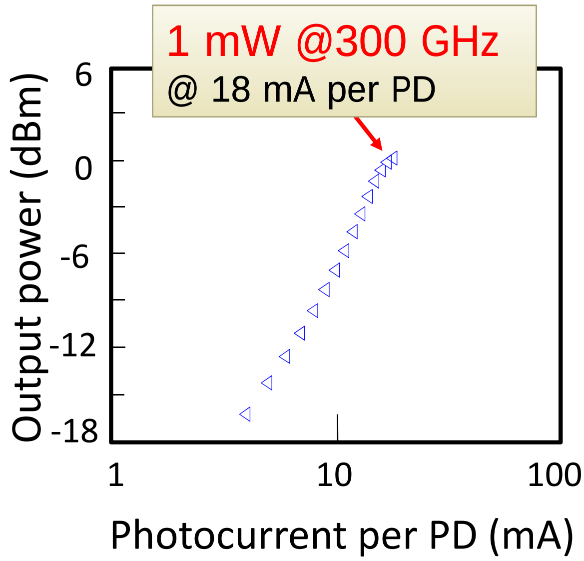
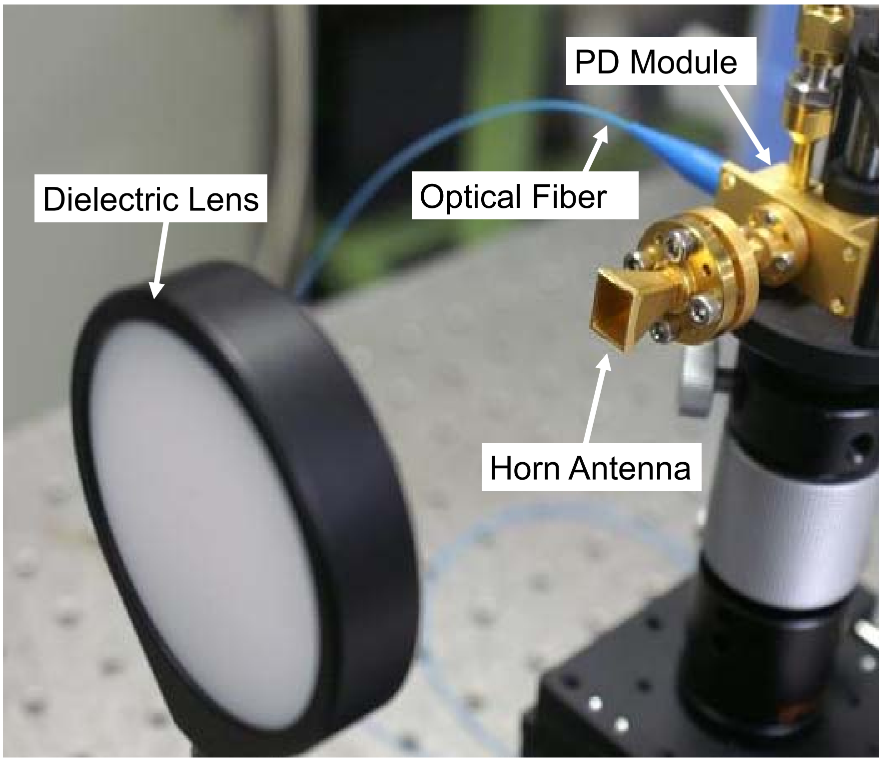
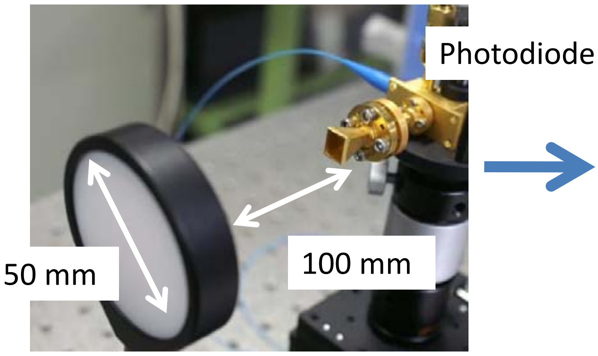
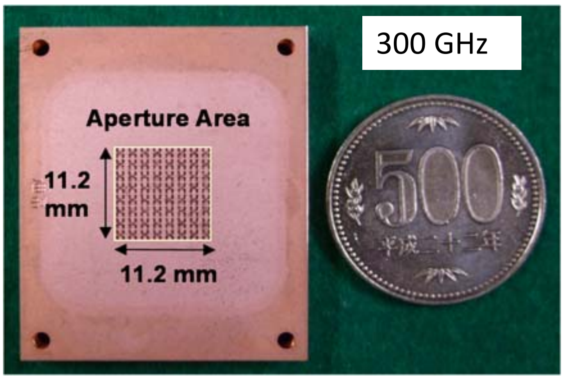


Photo of Transmitter

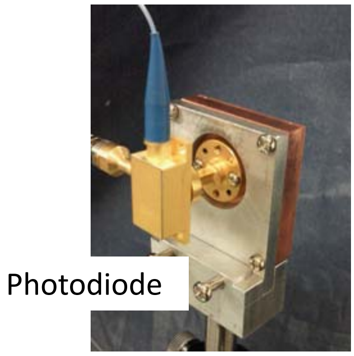


New Antenna Technology





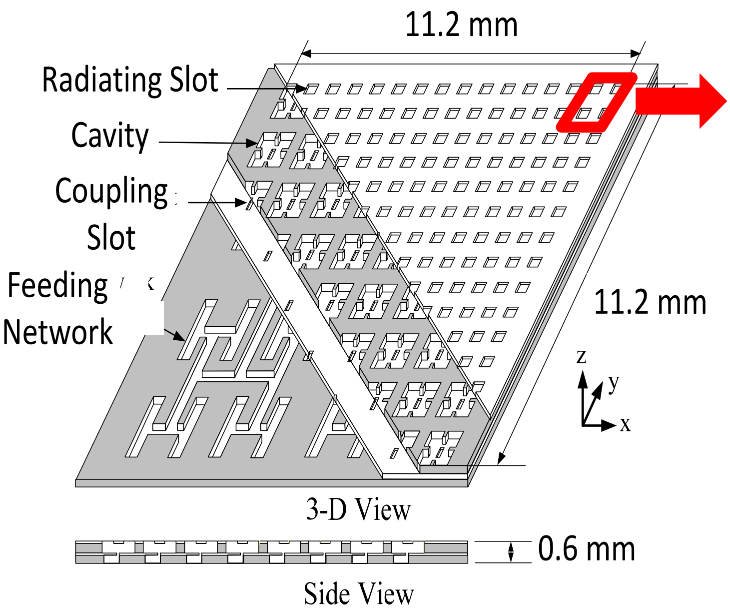
Collaboration with
J. Hirokawa and M. Ando
(Tokyo Inst. Tech)

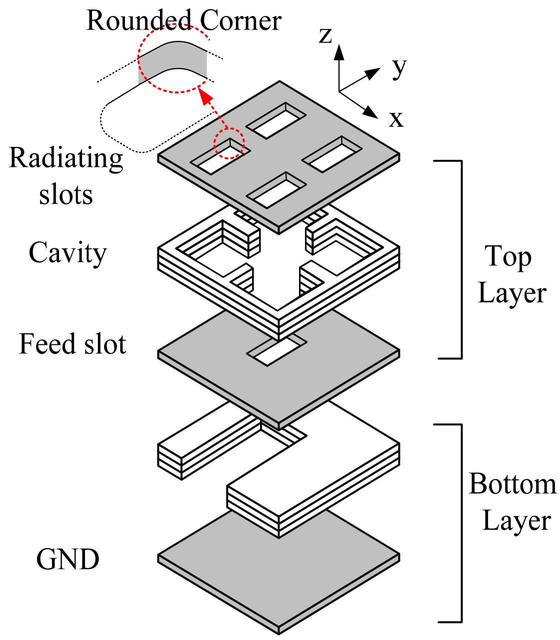


Low-profile Array Antenna

Plate-laminated waveguide slot array antenna

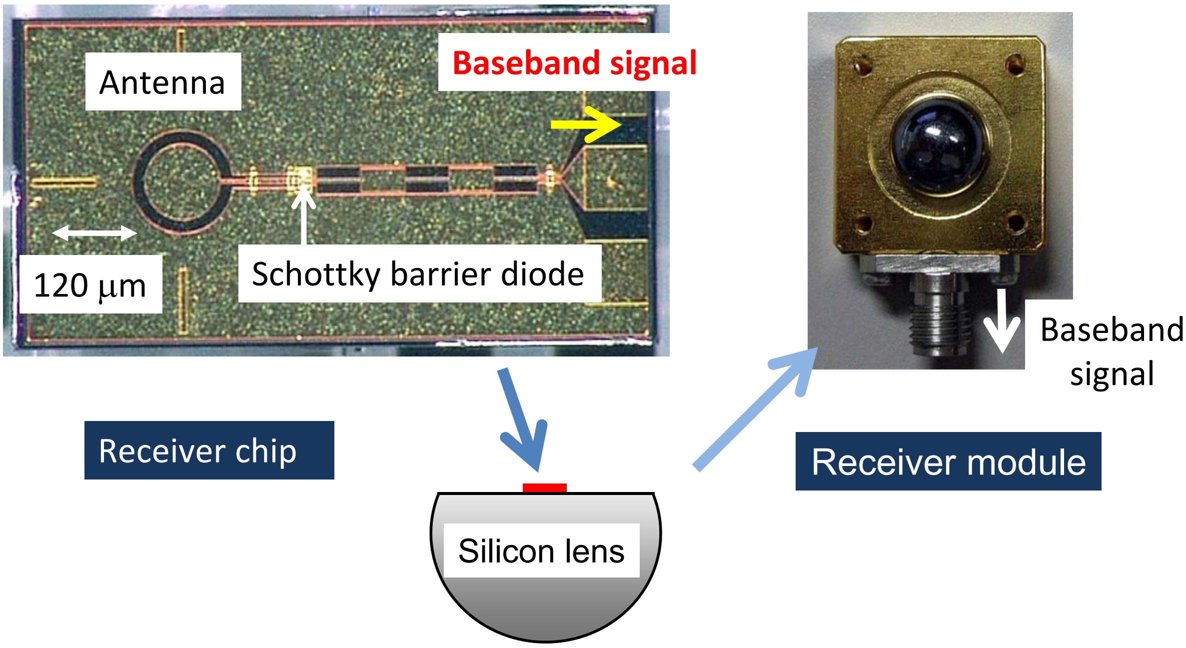
16 x 16 (256), 32 dBi



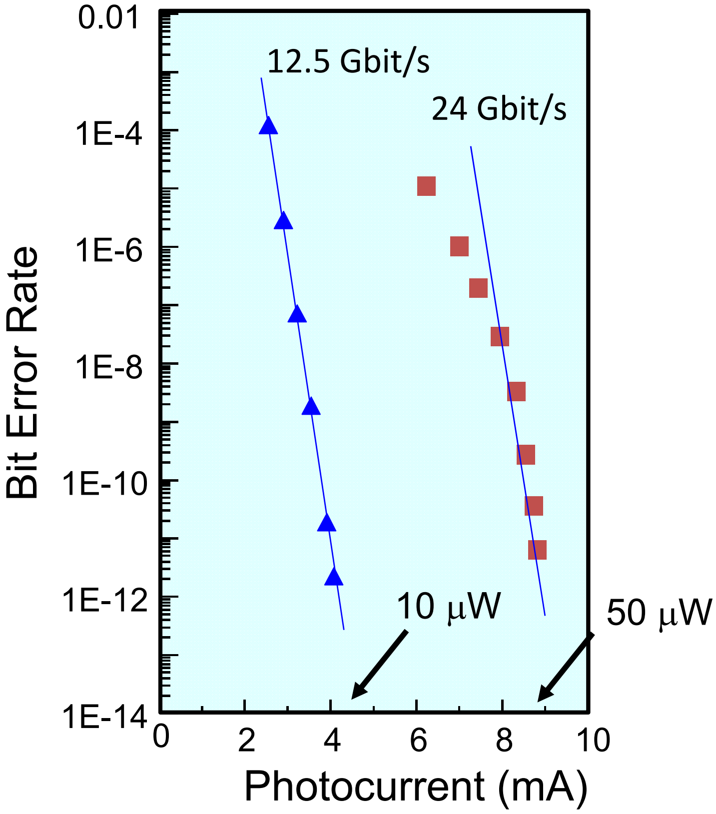


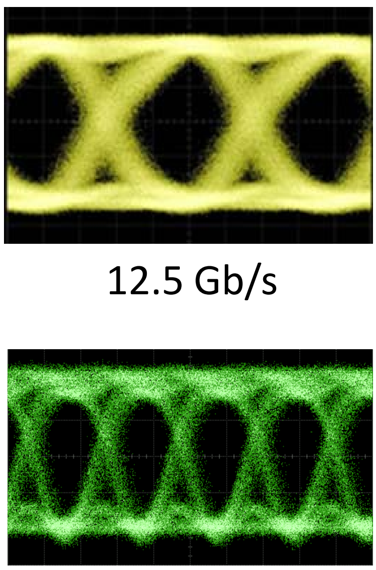
Receiver Configuration

Bandwidth of baseband signals~ 20 GHz



24 Gbit/s Error Free



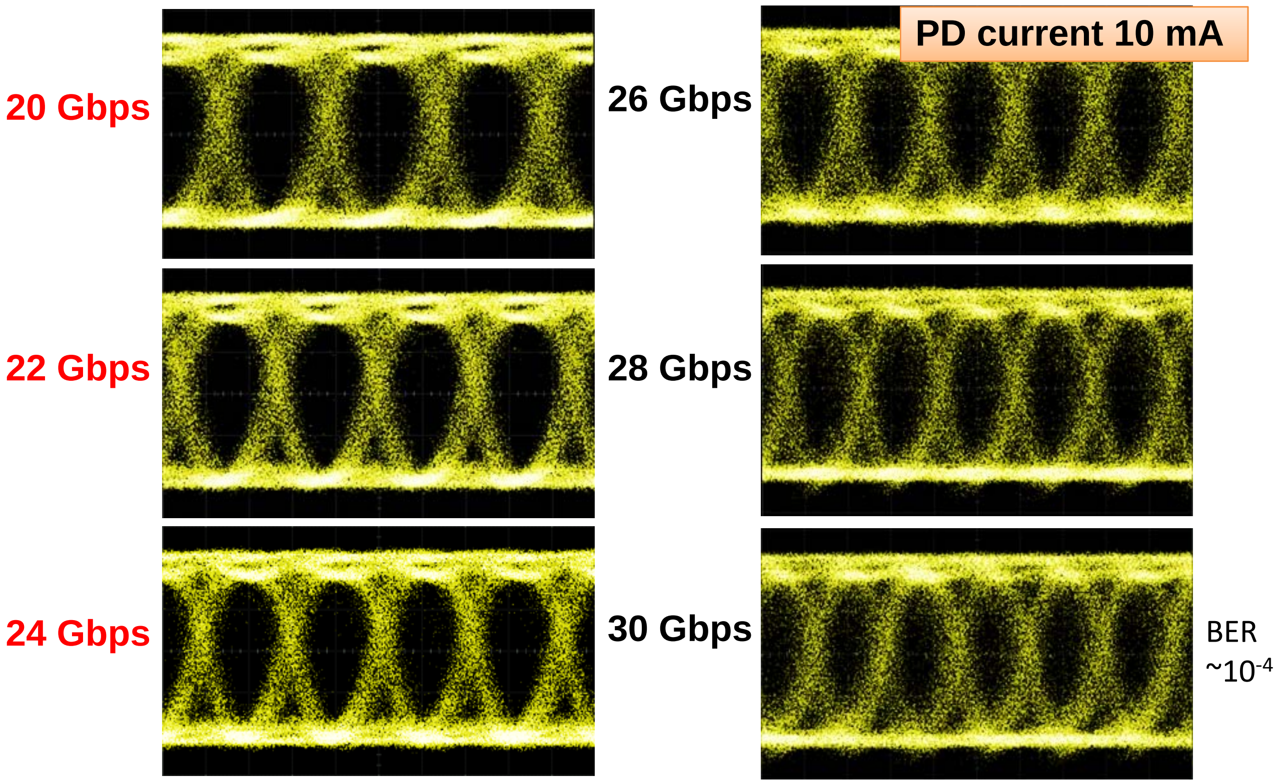


12.5 Gb/s

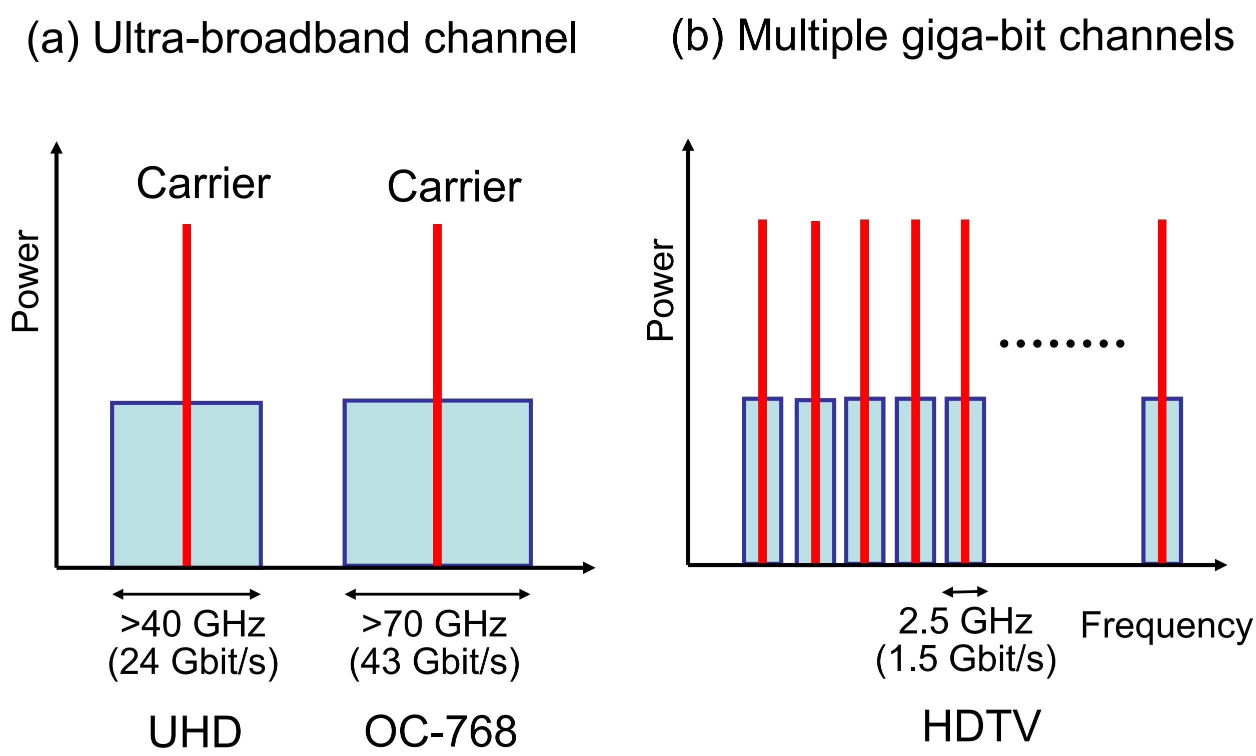
24 Gb/s

Minimum data rate for UHD

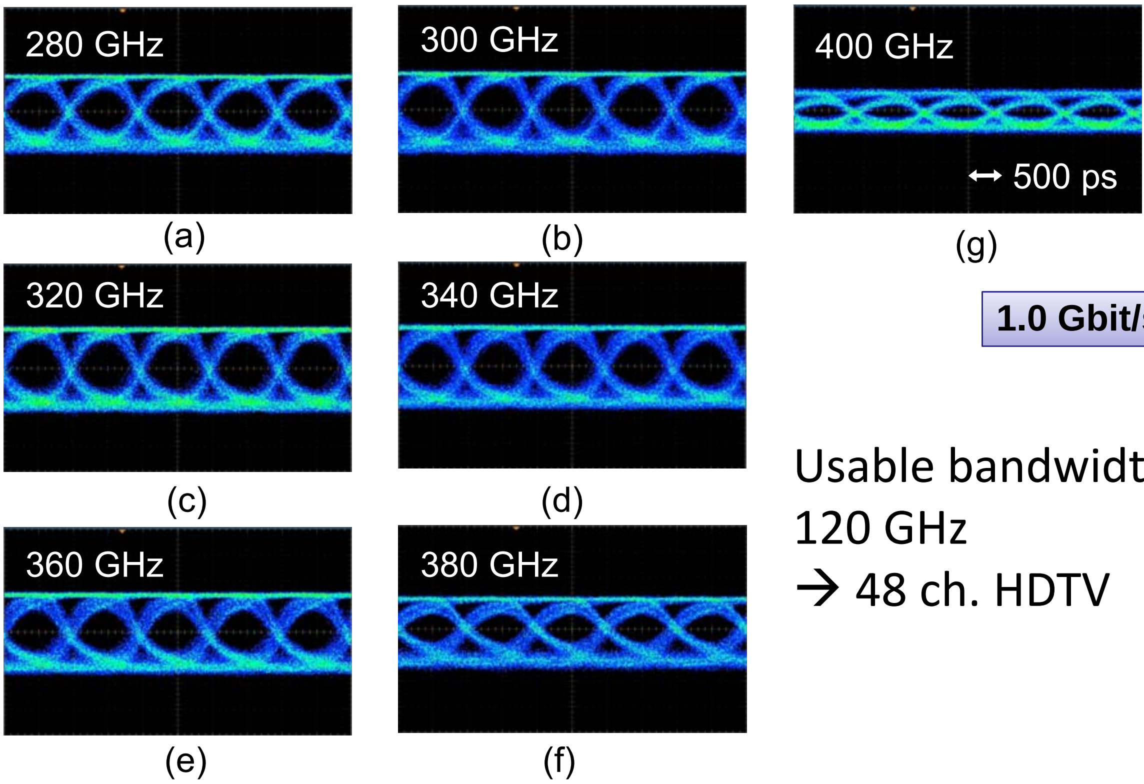
Eye Diagrams up to 30 Gbit/s



Use of Ultra-Broadband



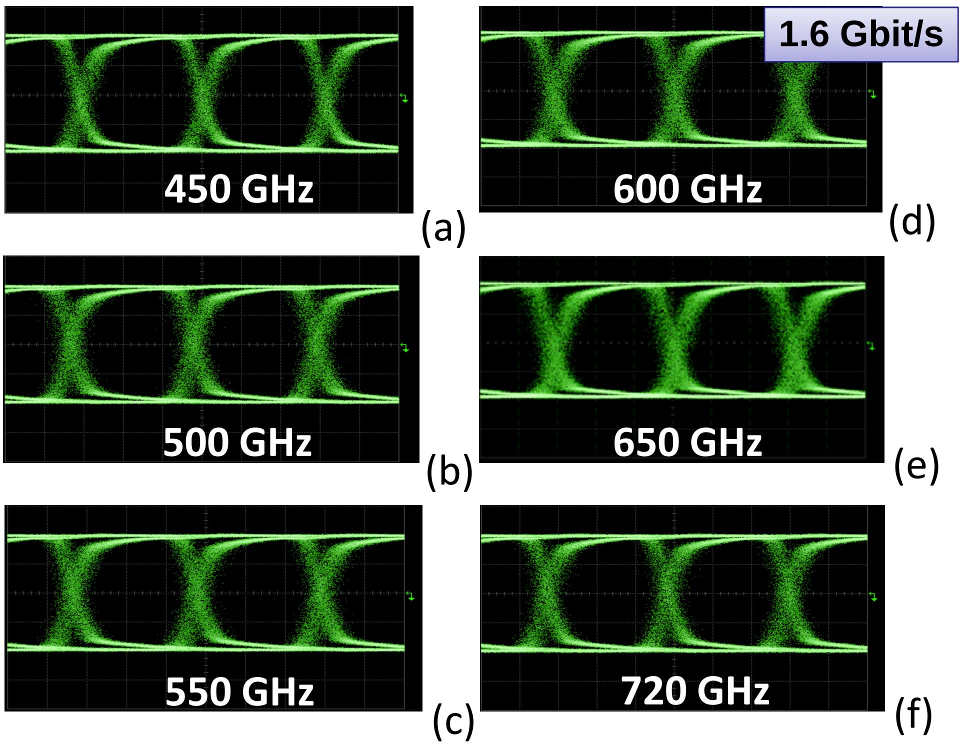
280 to 400 GHz Experiments



1.0 Gbit/s

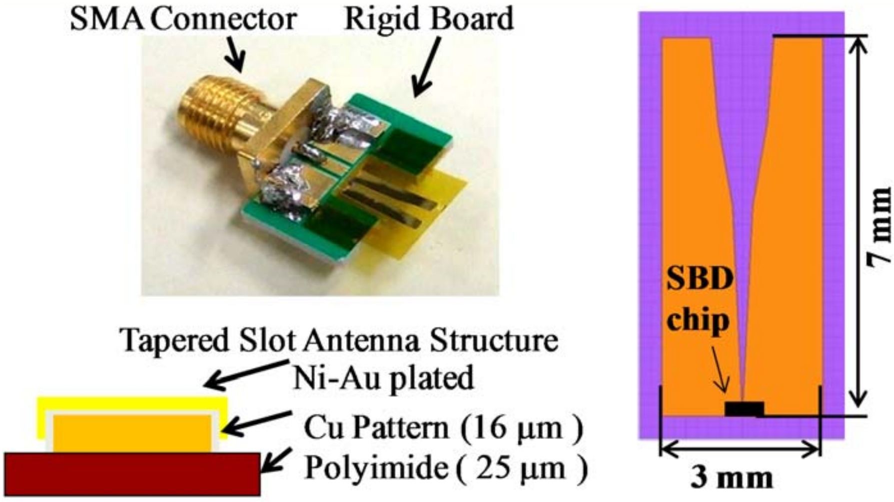
Usable bandwidth:
120 GHz
→ 48 ch. HDTV

450 to 720 GHz Experiments

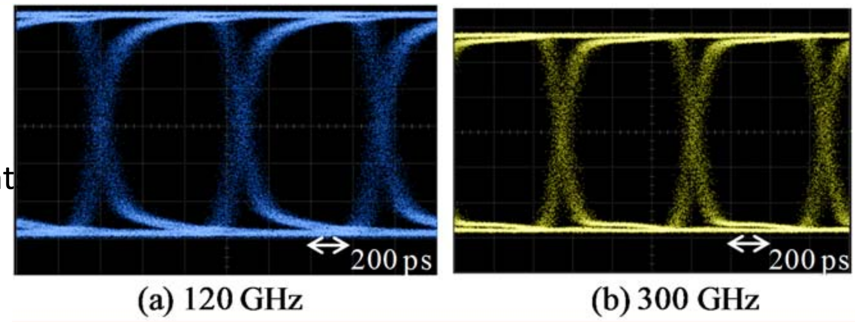


Usable bandwidth: 270 GHz → 108 ch. HDTV

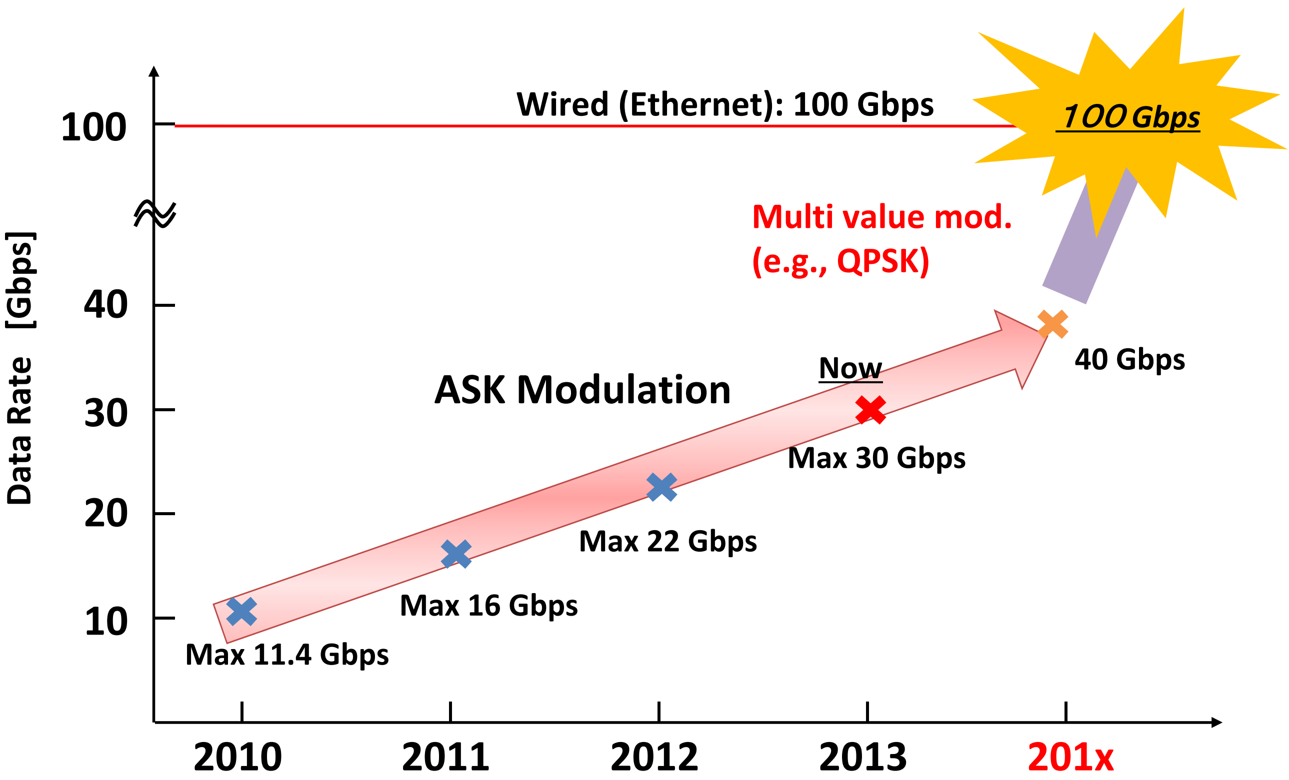
Multi-band Receivers



1.5 Gbps Experiment



Future Strategy



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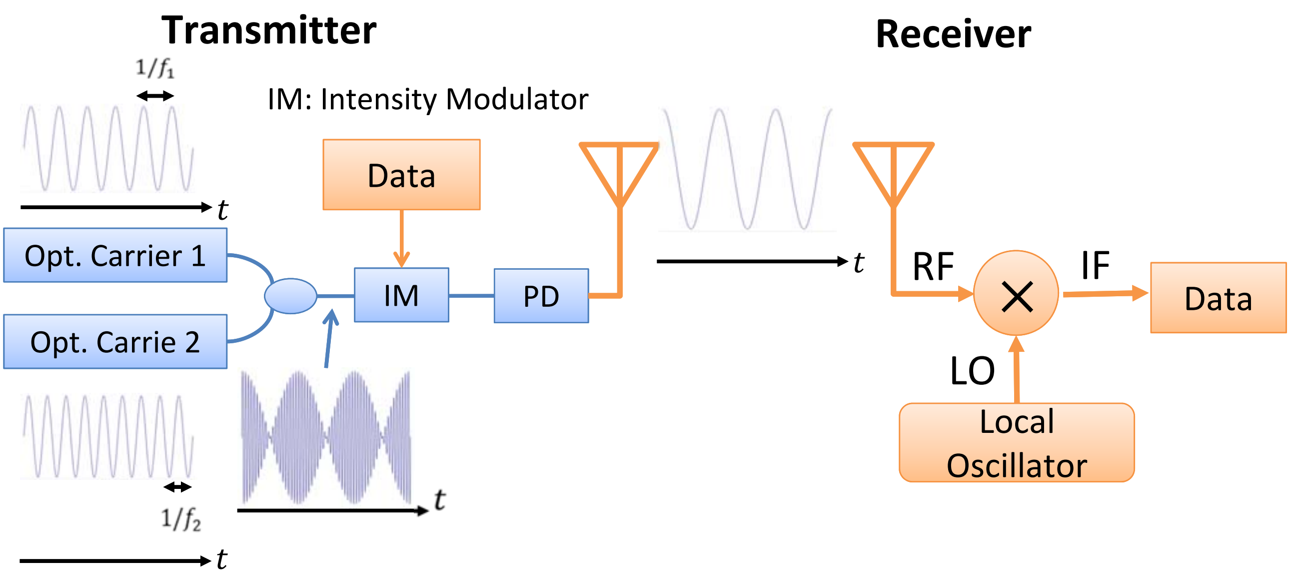
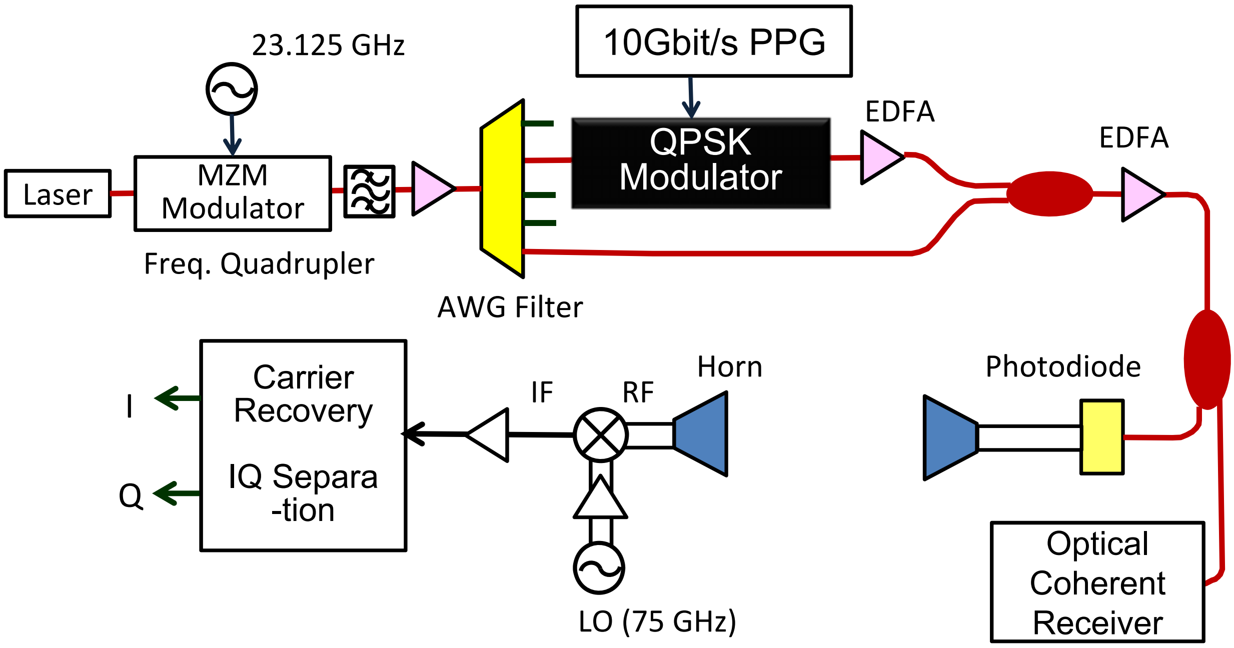
Towards Coherent Detection



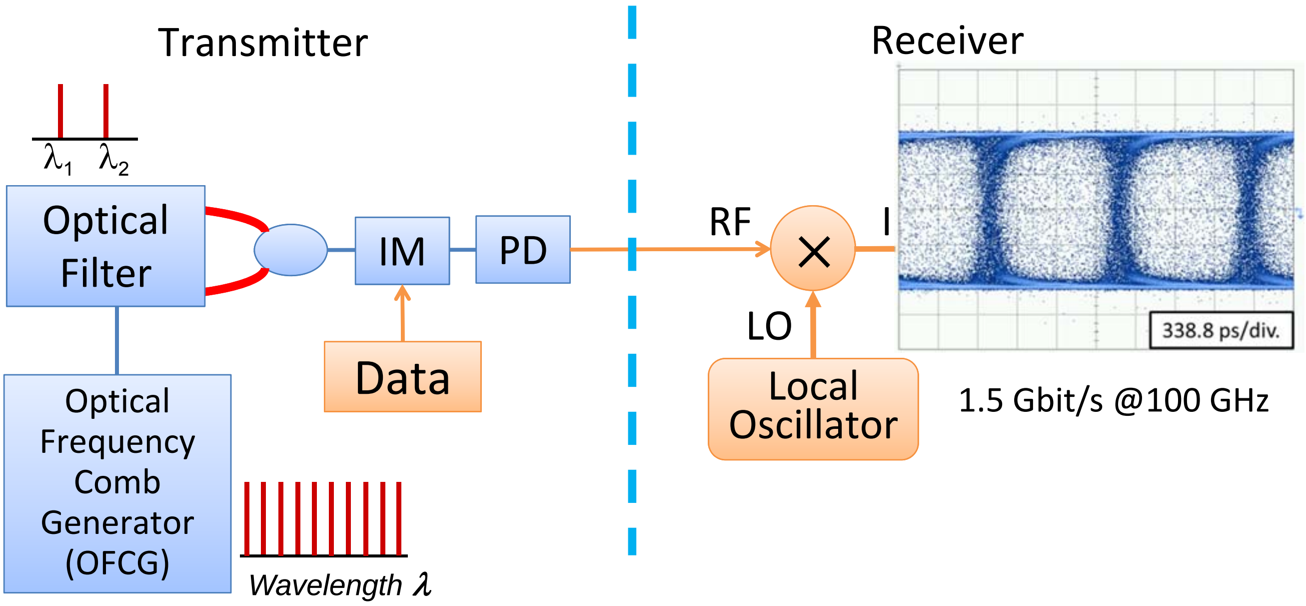
Stability of RF signal is dependent on those of optical carriers
→ Frequency difference in optical carriers should be stabilized

Example of Recent Studies



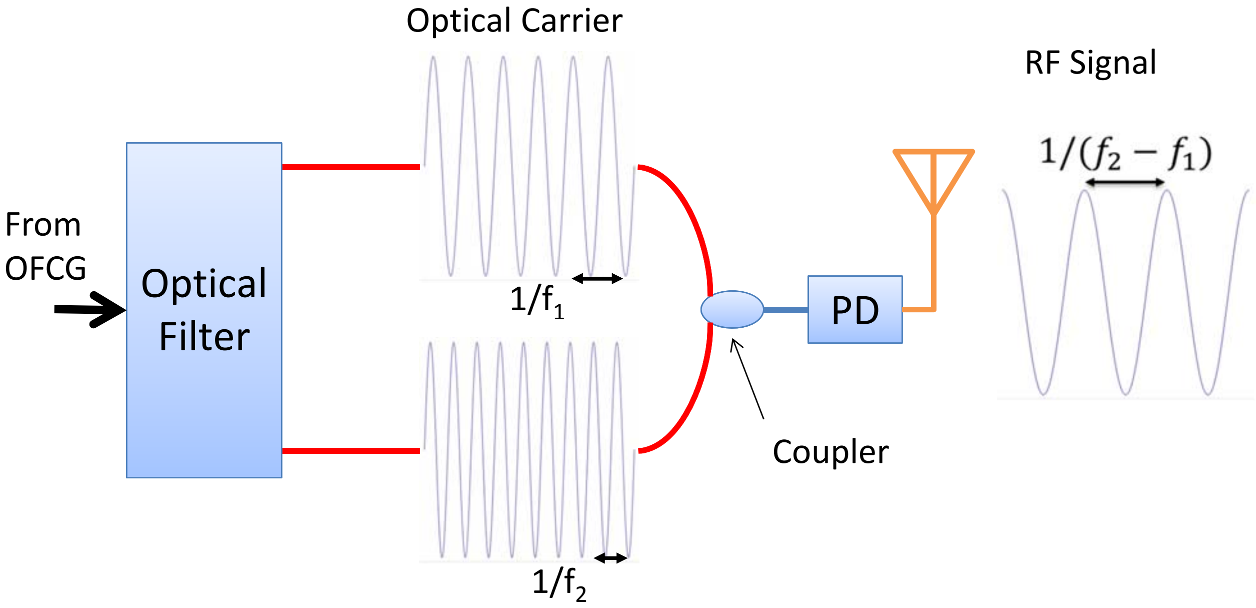
Kanno et al., IEICE Electronics Express, vol. 8, no. 8, pp. 612-617 (2011).

Use of Optical Frequency Comb



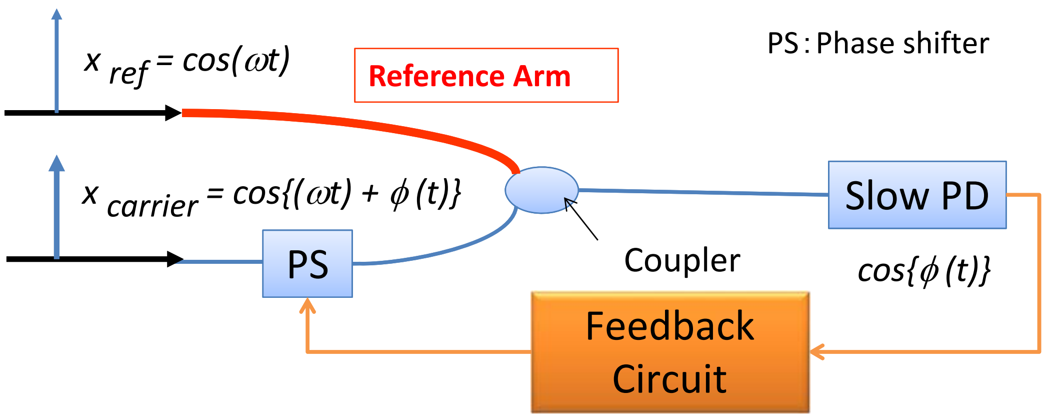
Frequency is stabilized
→ Unstable transmission

Origin of Instability



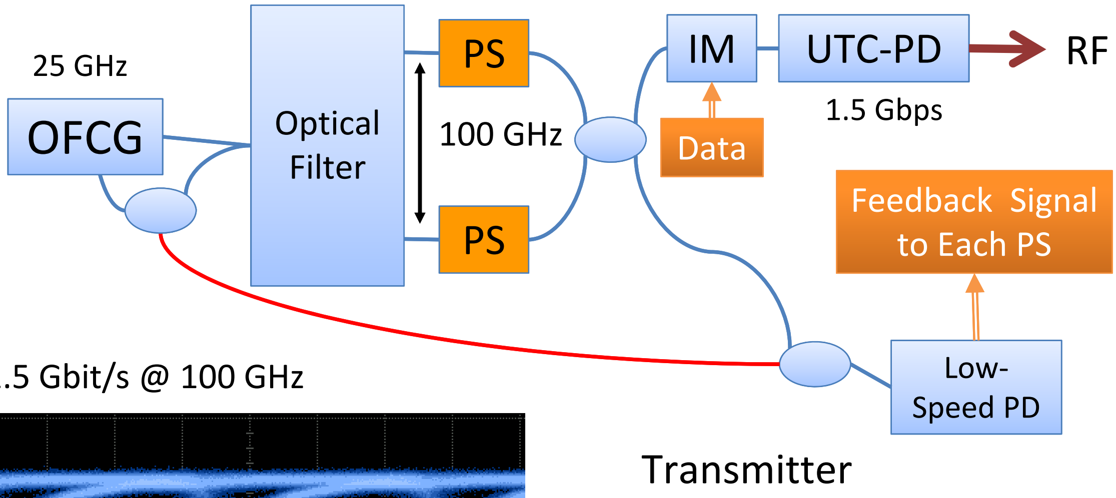
Phase instability between optical carriers
→ Jitter of photonically generated RF signal

Countermeasure

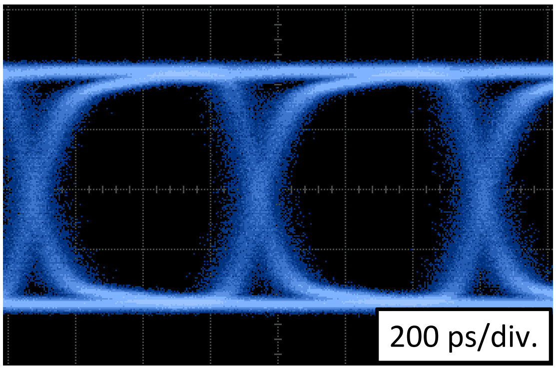


Locking to the reference optical signal
by feedback circuitry

Stabilized Transmission

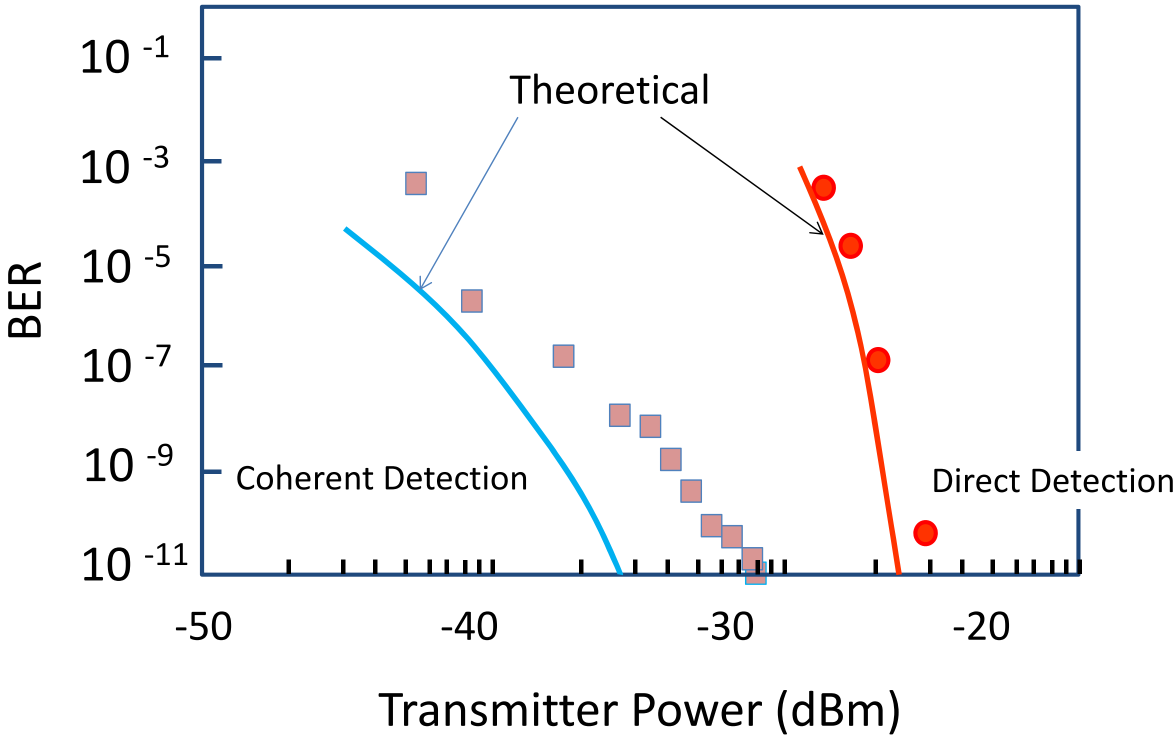


1.5 Gbit/s @ 100 GHz



Optimized FB
→ Error free transmission

BER Characteristics



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Output Power by Electronics

High power MMW amplifier + Frequency multiplier

20~40 μW (w/ x12) @ 1.7~1.9 THz

Transistor–based oscillator IC

100-300 μW @ 250-350 GHz with InP DHBT,

780 μW at 290 GHz, 160 μW at 480 GHz with CMOS

Resonant tunneling diode (RTD) oscillator

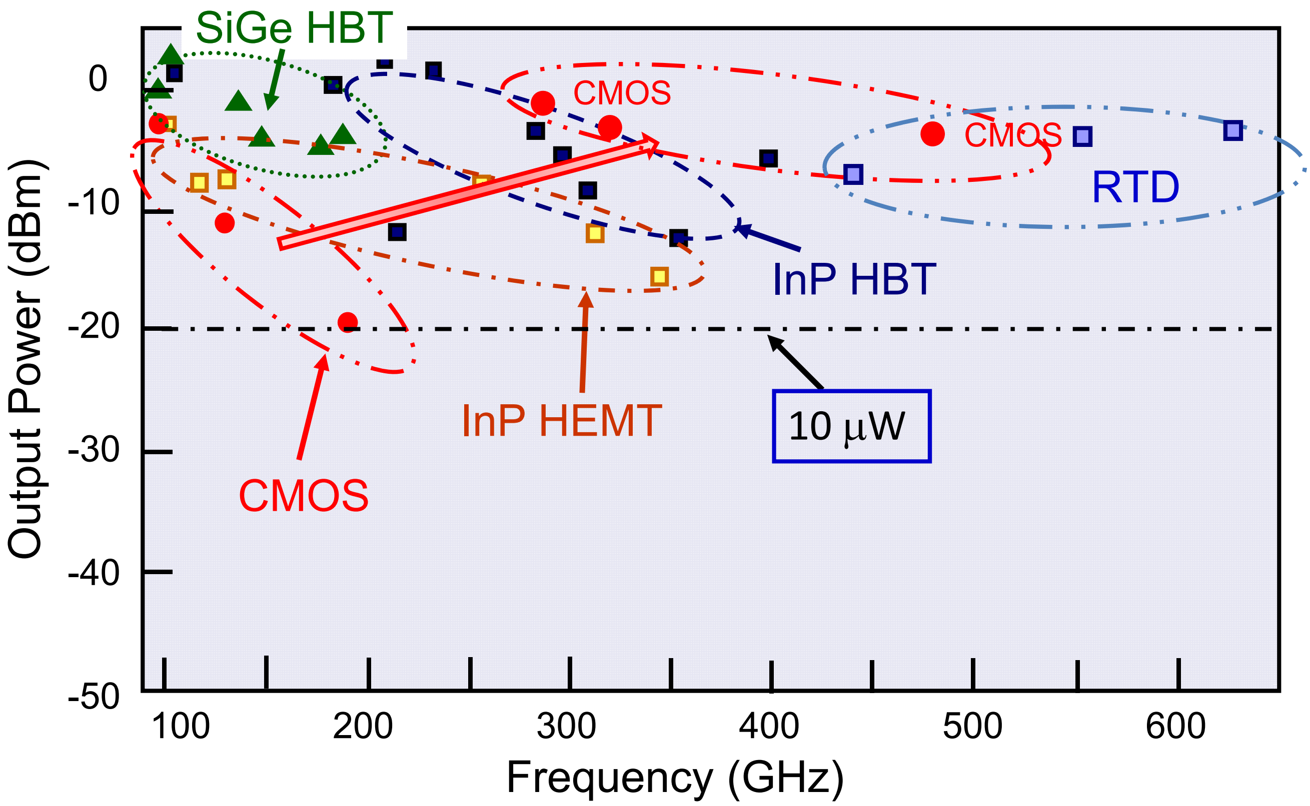
200 μW @ 443 GHz, 610 μW @ 620 GHz (2 arrays),

10 μW @ 1.3 THz

T. Nagatsuma, "Terahertz Technologies; Present and Future", IEICE Electronics, Express, Vol.8, No. 14, 1127 (2011).

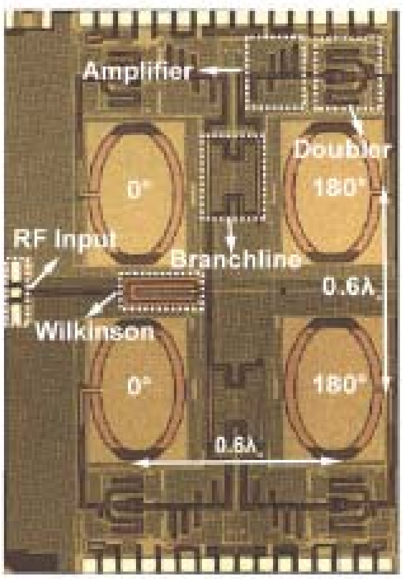
Lorene A. Samoska, "An Overview of Solid-State Integrated Circuit Amplifiers in the Submillimeter-Wave and THz Regime", IEEE Trans. Terahertz Science Tech., Vol. 1, No. 1, 9(2011).

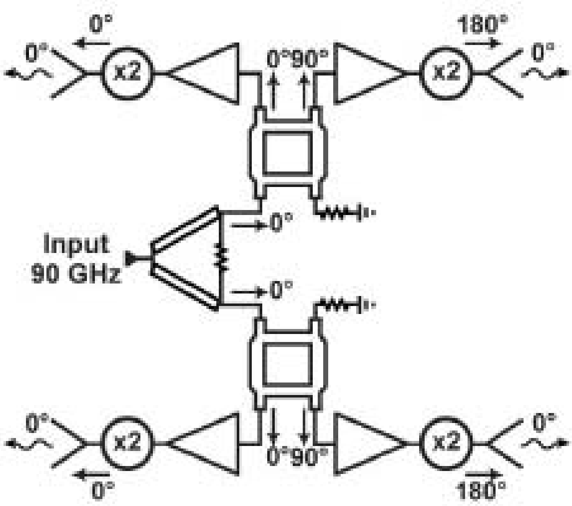
Comparison



CMOS-based Generator

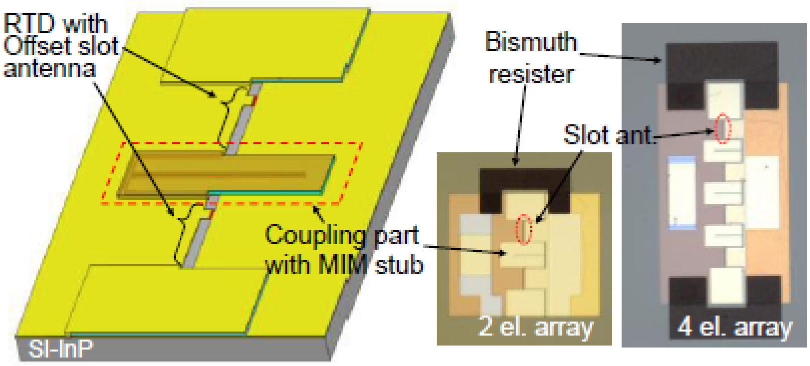
45nm CMOS: ~1mW (2x2) @ 180~190GHz



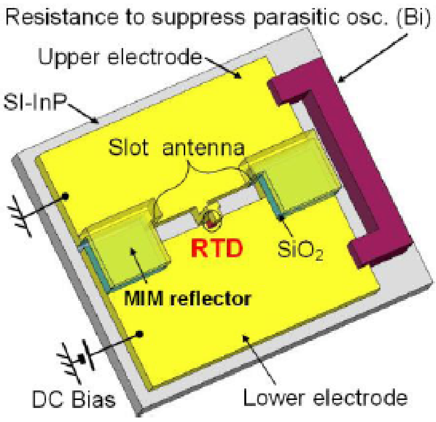


M. Uzunkol et al., Tech. Dig. IMS 2013, 17-22 June 2012

Progress in Resonant Tunneling Diode

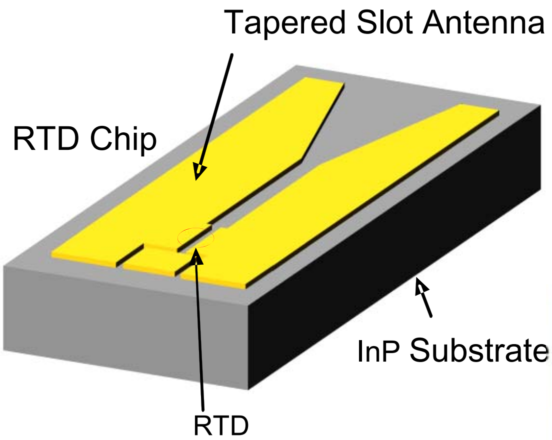


2 element array
610μW @624GHz
(S. Suzuki et al., IEEE J. Select. QE, 2012.)

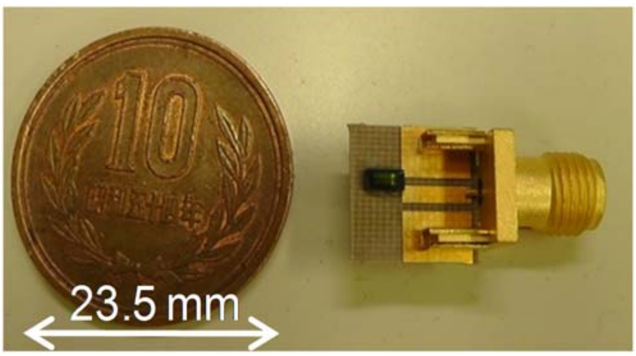


Single
~10μW @1.4 THz
(H. Kanaya et al., IPRM 2012)

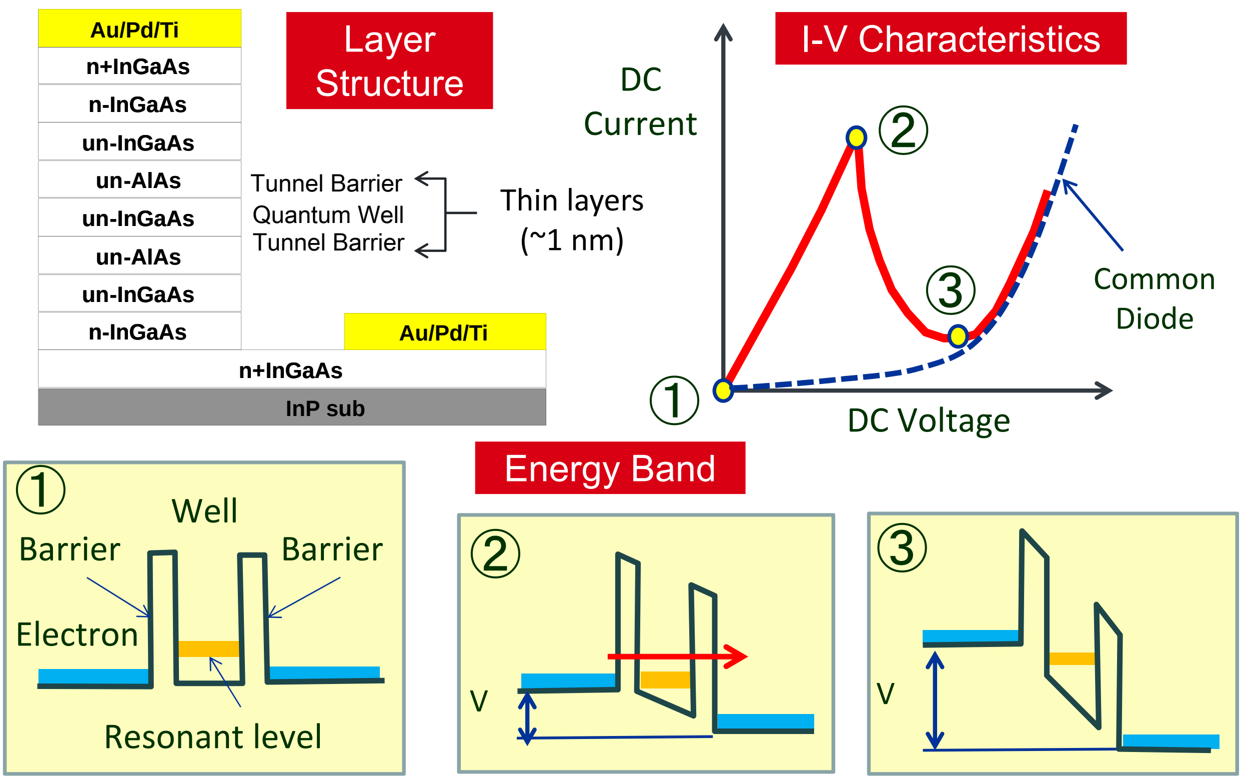
Antenna-integrated RTD



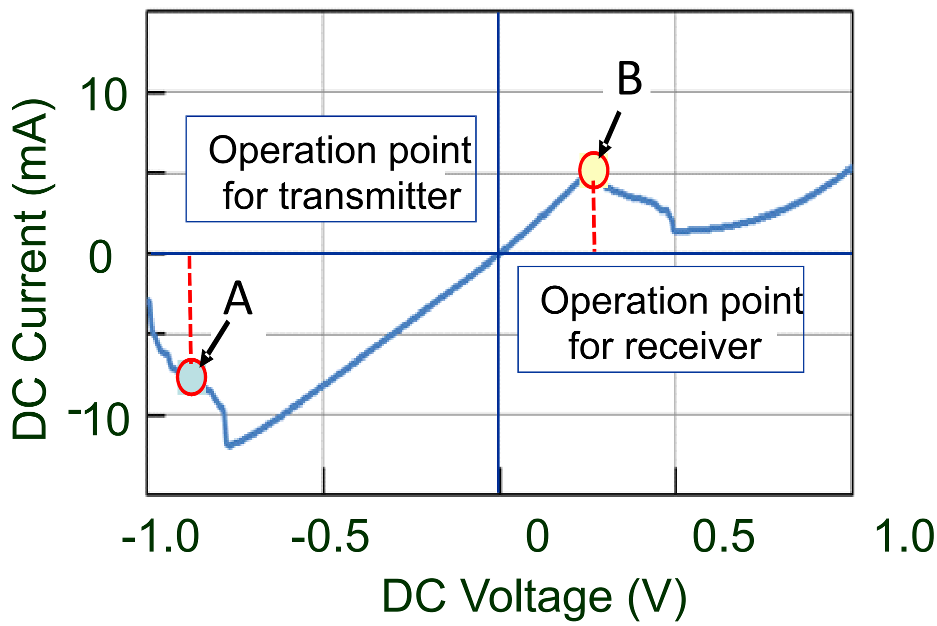
Electrode		
n+InGaAs 8nm		
n+InGaAs 15nm		
n-InGaAs 25nm		
un-InGaAs 20nm		
un-AlAs 1.1nm	Tunnel Barrier	
un-InGaAs 4.5nm	Quantum Well	
un-AlAs 1.1nm	Tunnel Barrier	
un-InGaAs 2nm		
n-InGaAs 25nm		Electrode
n+InGaAs 400nm		



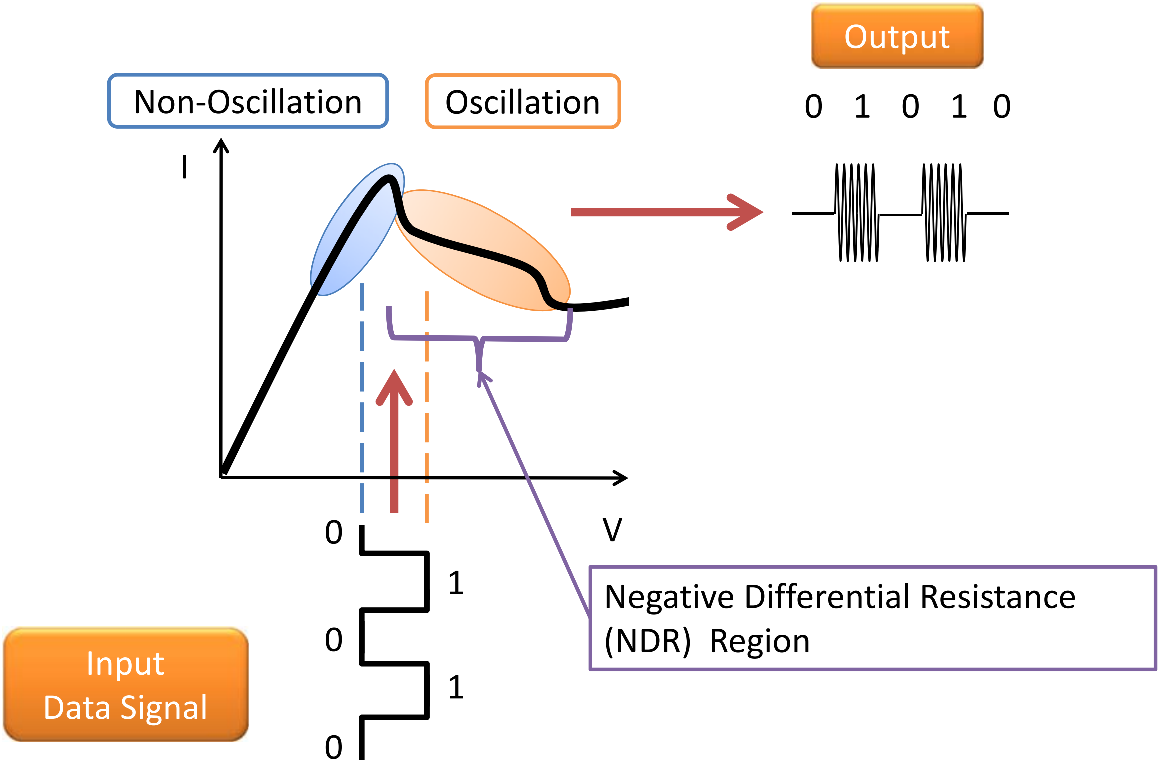
Principle of RTD



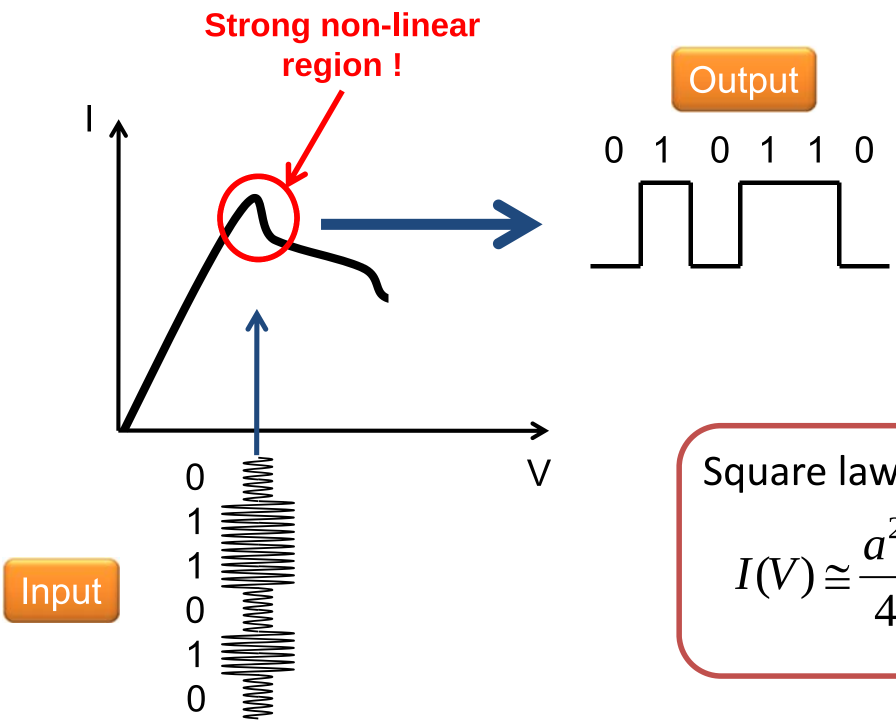
Operation Points



Transmitter Operation



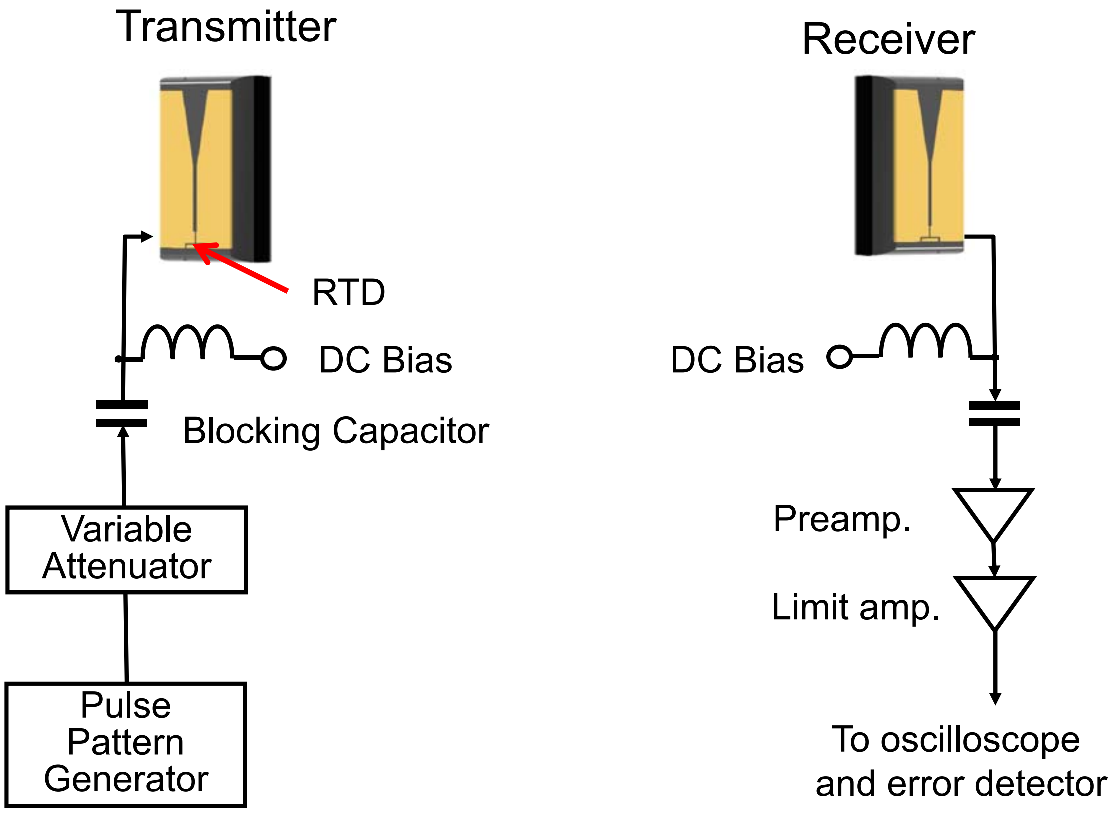
Receiver Operation



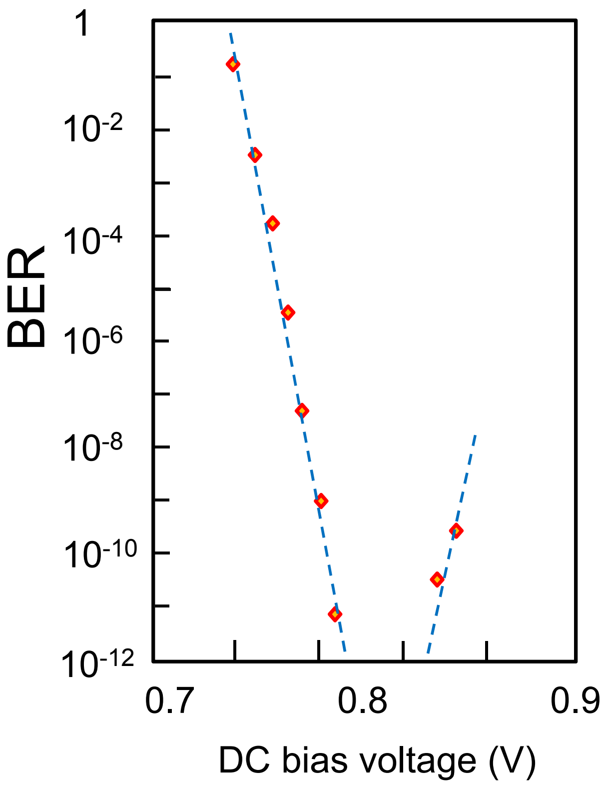
Square law detection

$$I(V) \cong \frac{a^2}{4} \frac{d^2 I}{dV^2}\bigg|_{V=V_0}$$

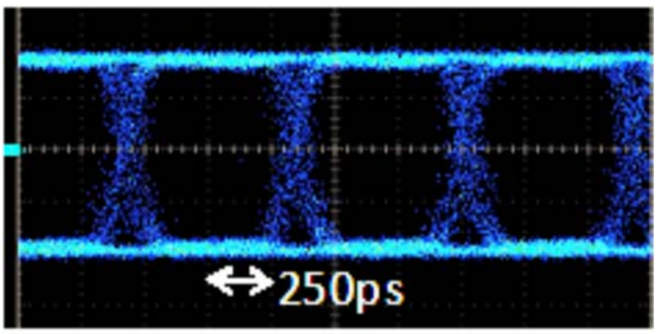
RTD Transceiver



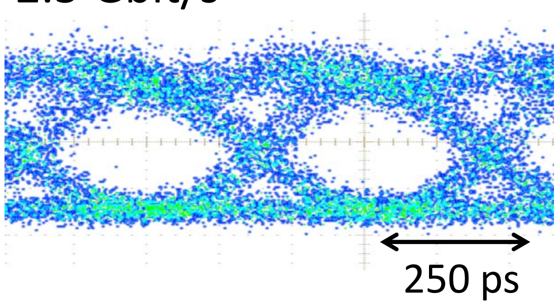
BER and Eye Diagram

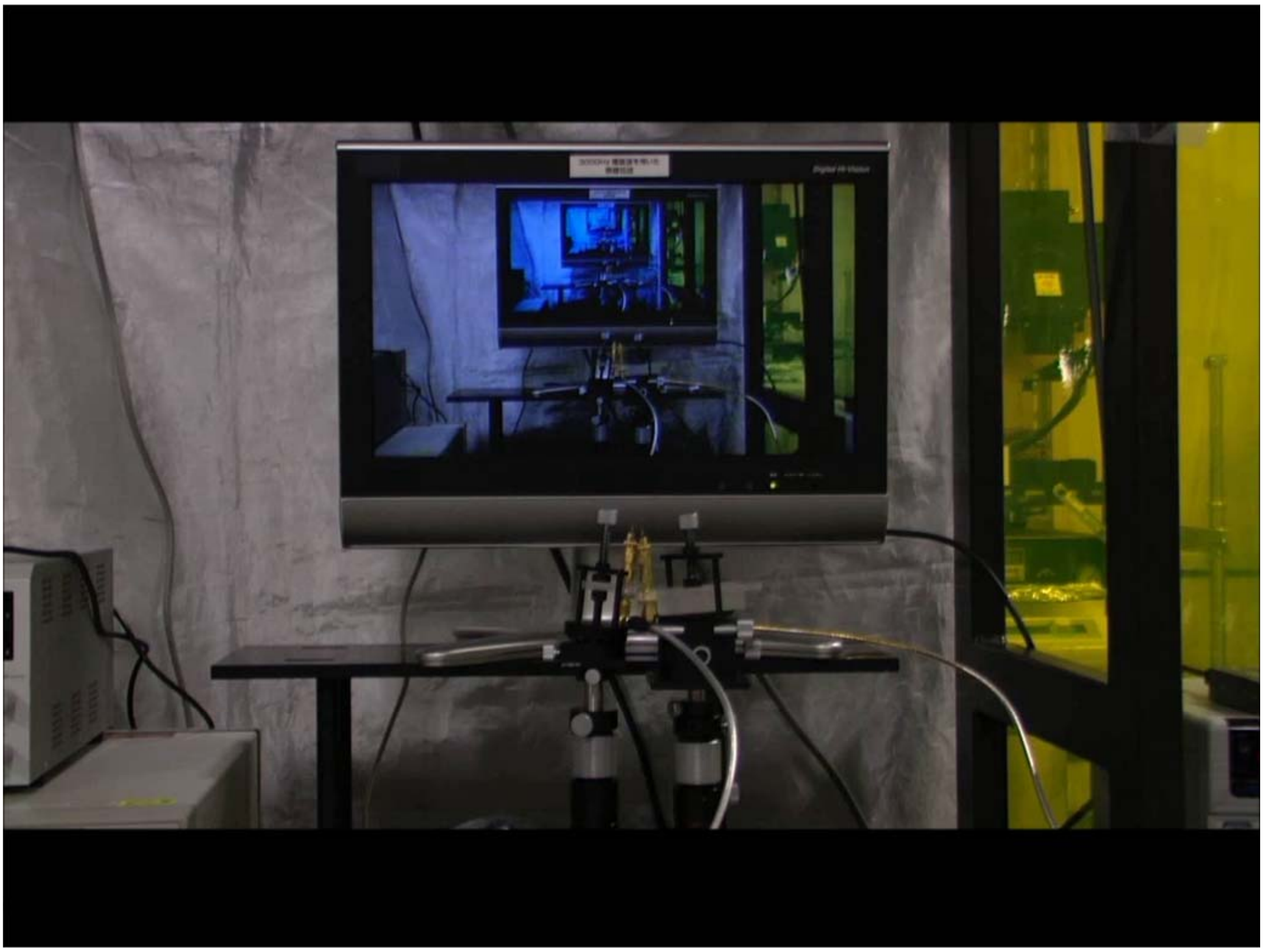


1.5 Gbit/s

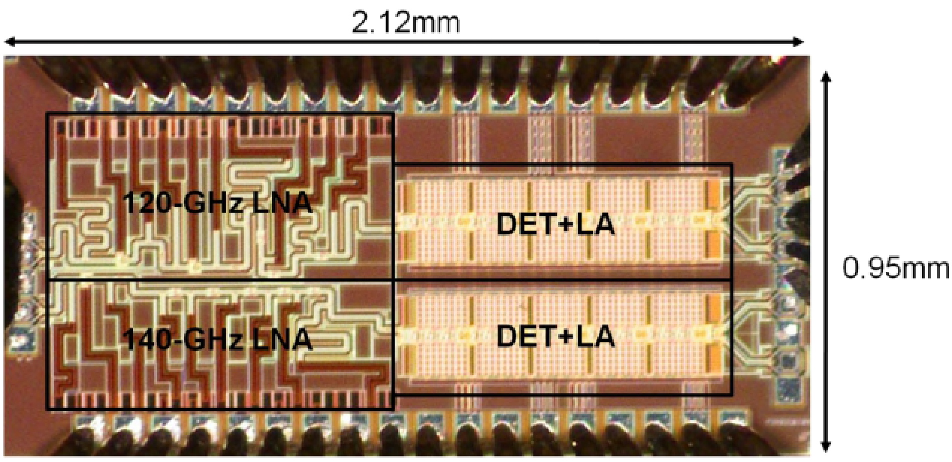


2.5 Gbit/s





120GHz/140GHz Rx IC (Hiroshima U)



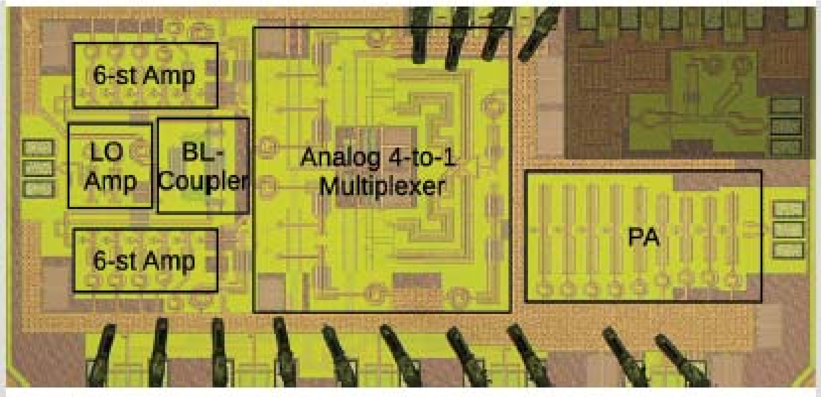
65nm CMOS Technology
Supply Voltage: 1.2V
Power Consumption: 85.7mW (120GHz-RX)
111.7 mW (140GHz-RX)

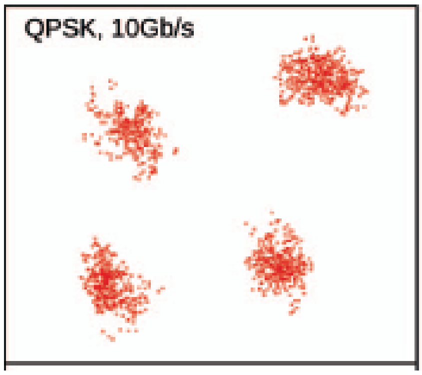
Data rate: 3~4 Gb/s, Distance: 30~40 cm w/ 25-dBi horn

SSCS Distinguish Lecture (Prof. Fujishima)

120 GHz Tx IC (KULeuven)

Noël Deferm, Patrick Reynaert, ISSCC2011, 16.7



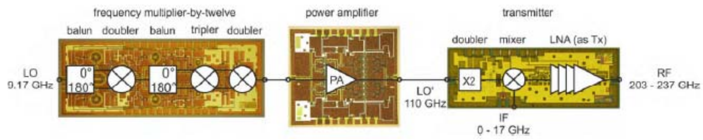


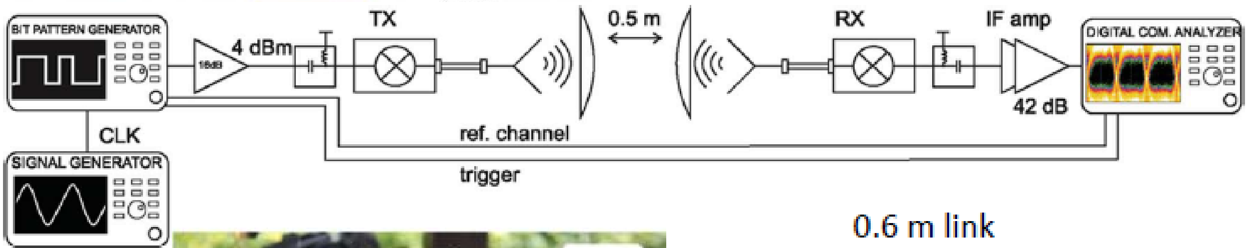
65nm LP CMOS Technology
Supply voltage: 1V
Power consumption: 200 mW

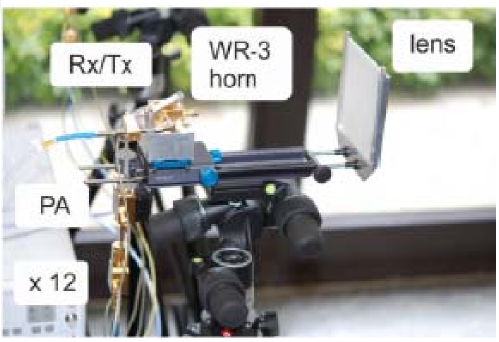
Data rate: 10 Gb/s(QPSK), 6 Gbit/s(8QAM)

220 GHz-band System with MMICs

Fraunhofer IAF





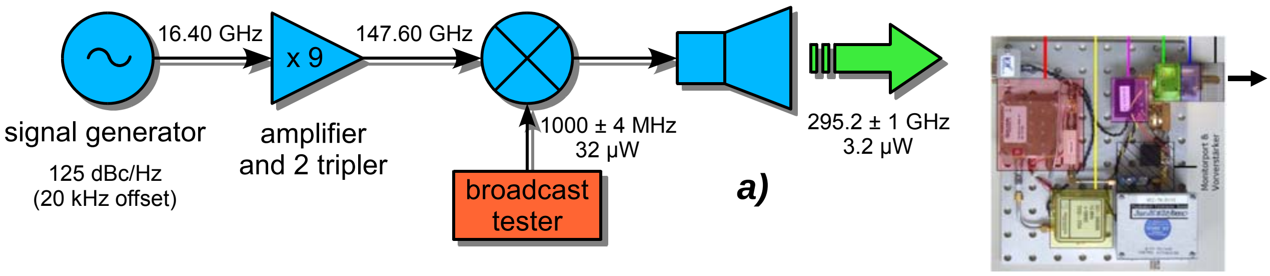


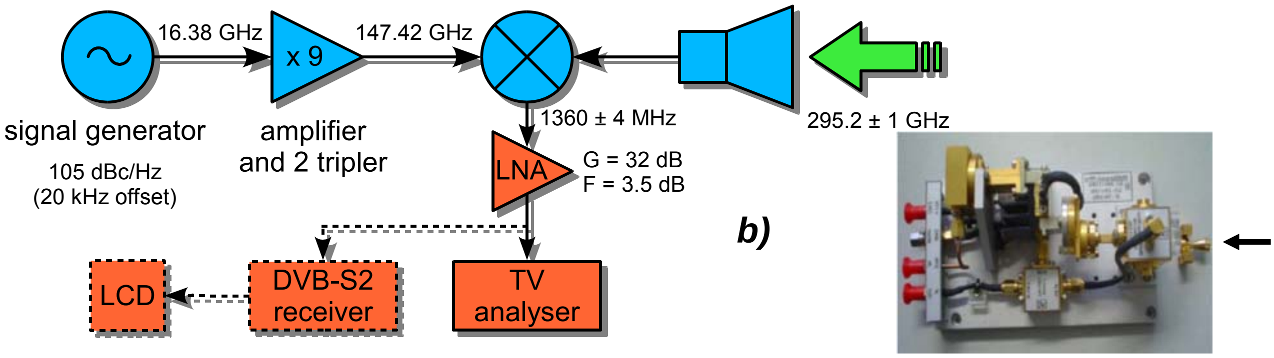
0.6 m link

Rate	BER
10 Gbit/s	$< 1 \cdot 10^{-11}$
15 Gbit/s	$6.0 \cdot 10^{-6}$
20 Gbit/s	$7.4 \cdot 10^{-6}$
25 Gbit/s	$5.0 \cdot 10^{-4}$

I. Kallfass et al., “All active MMIC-based wireless communication at 220 GHz”, IEEE Trans. Terahertz Science and Technology, Vol. 1, 577(2011).

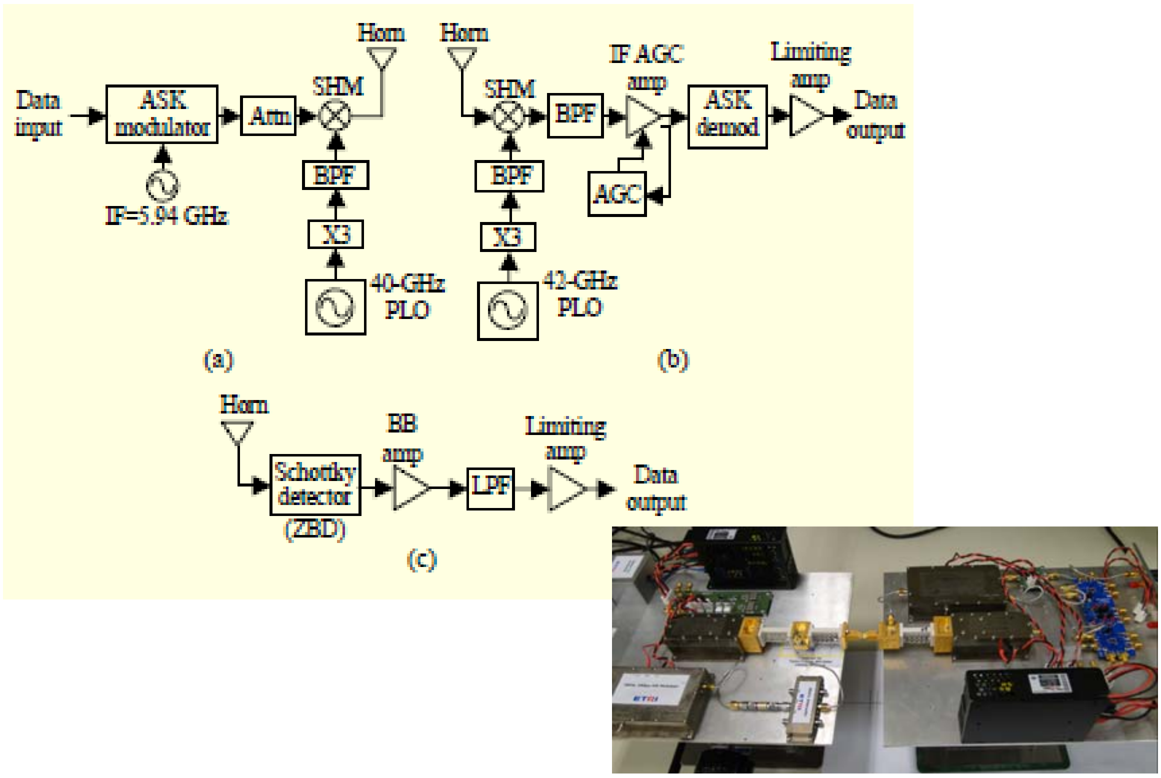
300-GHz Band Wireless Link (TUBraunschweig)





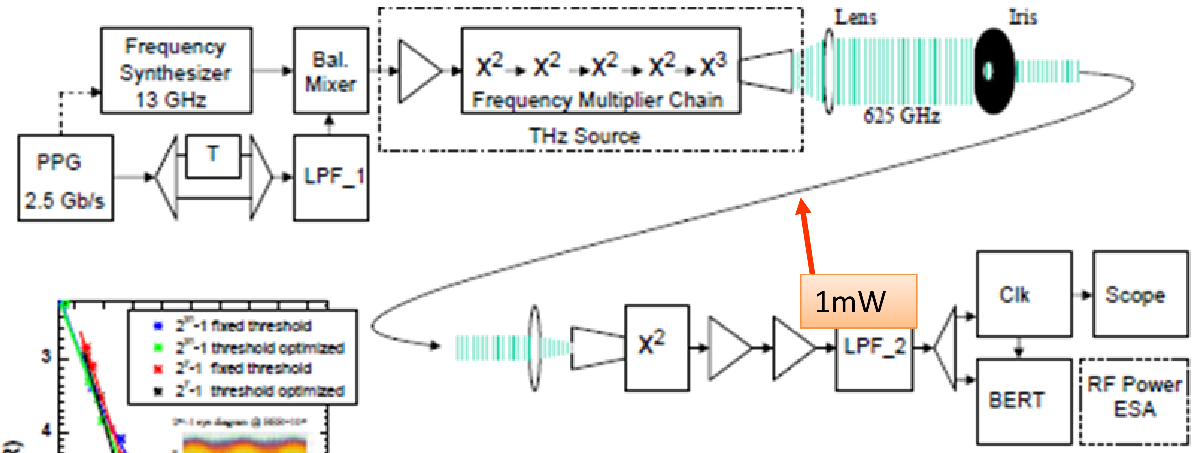
C. Jastrow, S. Priebe, B. Spitschan, J. Hartmann, M. Jacob, T. Kürner, T. Schrader and T. Kleine-Ostmann, Wireless digital data transmission at 300 GHz, Electron. Lett. **46**, 661-663 (2010).

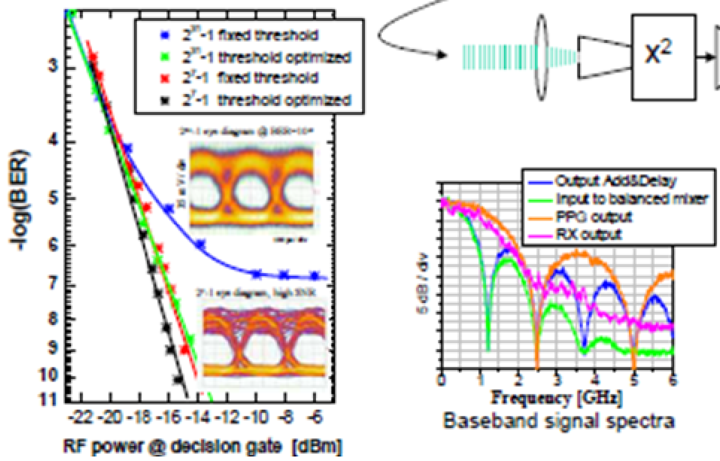
300 GHz Band Link (ETRI/Korea)



ETRI Journal, Volume 33, Number 6, December 2011.

600 GHz Band Link (Bell Lab/NJIT)





- 2.5 Gb/s error-free transmission over lab distance
- BER depends on PRBS and received power
- NRZ baseband signal at RX output
- Iris adjusts received power

doc.: IEEE 802.15-11-0777-01-0thz

Outline

- Background and motivation
  - *needs for high-speed wireless*
  - *why THz?*
  - *who pays for THz wireless?*
- Enabling Technologies
  - *photonics vs. electronics*
- Photonics-base approach
  - *direct detection*
  - *coherent detection*
- Electronics-based approach
- Future issues
- Summary

Towards THz ICs

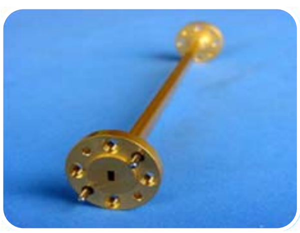
3rd Phase: integration
Smaller & cheaper for mass-production/use

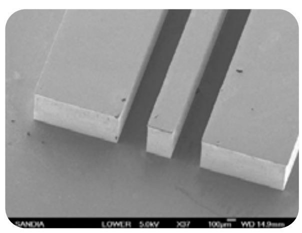
WE ARE HERE

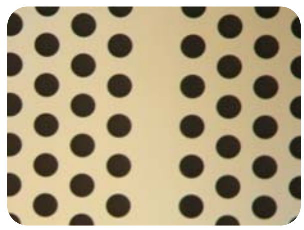
2nd Phase: transistor & passives
More performance & functional
*Active: **THz amplifiers and oscillators***
*Passive: **THz antennas, filters, absorbers***

1st Phase: diode
Technology demonstration
Investigate advantages, disadvantages, usefulness of THz
Modeling THz propagation, reflection…

Transmission Lines for THz ICs

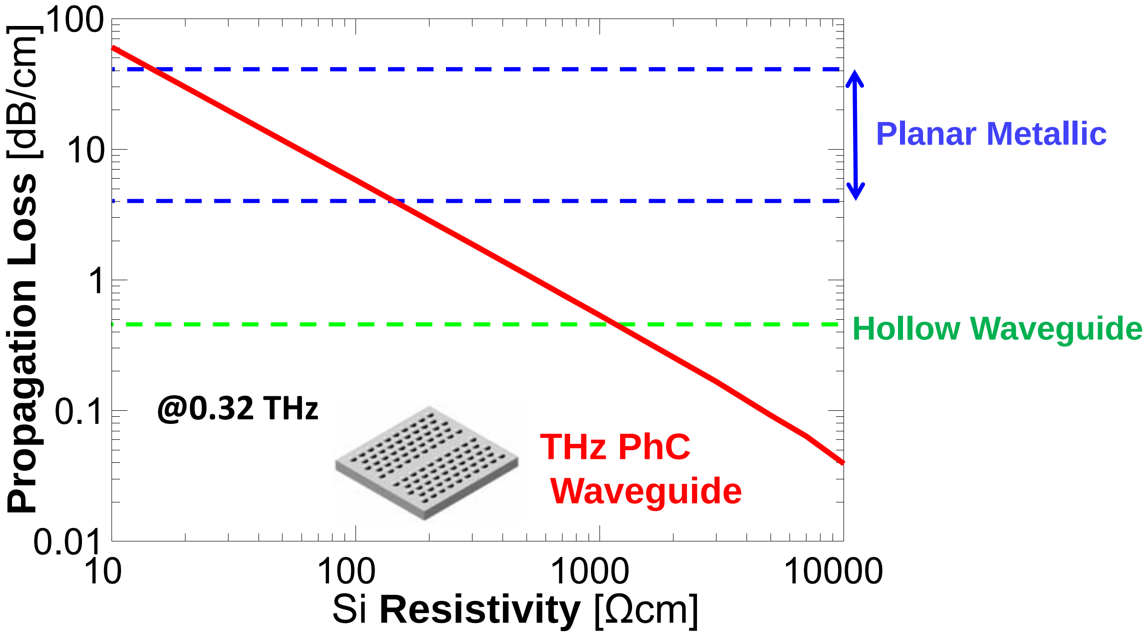




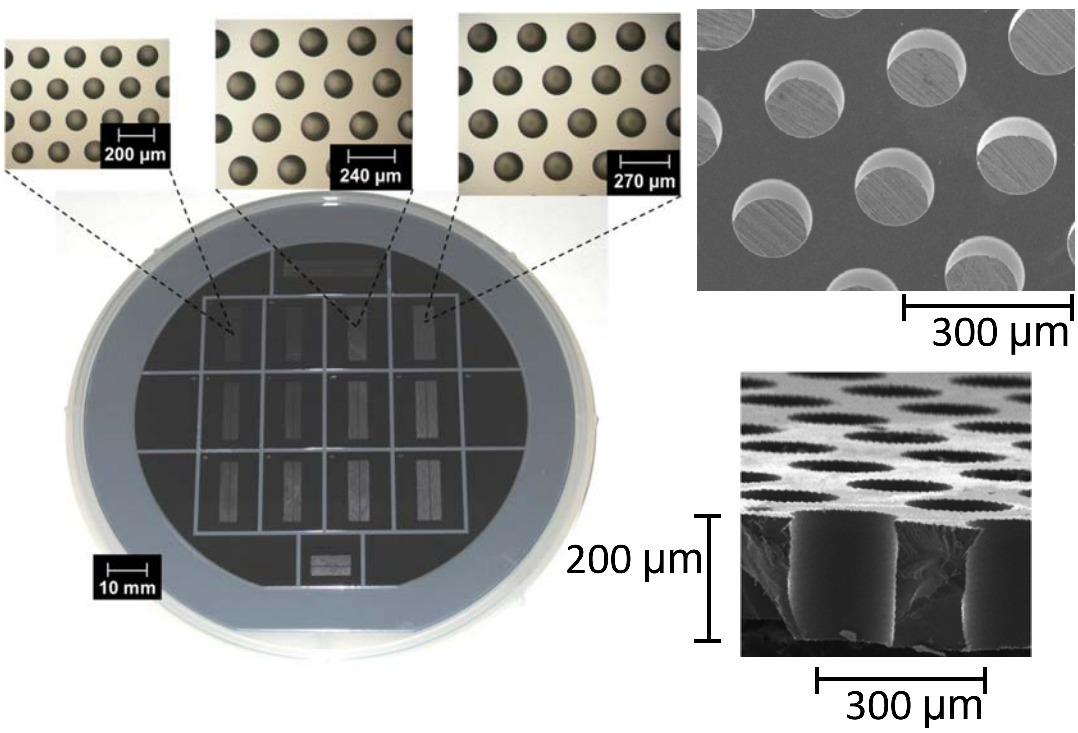


	Hollow Waveguide	Metallic	PhC Waveguide
Loss	○	×	○
Size	△	○	○
Cost	×	○	○

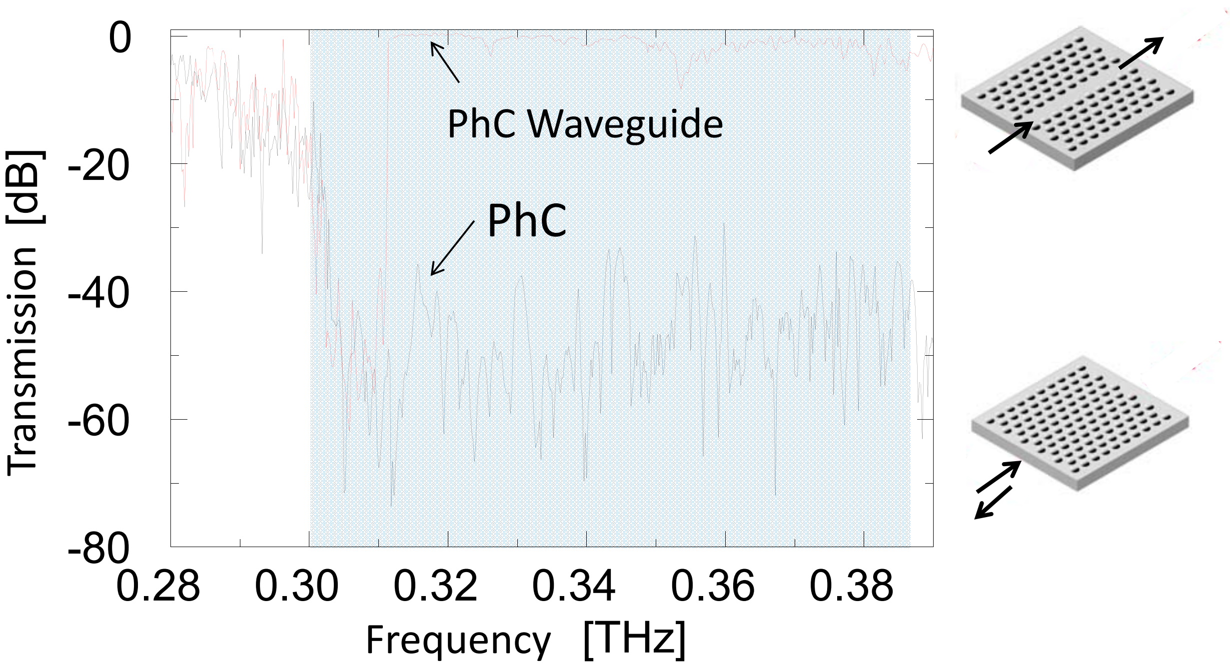
Comparison (Theoretical)



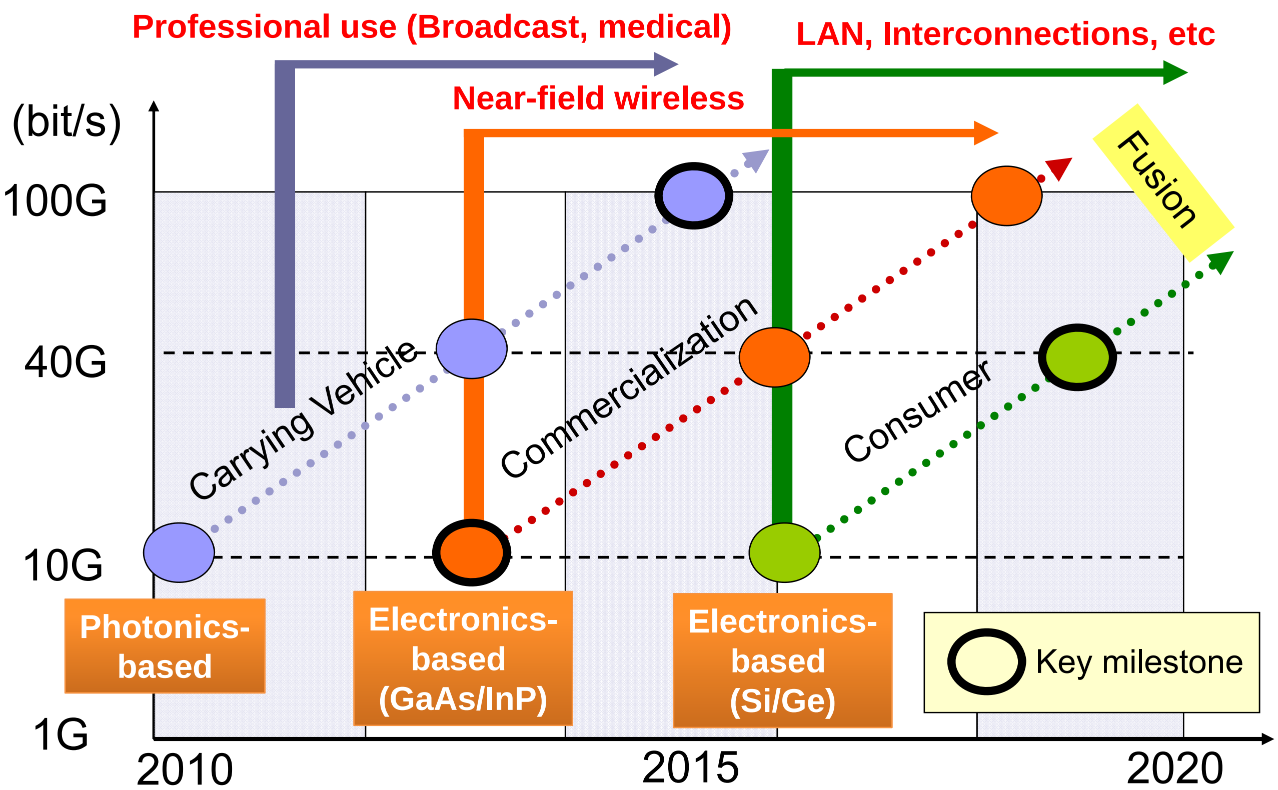
Fabrication on Si



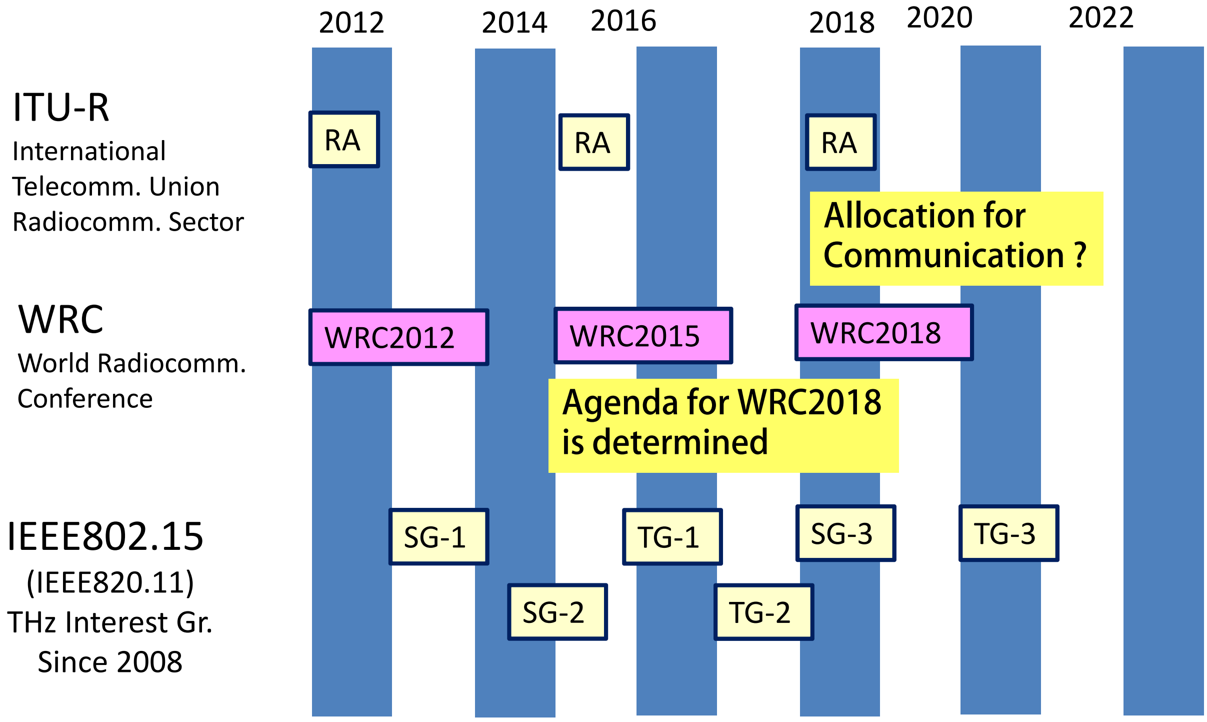
Preliminary Experiments



Roadmap

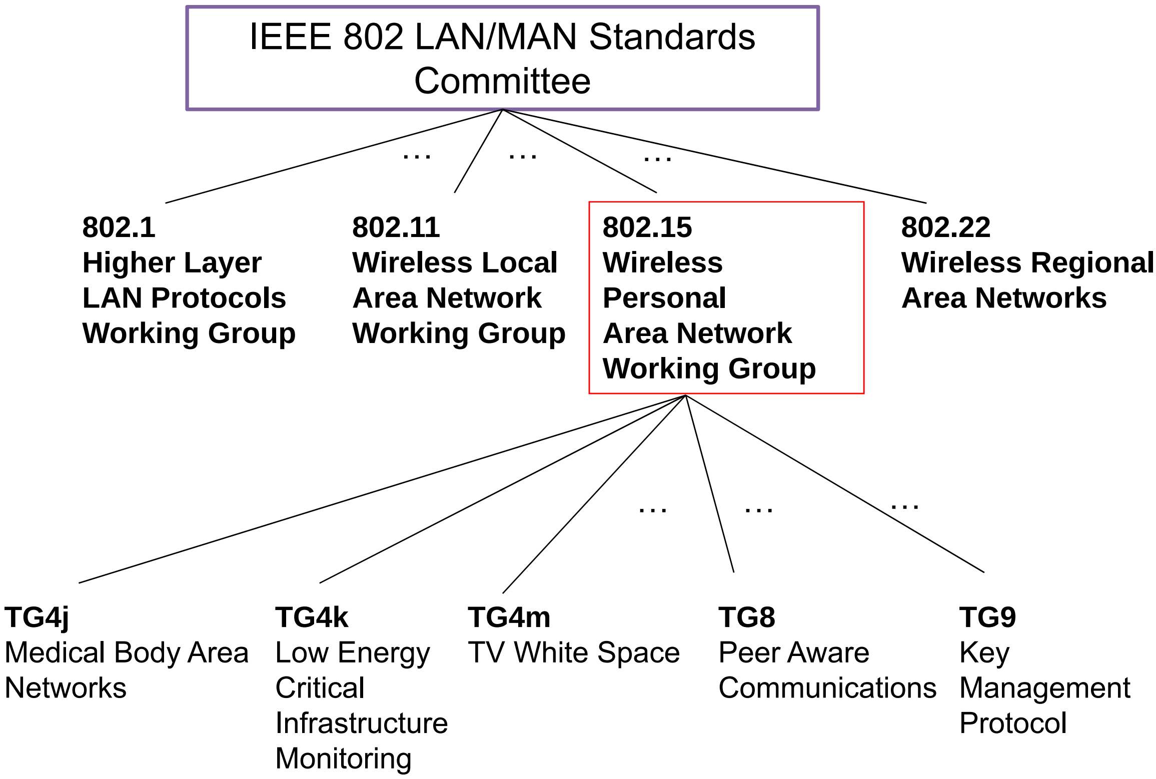


Timeline towards Freq. Allocations



（*RA*：. Radio-communication Assembly）

IEEE802.15



On-going Discussions (1)

ITU Radio Regulations Footnote 5.565:

The frequency band 275-1000 GHz may be used by administrations for experimentation with, and development of, various active and passive services.

- Radio astronomy service: 275-323 GHz, 327-371 GHz, 388-424 GHz, [...]
- Earth exploration-satellite service and space research service 275-277 GHz, 294-306 GHz, 316-334 GHz, [...]

Administrations are urged to take all practicable steps to protect these passive services from harmful interference.

→ Two options for THz communications:
1. Transmission in remaining free parts of the THz spectrum
2. Coexistent spectrum usage with radio astronomy/earth exploration

doc.: IEEE 802.15-15-12-0324-00-0thz

Footnote 5.565 (WRC-12)

The following frequency bands in the range 275-1 000 GHz are identified for use by administrations for passive service applications:

The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. *Administrations wishing to make frequencies in the 275-1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference* until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.

All frequencies in the range 1 000-3 000 GHz may be used by both active and passive services. (WRC-12)

On-going Discussions (2)

1. Transmission in remaining bands only
   - Very small bandwidths
   - Distributed over entire THz range

→ Not feasible for data rates >> 10 Gbit/s

2. Coexistent spectrum usage
   - Potential interference of active THz systems with
     - radio astronomy
     - spaceborn THz sensors

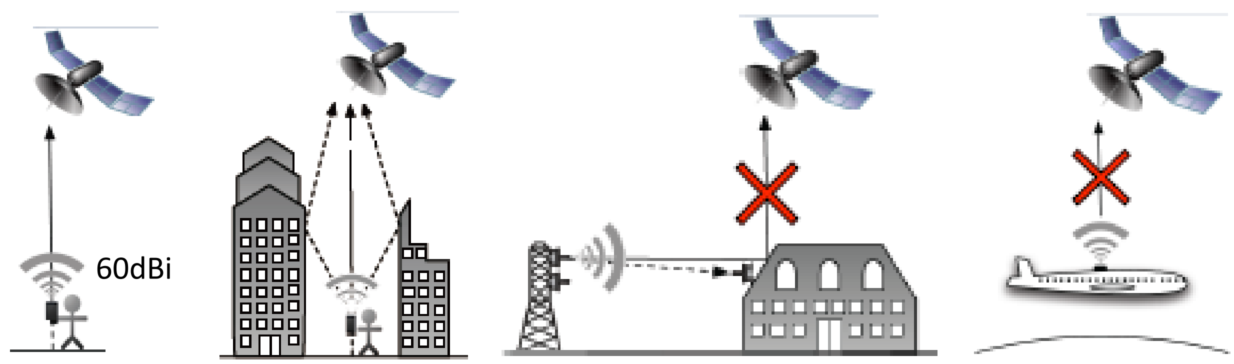
→ Interference investigations inevitable for standardization to comply with the ITU Radio Regulations

Remaining Frequency Bands	Total available Bandwidth
286-294 GHz	8 GHz
307-313 GHz	6 GHz
356-361 GHz	5 GHz
366-369 GHz	3 GHz
392-397 GHz	5 GHz
399-409 GHz	10 GHz
411-416 GHz	5 GHz
434-439 GHz	5 GHz
467-477 GHz	10 GHz
502-523 GHz	21 GHz
527-538 GHz	11 GHz
581-611 GHz	30 GHz

doc.: IEEE 802.15-15-12-0324-00-0thz

Study on Interference Effects

Operational heights of Earth exploration satellites: 705 – 850 km



S. Priebe et al., IEEE Trans. Terahertz Sci. Tech., vol. 2, no. 5, 525(2012).

Summary

- Use of high frequency carriers such as millimeter waves and terahertz waves is effective to increase the bit rate.
- Photonics-based signal generation and modulation technique enables seamless connections between wired and wireless networks.
- 300-GHz band wireless link with direct detection scheme has reached error-free 30 Gbit/s. 600-GHz band ensures higher.
- To increase the bit rate and receiver sensitivity, coherent detection scheme has been examined; a proof-of-concept experiment has been demonstrated at 100-GHz band.
- For low-cost and/or consumer applications, electronics-based approach is essential, and use of RTDs has been demonstrated at 300-GHz band, in addition to Si-based Tx/Rx.