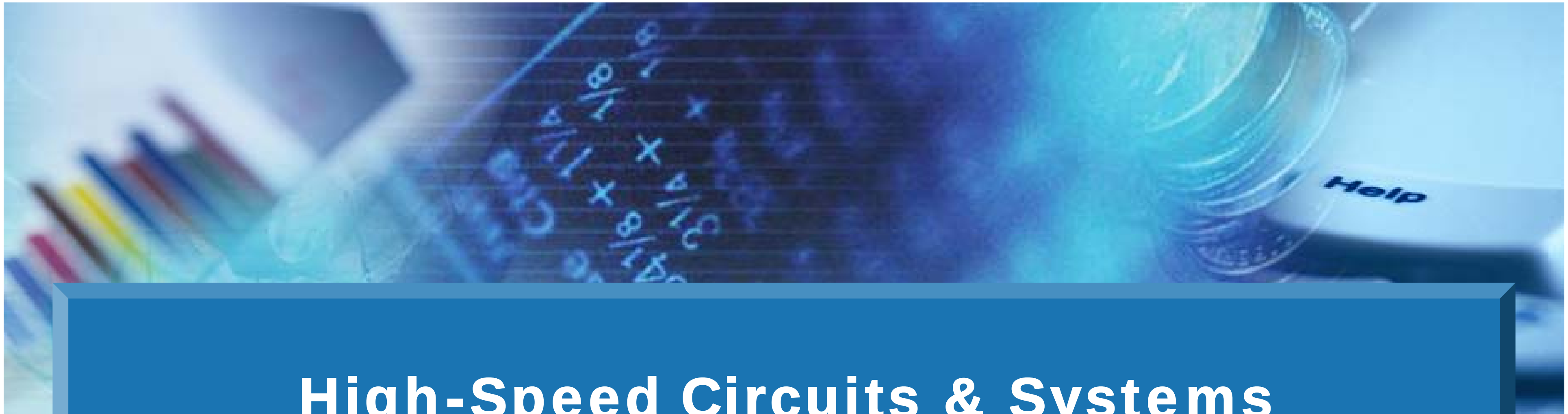


High-Speed Circuits & Systems

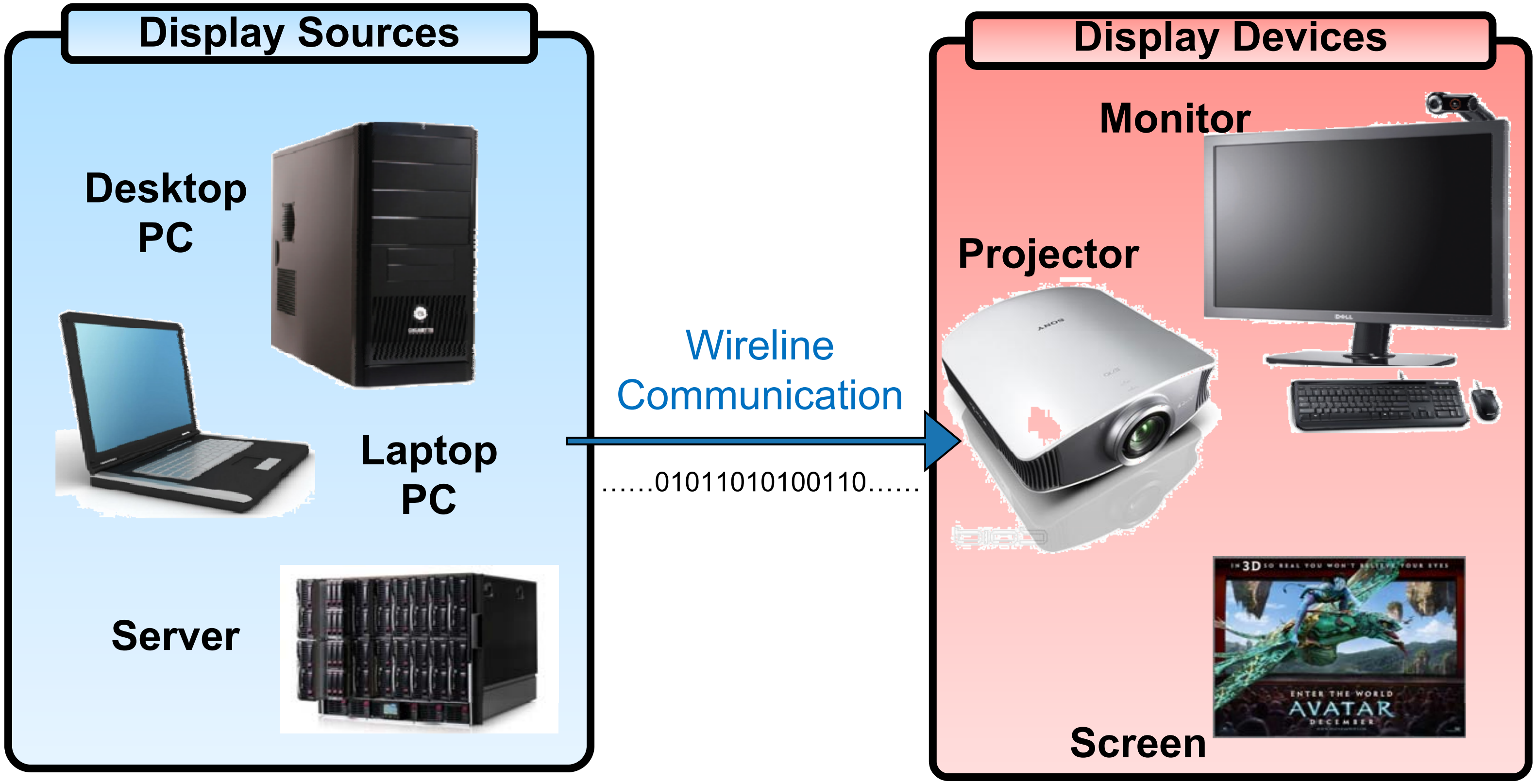
Woo-Young Choi

Department of Electrical and Electronic Engineering

Yonsei University

How Fast is Wireline Communications?

- How many bits are transfered per second?

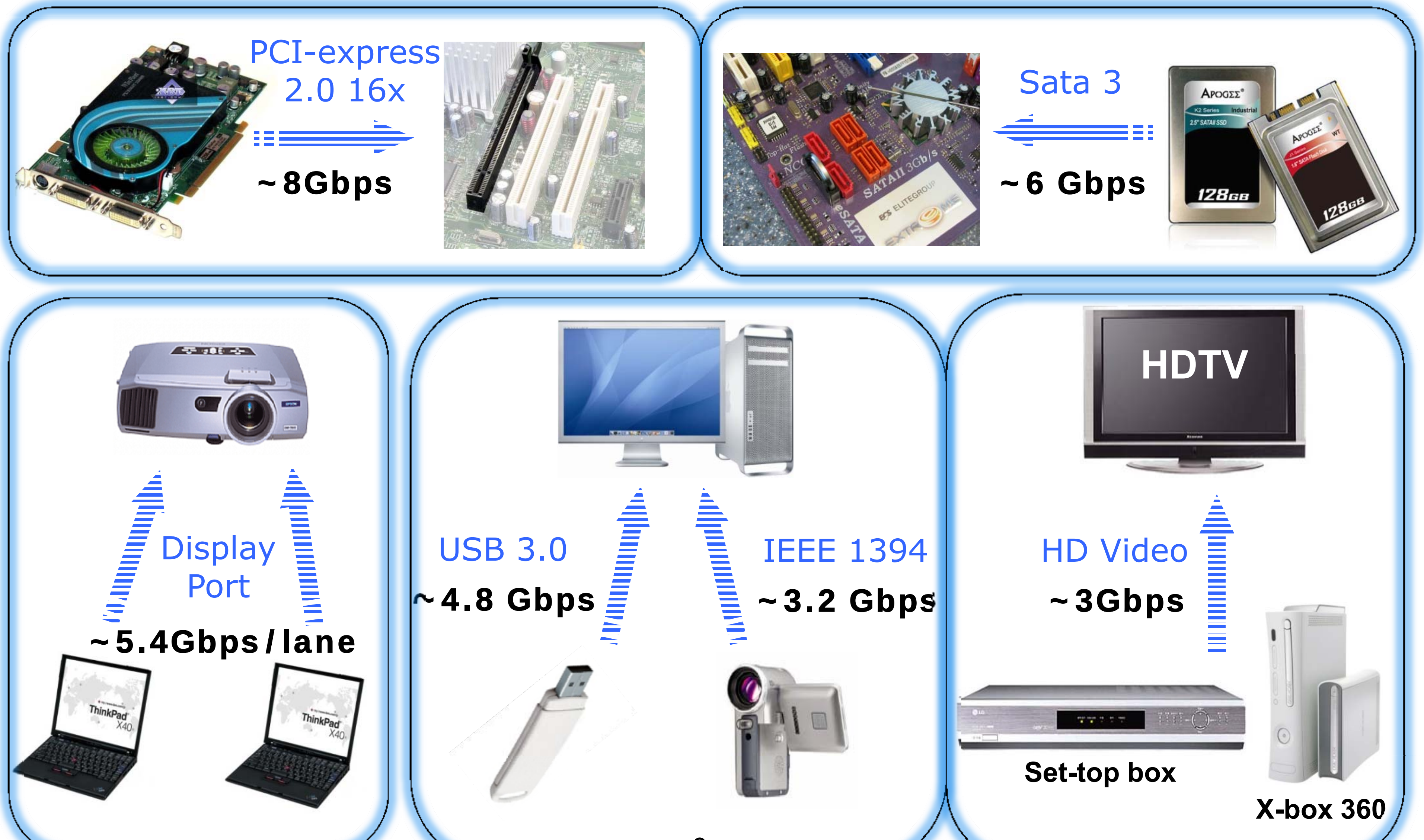


Data rate (bits/sec) = Resolution (pixels) x pixel bit (bits/pixel) x refresh (Hz)

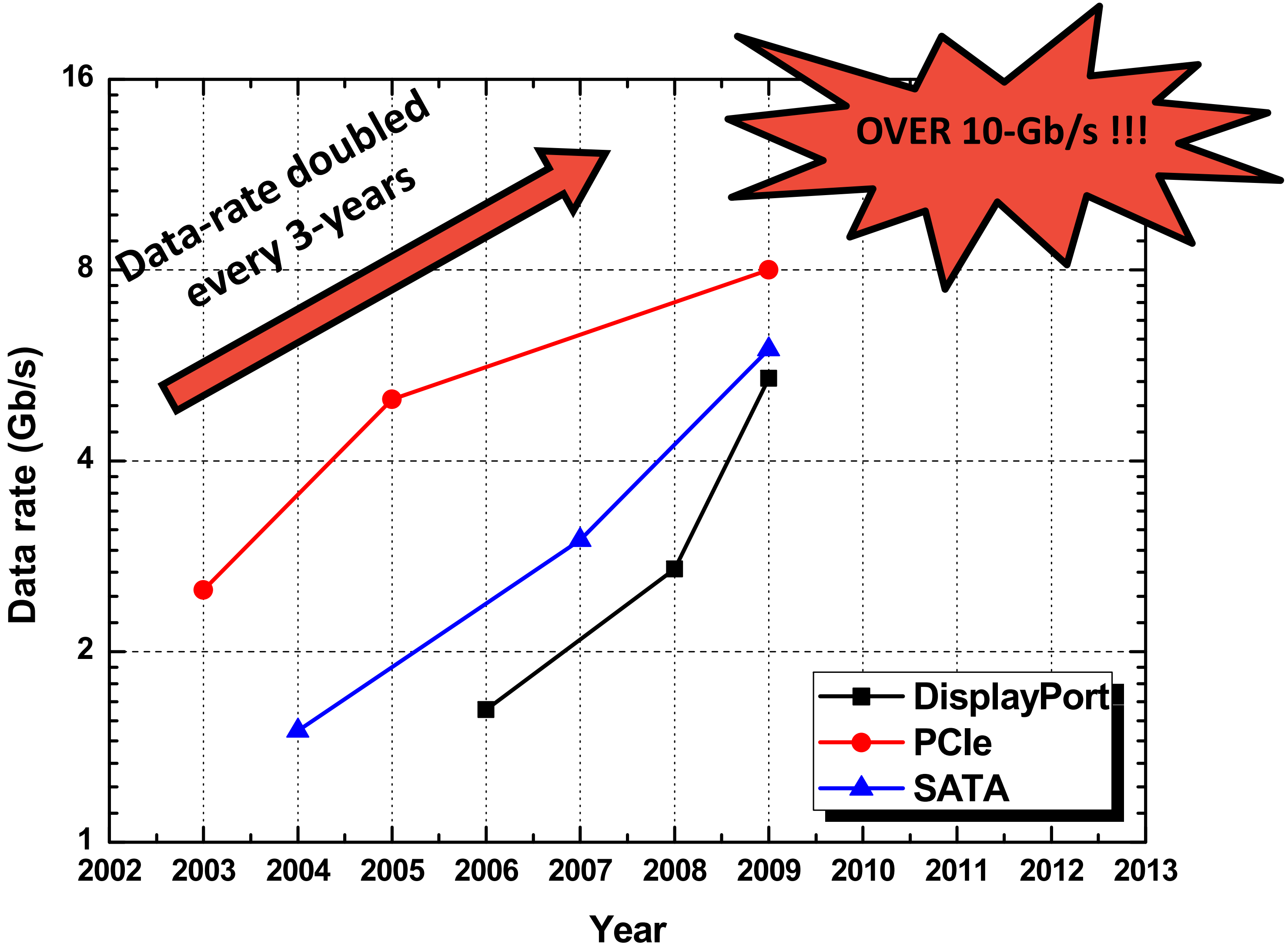
(Full HD) = (1920 x 1080) x 24 x 60 = 2.98 Gbps

YONSEI UNIVERSITY

Data Capacity of Wireline Communications



Data Rate Increase



Why does it keep increasing?

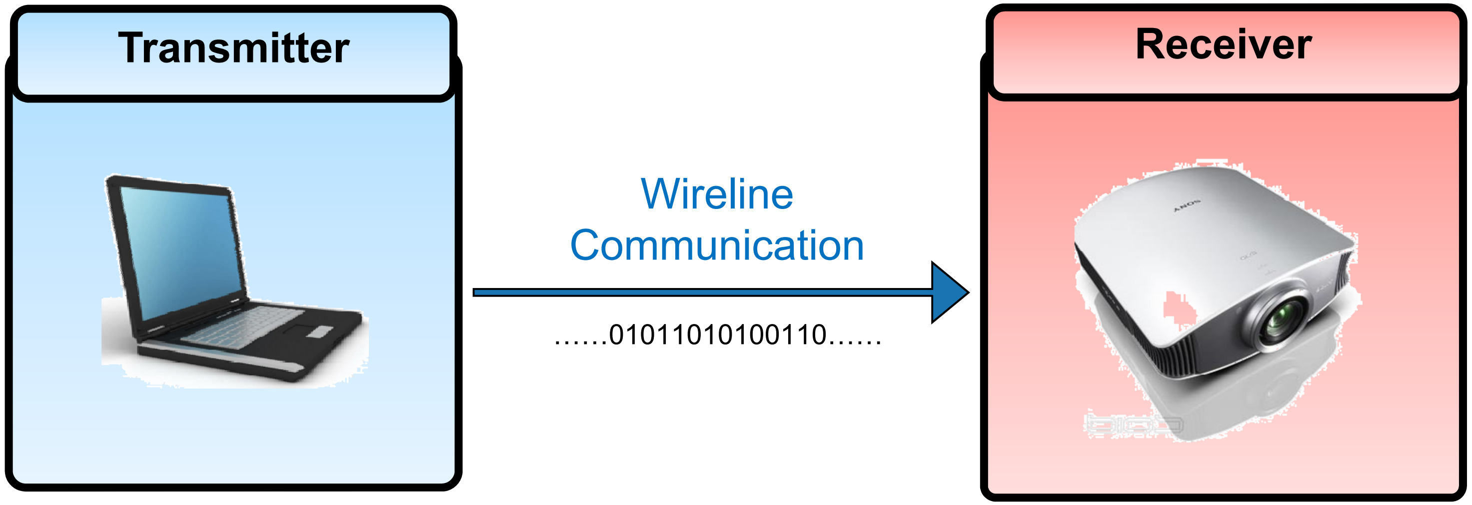
-Consumers demand better performances

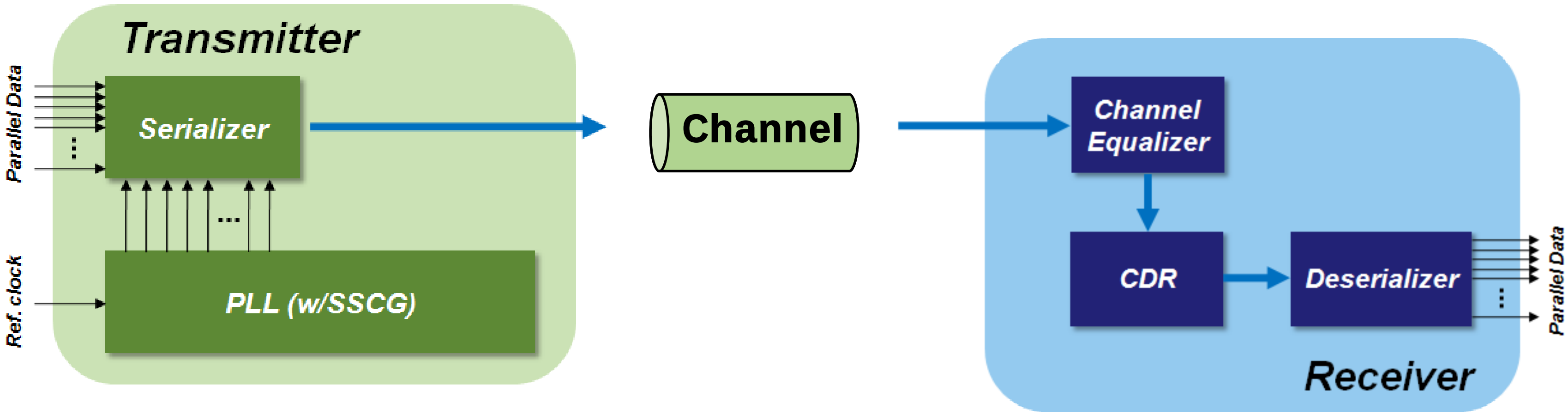
→New digital solutions
(Digital camera, Camcoder, YouTube …)

- Suppliers have to keep providing better performances

→ Faster, better quality, not necessarily cheaper

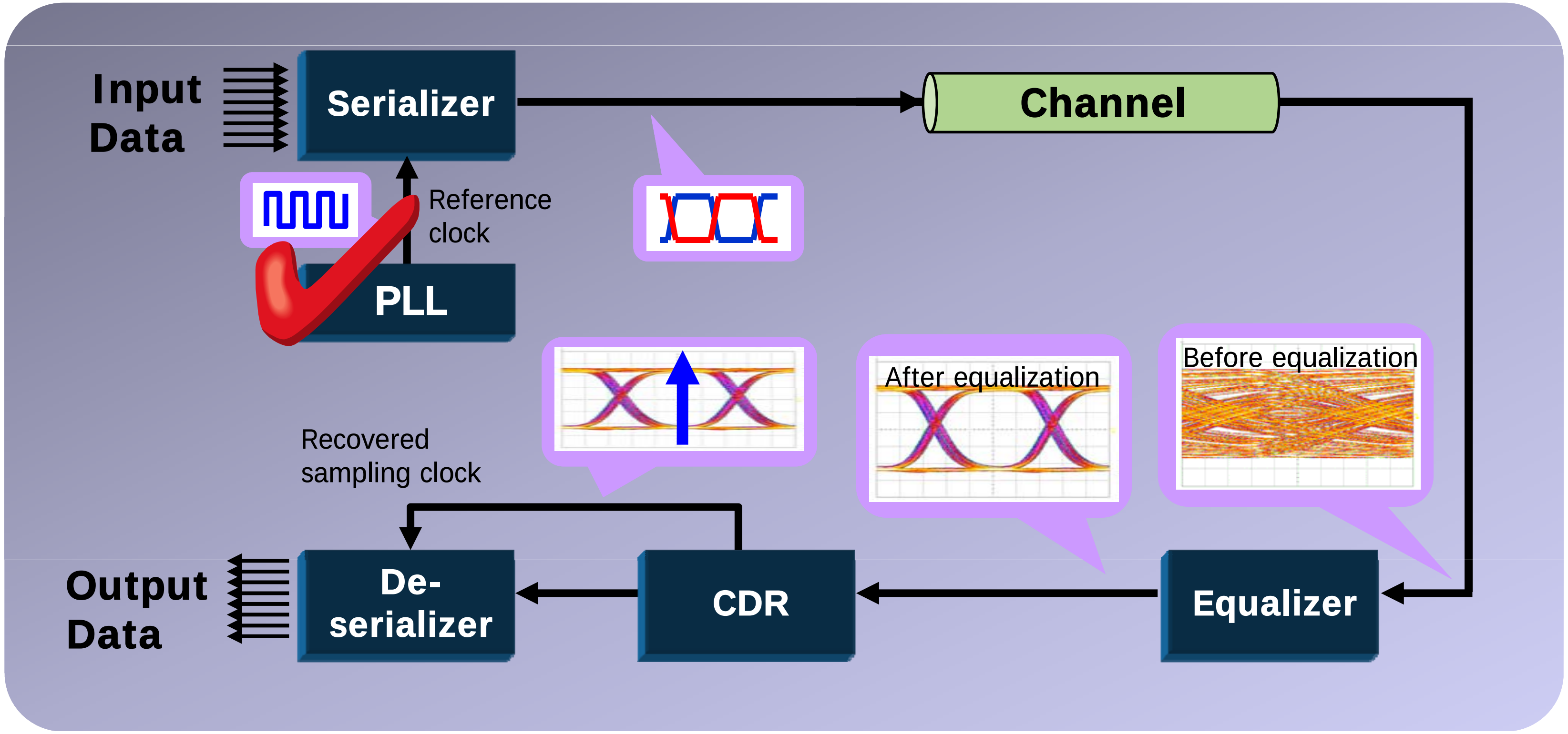
What is inside high-speed serial link?





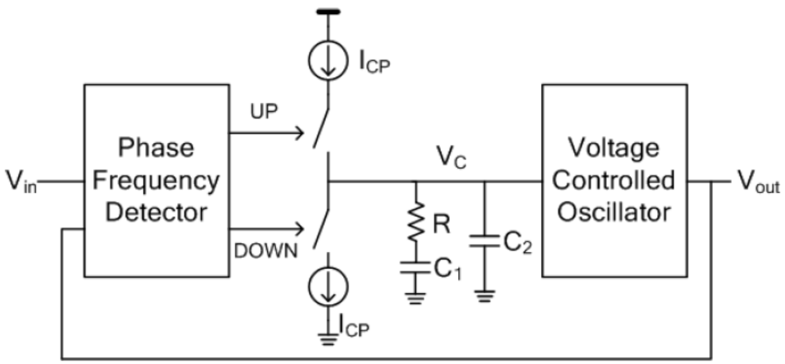
PLL (Phase-Locked Loop)

- 1 port serial line communication.

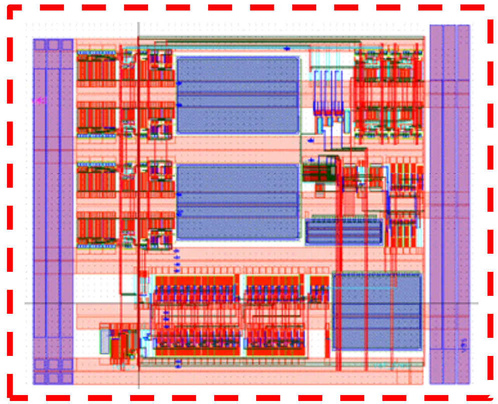


PLL (Phase-Locked Loop)

-PLL provides clean digital clock signal



• **Charge Pump PLL**

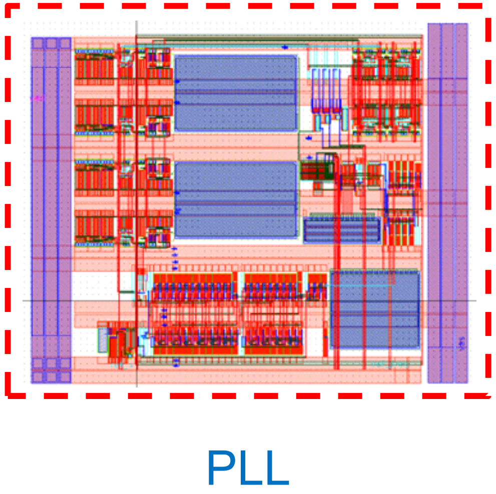


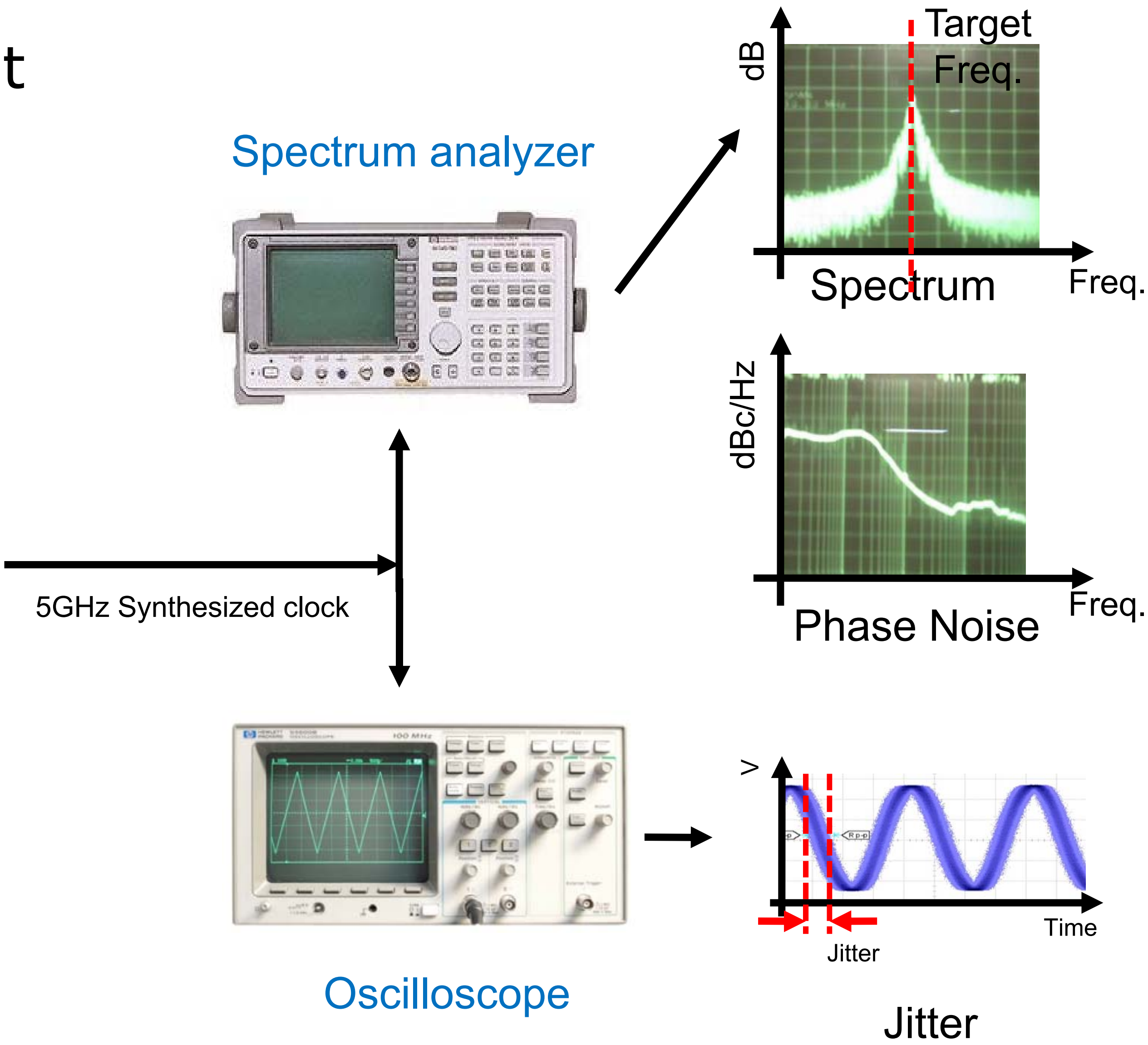
- Fabrication : Samsung 0.13um CMOS
- Spec.

target freq.	: 2.7GHz
Dividing ratio	: 80
Ref. freq.	: 33.75MHz
Rms Jitter	: <18.5ps
Phase noise	: <95dBc/Hz

PLL (Phase-Locked Loop)

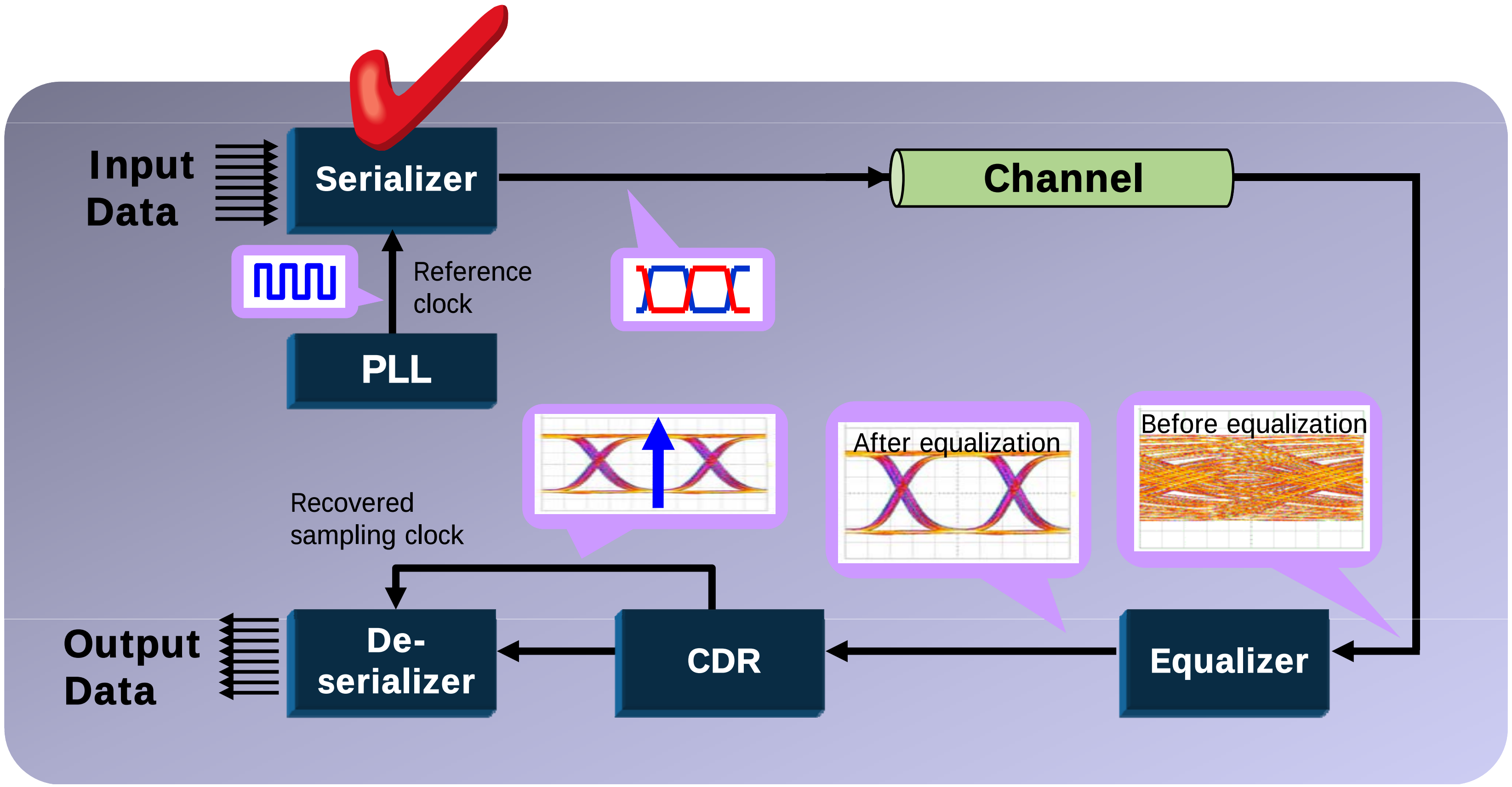
- Measurement





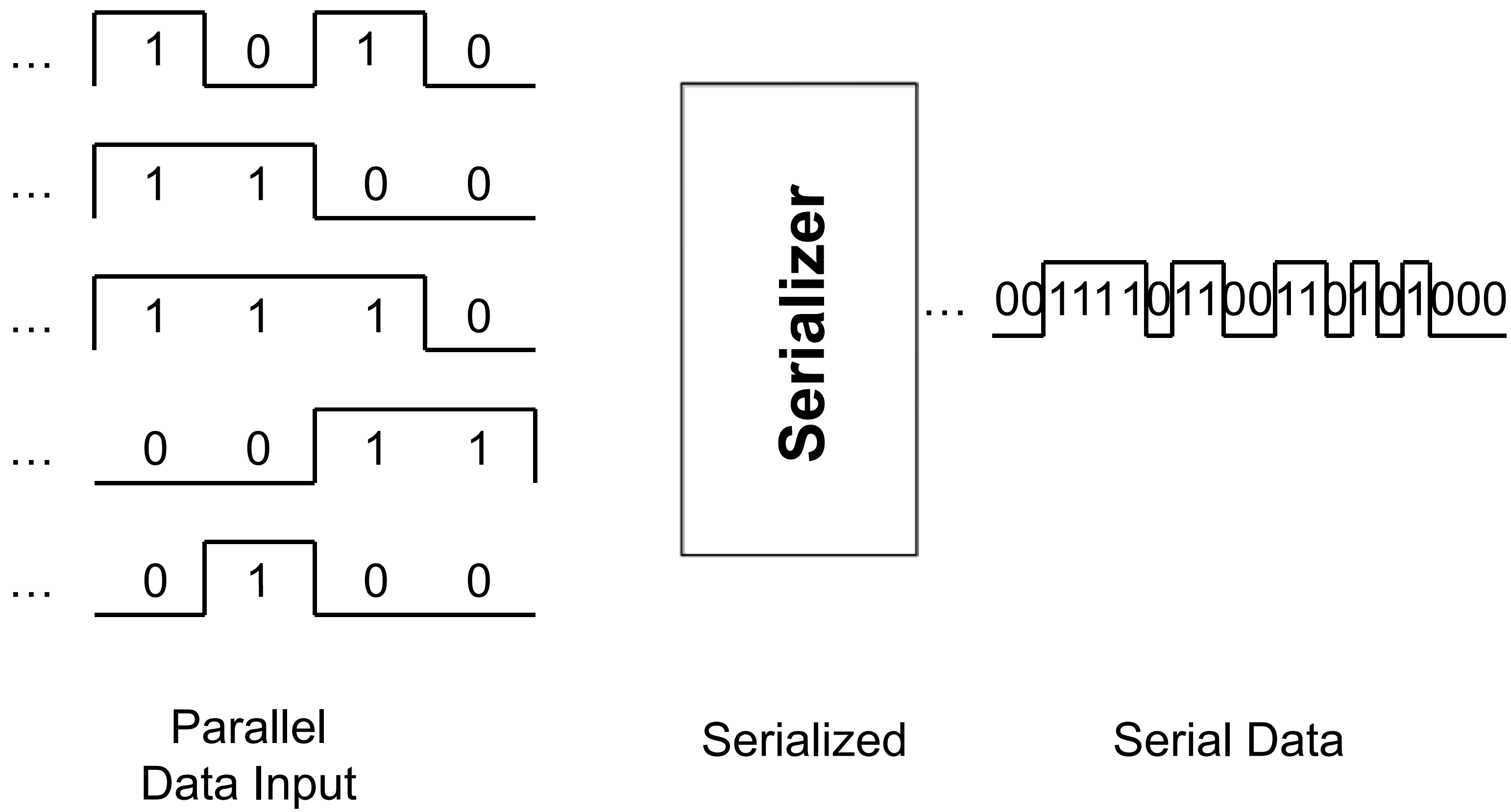
Serializer

- 1 port serial line communication.



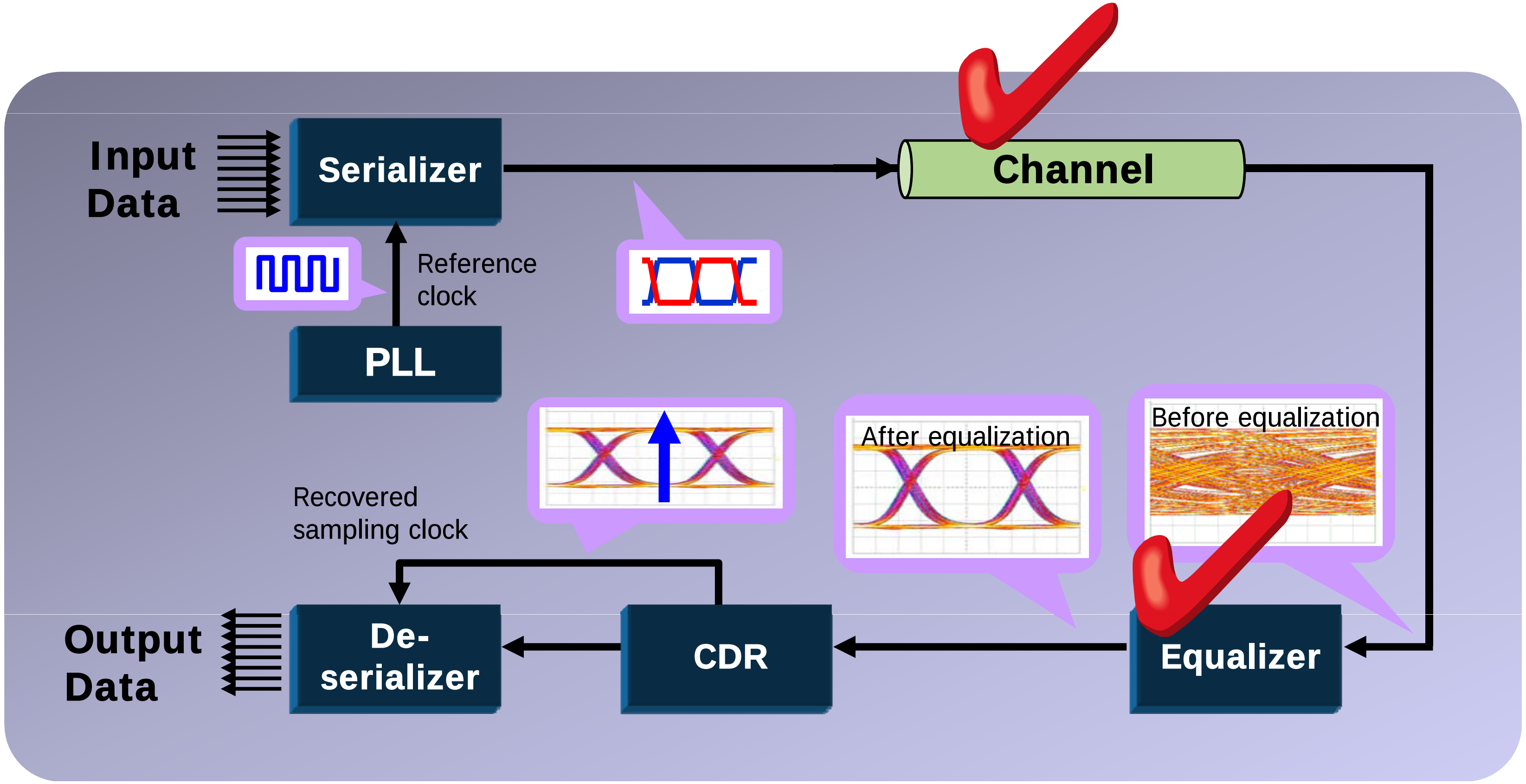
Serializer

- Data flow through serializer.

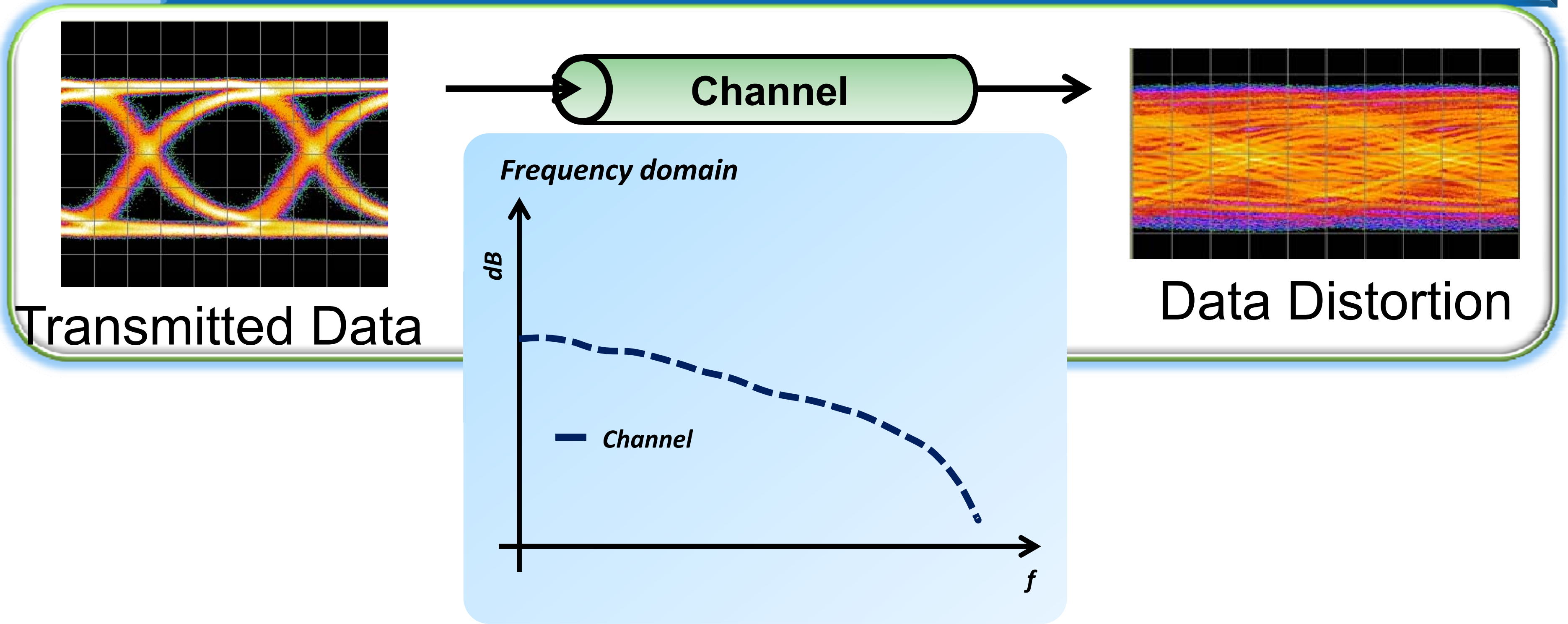


Channel & Equalizer

- 1 port serial line communication.



Channel Characteristics (Low-Pass Filter)

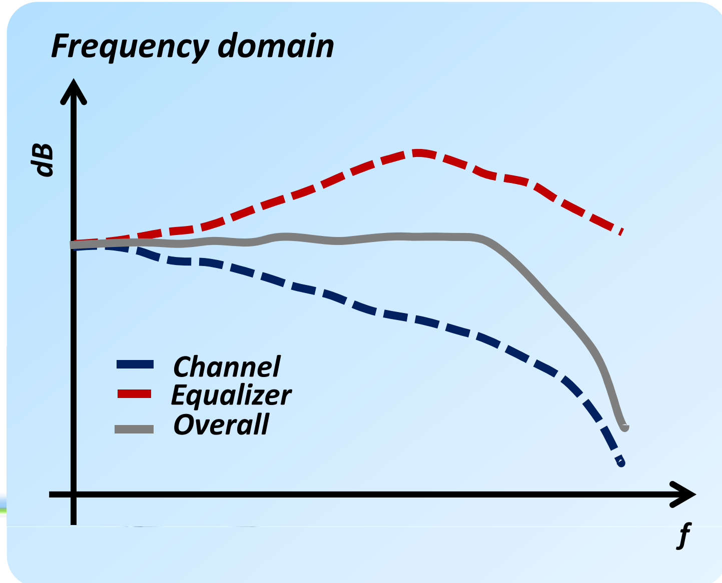


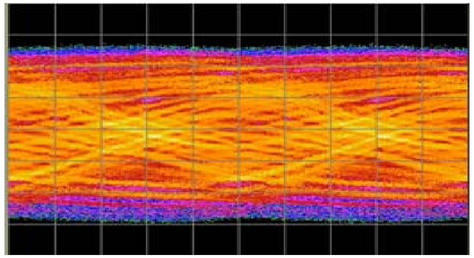
Transmission channel shows
low-pass filter characteristic.

Channel & Equalizer

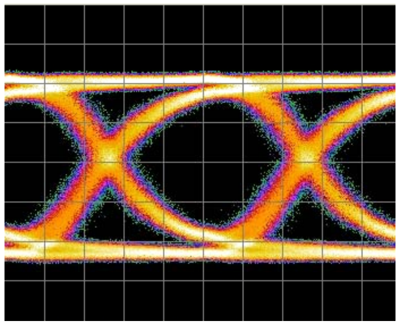
Equalizer Characteristic (High-Pass Filter)

→ Compensate the channel effect

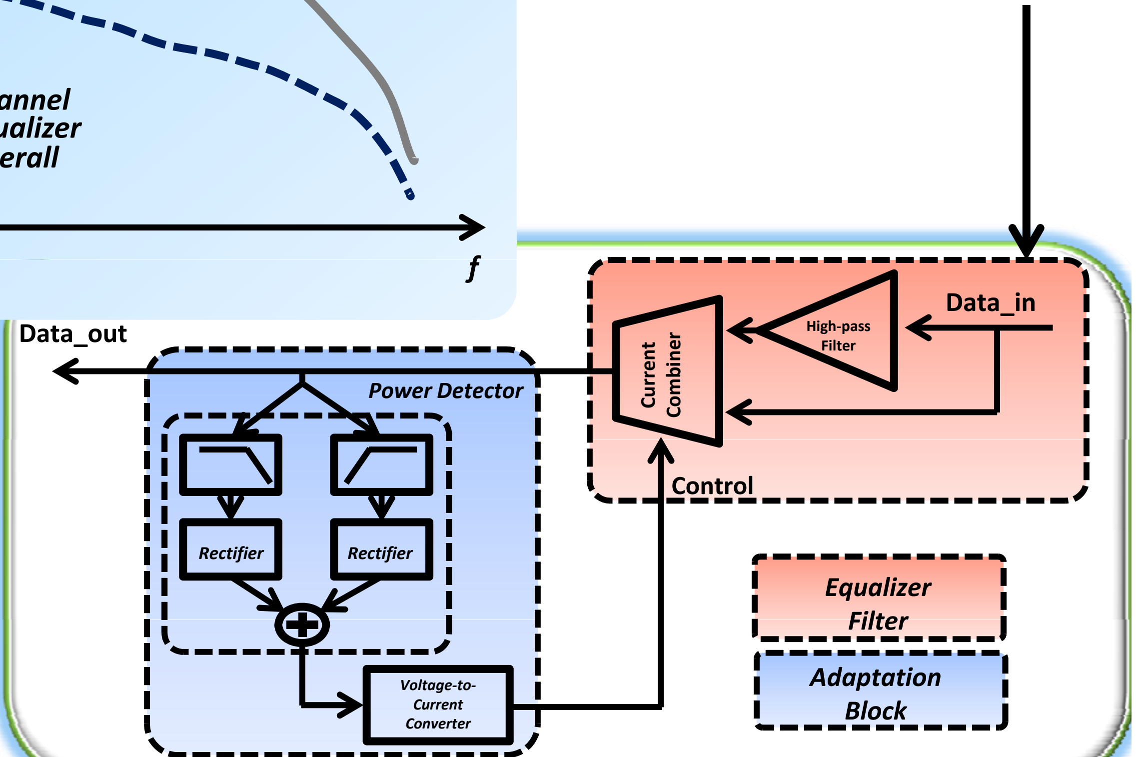




Data Distortion

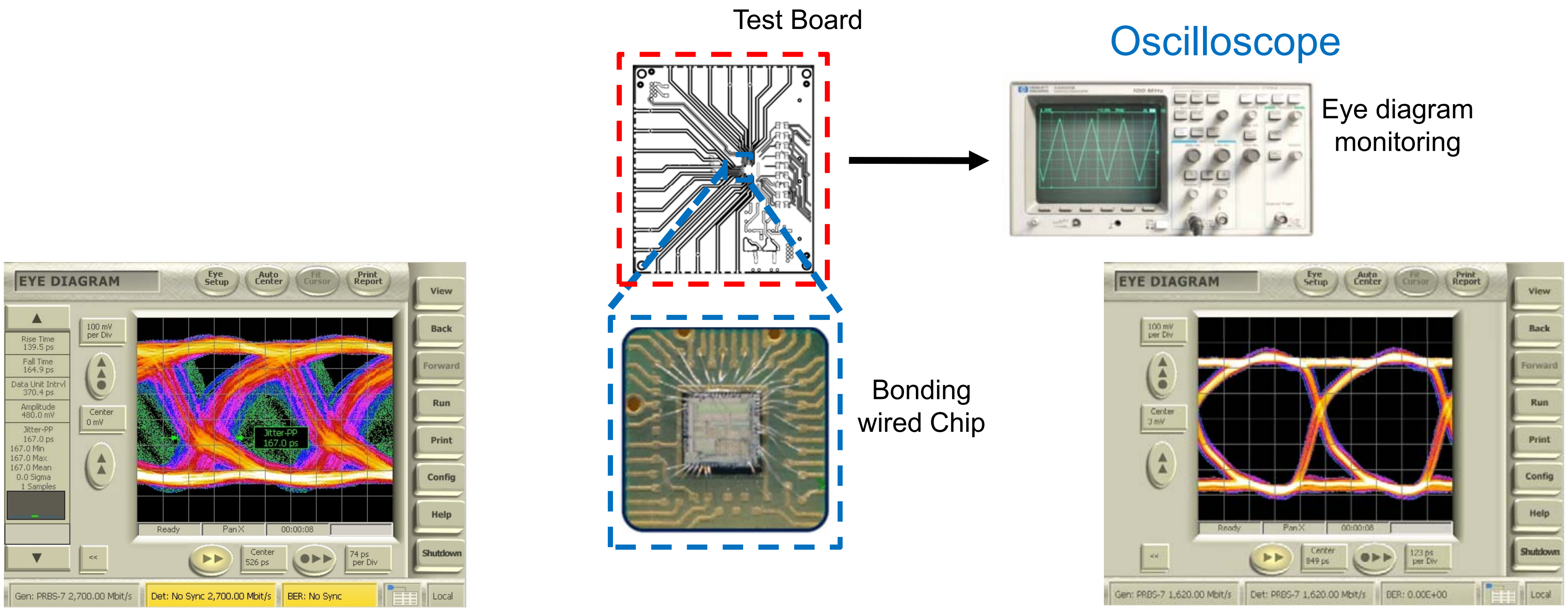


Recoverd Data



Channel & Equalizer

- Measurement



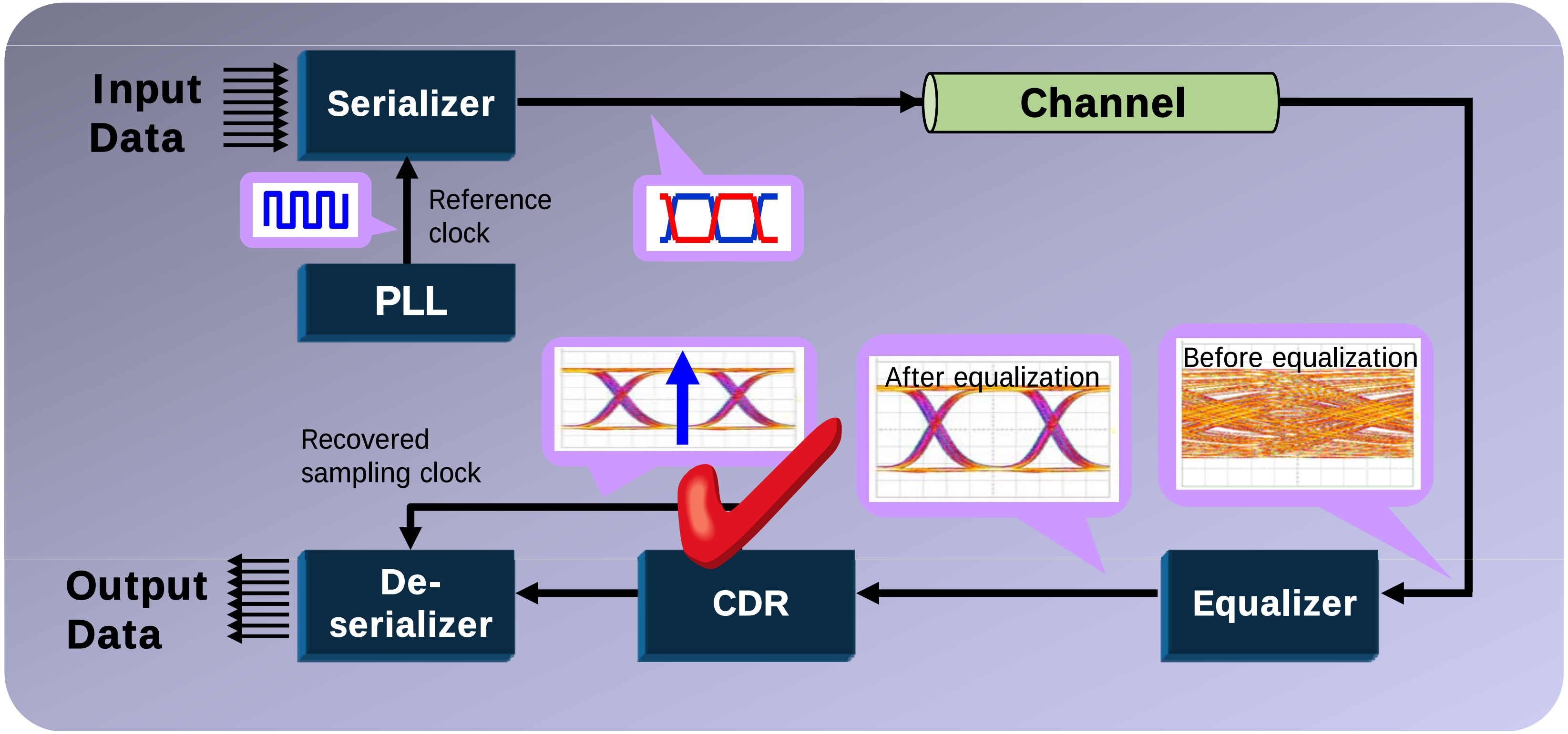
Transmitted Data

Equalizer

Recovered Data

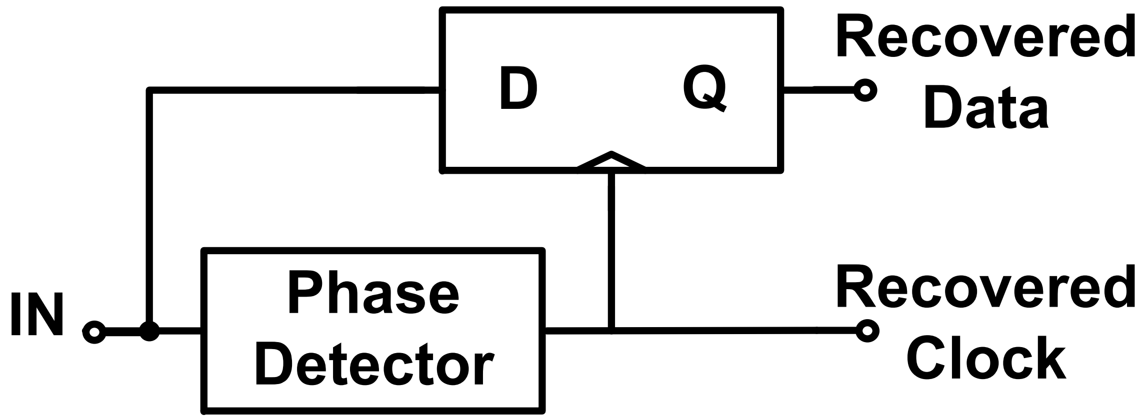
CDR (Clock & Data Recovery)

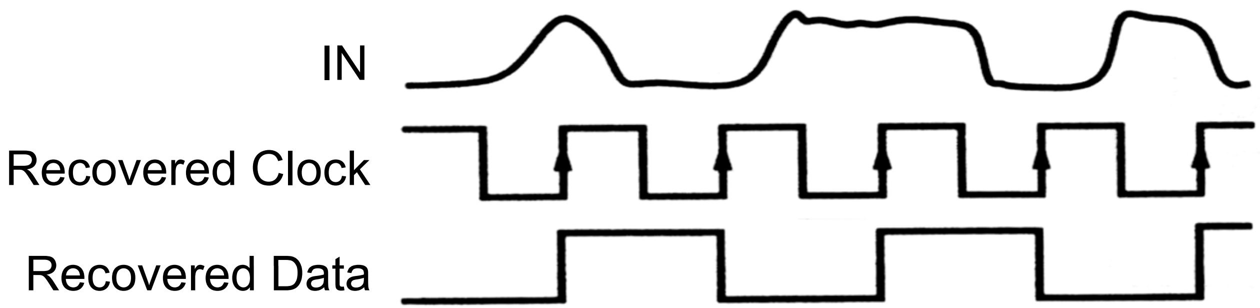
- 1 port serial line communication.



CDR (Clock & Data Recovery)

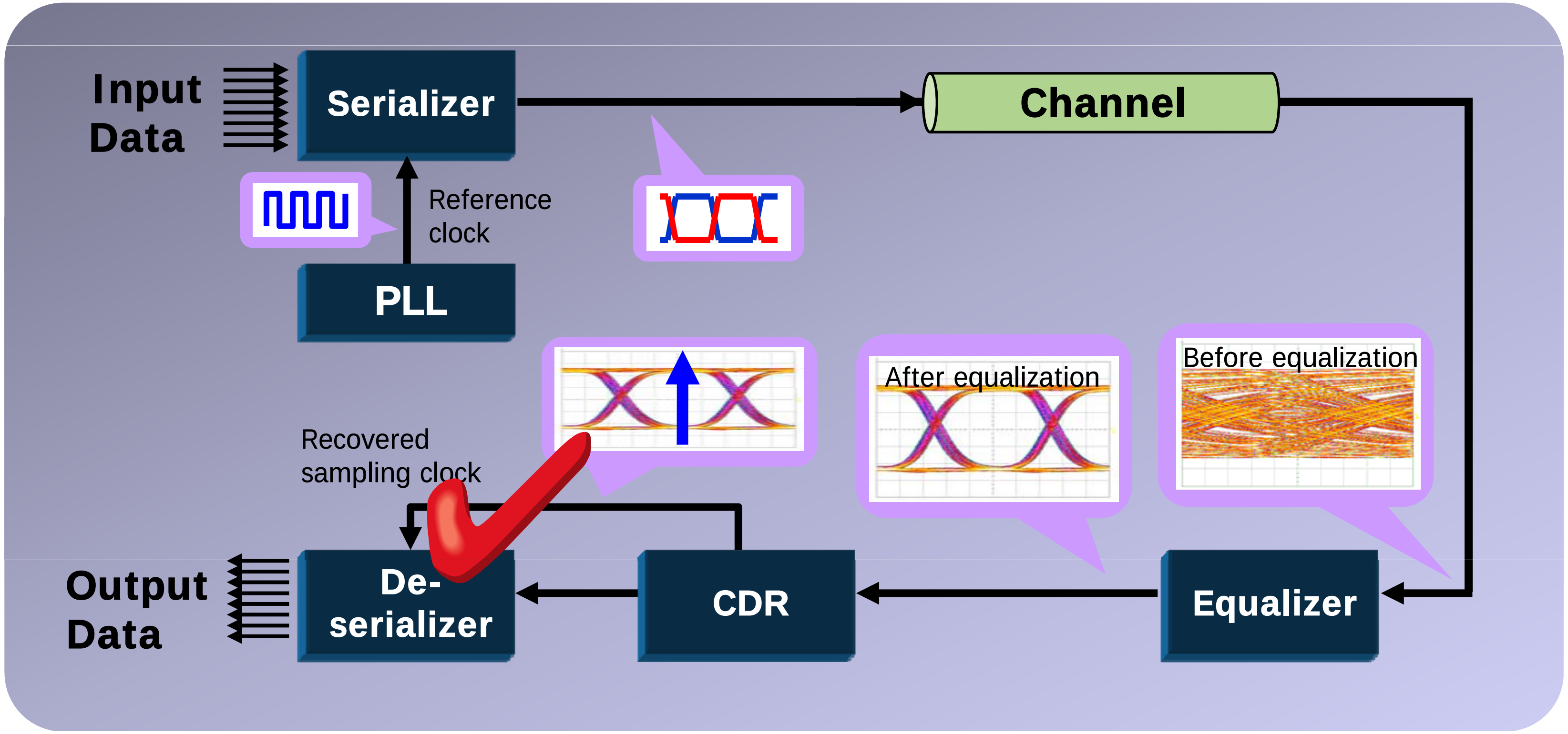
- CDR





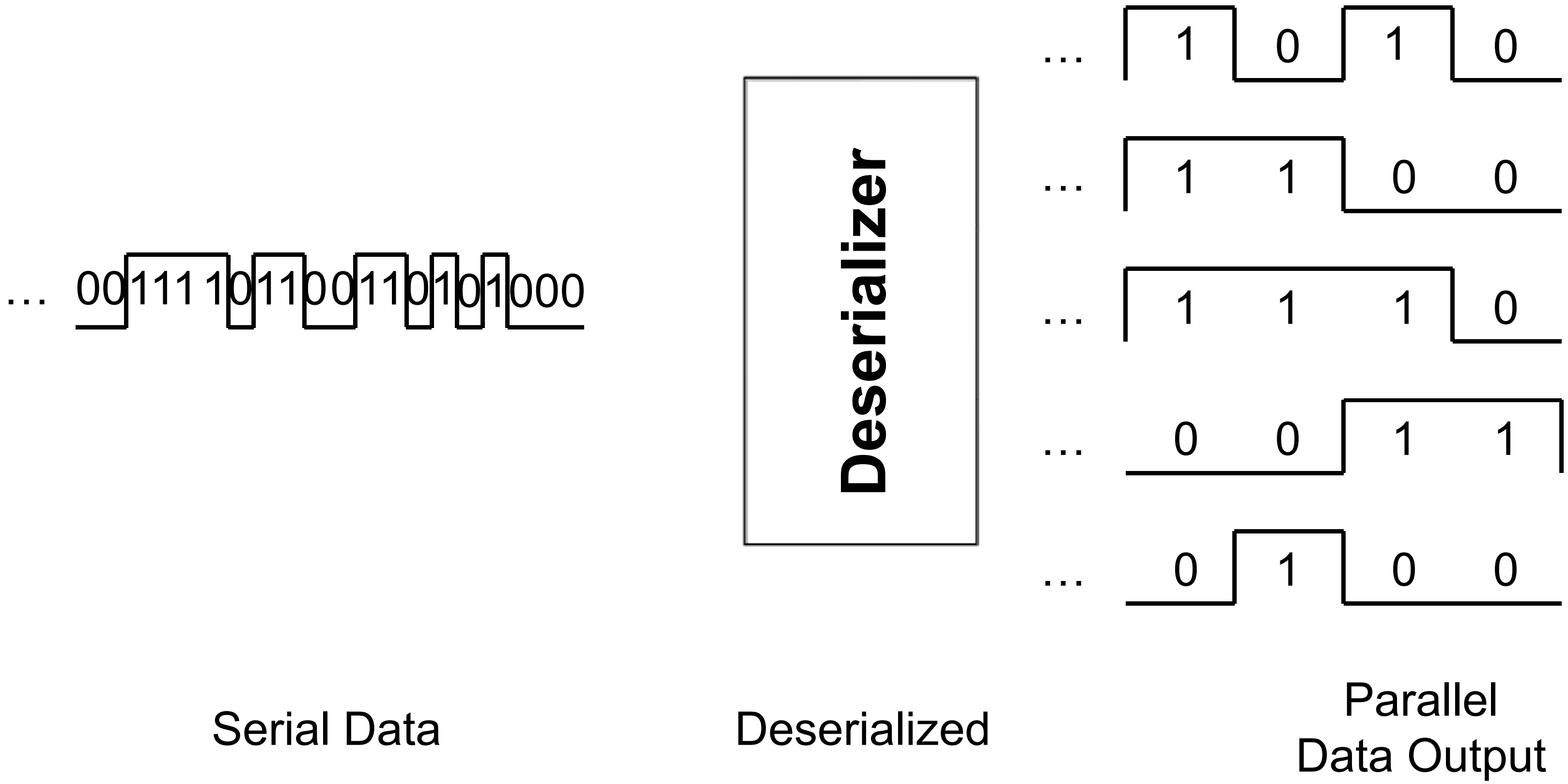
Deserializer

- 1 port serial line communication.



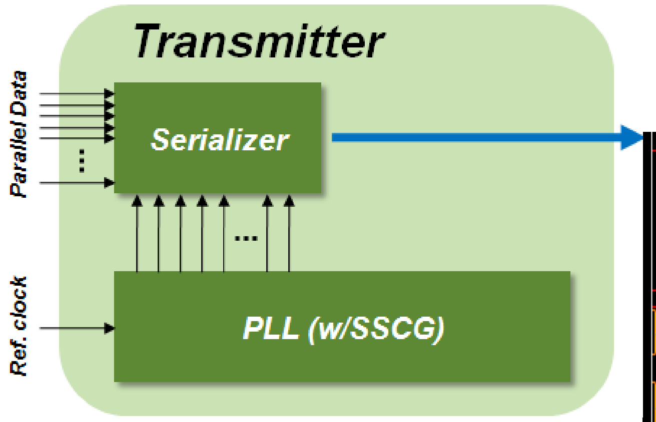
Deserializer

- Data flow through deserializer.

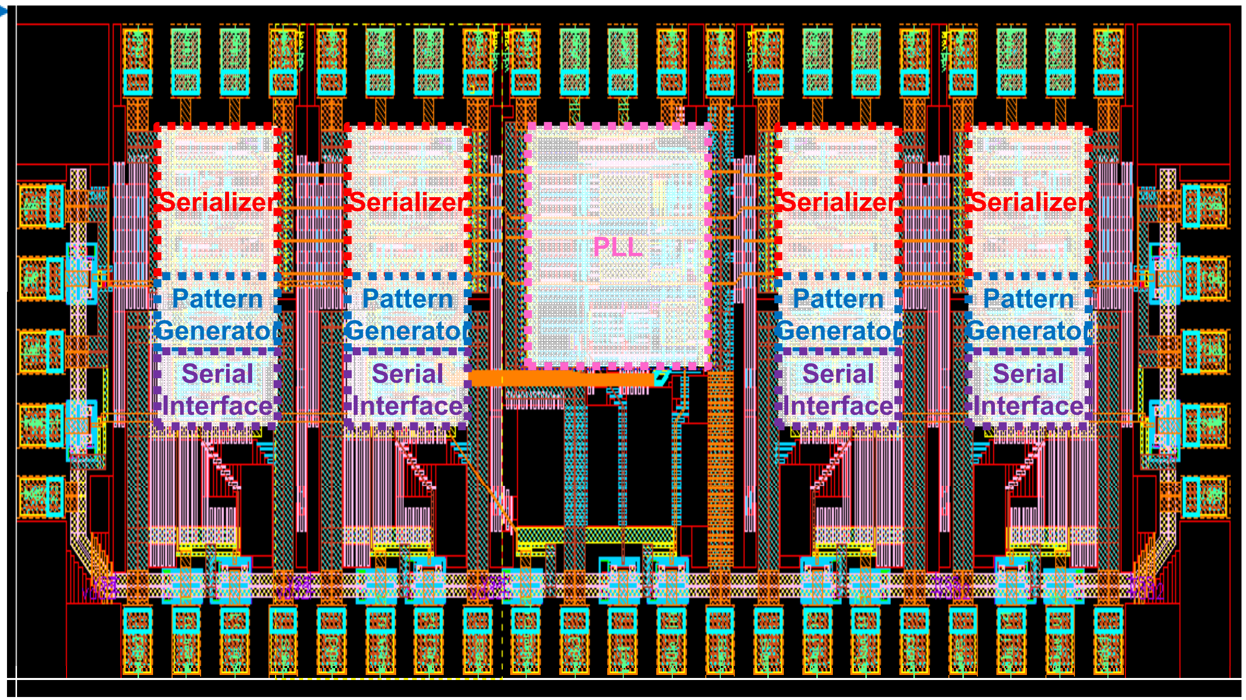


Chip Layout

- Chip Layout – Tx



Process: Samsung 013

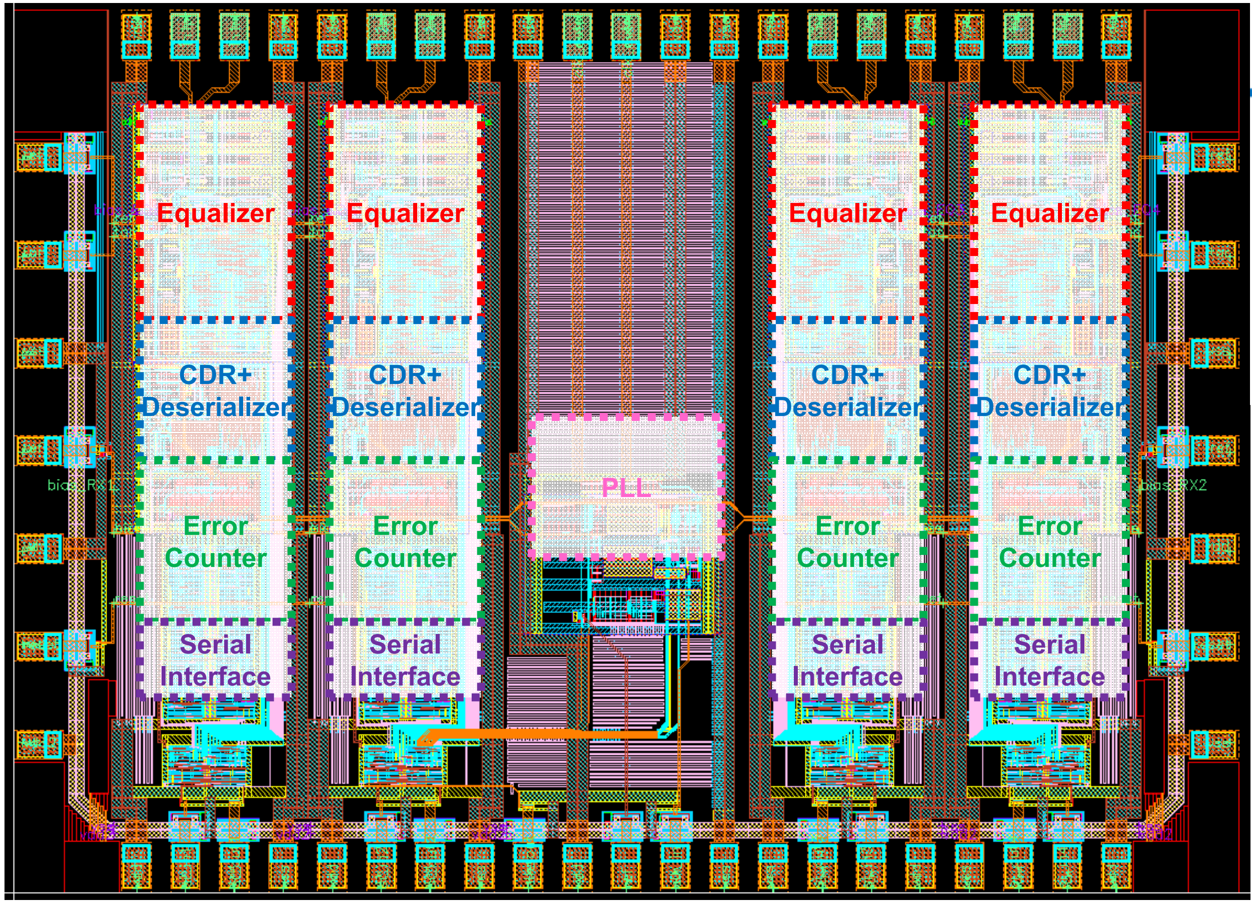


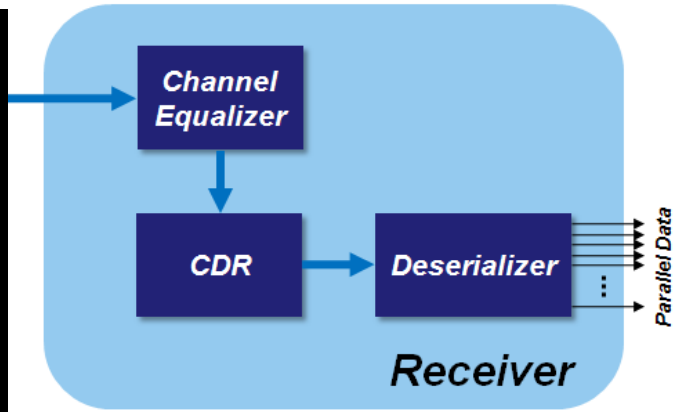
2500 X 900

Chip Layout

- Chip Layout – Rx

Process: Samsung 013





2500 X 1800

Chip Design Process

- Circuit Design
- Schematic simulation
- Layout
- Verification
- Post-layout simulation with parasitic RC
- Tape out
- Chip on Board & Probing
- Measurement

Design tool

➔ HSPICE_vC-2009 (SYNOPSYS)

Text mode netlist

```
**** Input & Clock
Xgen        clkl datal data0 val            va_serializer
Ycom        com           vss                         0.95
Edatalp     datalp1 com                      VCVS datal vss 1
Edataln     dataln1 com                      VCVS datal vss -1
Edata0p     data0p1 com                      VCVS data0 vss 1
Edata0n     data0n1 com                      VCVS data0 vss -1

Yclkl       clkl    vss                      pulse (0.25 -0.25 '1.0/rate' 1p 1p '1/rate' '2/rate')
Eclklp      rclklp  com                      VCVS clkl vss 1
Eclkln      rclkln  com                      VCVS clkl vss -1
Xclkbuf     bias rclkln rclklp clkln clklp vdd2 vss       BIGBANG200906_kimdor_buffer_1500
Xdatalbuf   bias dataln1 datalp1 dataln datalp vdd2 vss          BIGBANG200906_kimdor_buffer_1500
Xdata0buf   bias data0n1 data0p1 data0n data0p vdd2 vss          BIGBANG200906_kimdor_buffer_1500

**** DUT
Xdes        bias clkln clkout clklp d0 d1 d2 d3 d4
+               d5 d6 d7 d8 d9 dA dB dC dD dE dF dataln datalp data0n data0p vdd vss
+               BIGBANG200906_c3kc_Deserializer

**** Simulation Setting
.TRAN       10p           60n
.param      rate = '10.8g'
.options    probe
```

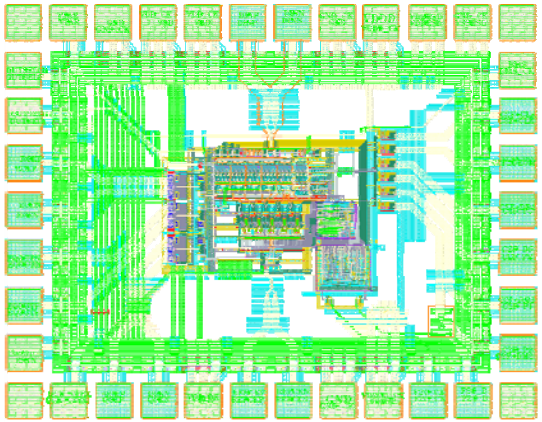
Simulation result

```
******  Runtime Statistics (seconds)  ******

analysis           time    # points   tot. iter  conv.iter
op point           0.00           1         19
transient          0.77        1001      16391       6097 rev=        98
readin             0.05
errchk             0.01
setup              0.00
output             0.00


         total memory used          192  kbytes
         total cpu time            0.83 seconds
         total elapsed time        1.07 seconds
         job started at     19:56:05 02/23/2010
         job ended   at     19:56:06 02/23/2010


Init: hspice initialization file: /home/tools/synopsys/Hspice_vC-2009.03/hspice/hspice.ini
lic: Release hspice token(s)
                                                                        1362,30       Bot
```

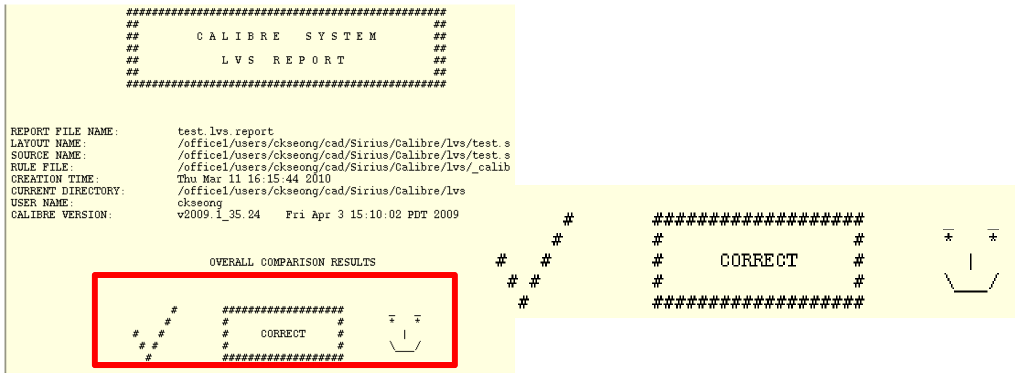
Chip Design Process

- Circuit Design
- Schematic simulation
- Layout
- Verification
- Post-layout simulation with parasitic RC
- Tape out
- Chip on Board & Probing
- Measurement

Layout tool
➔ Virtuoso (Cadence)



Verification tool
➔ Calibre (Mentor)



Chip Design Process

- Circuit Design
- Schematic simulation
- Layout
- Verification
- **Post-layout simulation with parasitic RC**
- Tape out
- Chip on Board & Probing
- Measurement

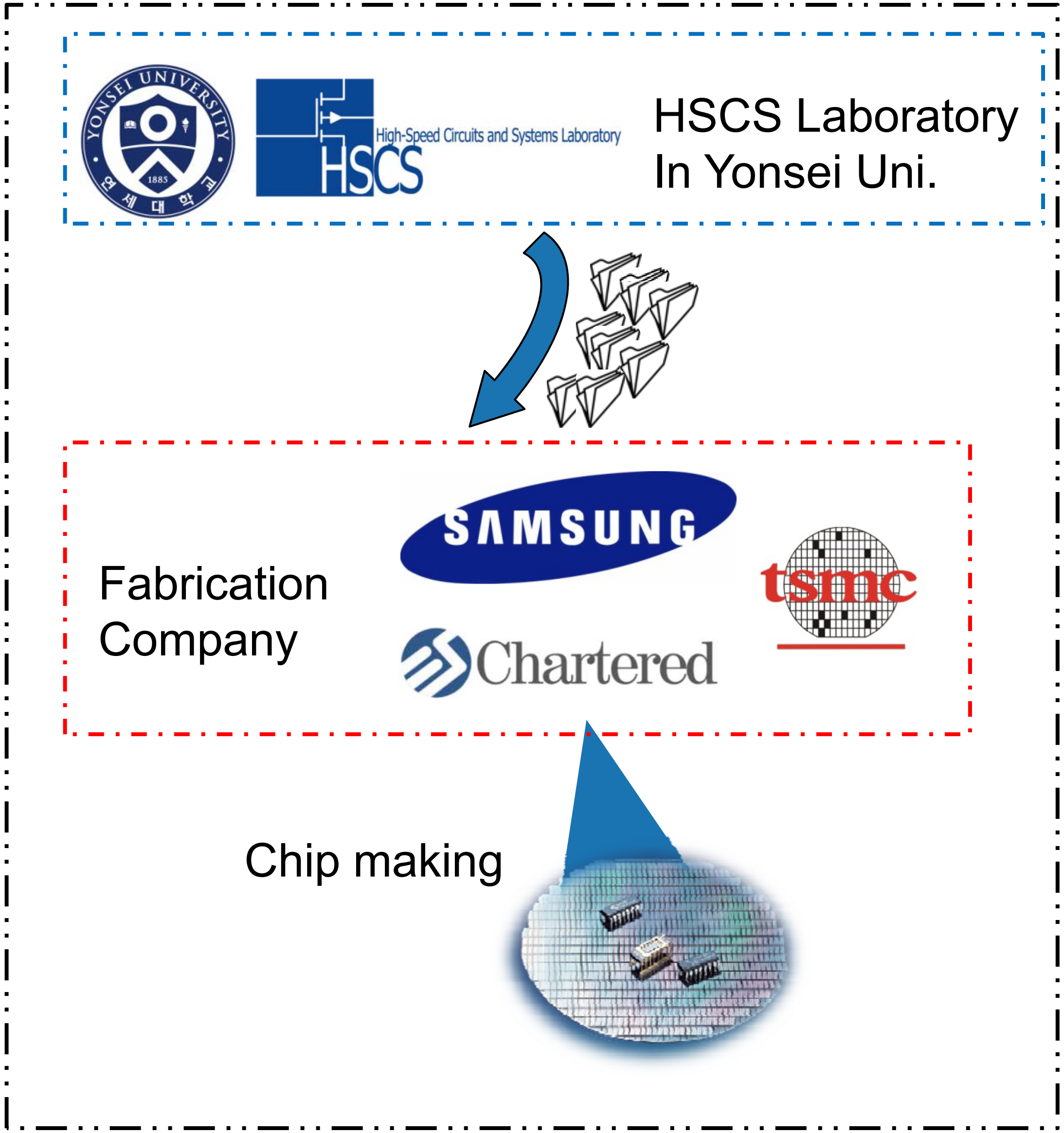
Post-layout netlist

```
XI1/MPM19 I1/NET098:F6463 BIASP:F6464 I1/NET0182:F6465 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MNM10@5 I1/NET098:F6606 I1/NET098:F6607 GND:F6608 GND nmos_1p2_ps SA=3.53 SB=4.3 ad=1.058p as=1.058p l=0.3u nrd=0.0
52 nrs=0.052 pd=4.97u ps=4.97u w=4.5u
XI1/MNM10@6 I1/NET098:F6612 I1/NET098:F6611 GND:F6610 GND nmos_1p2_ps SA=4.3 SB=3.53 ad=1.058p as=1.058p l=0.3u nrd=0.0
52 nrs=0.052 pd=4.97u ps=4.97u w=4.5u
XI1/MPM23 I1/NET0182:F5828 GND:F5827 VDD:F5826 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM25 I1/NET0182:F6127 GND:F6126 VDD:F6125 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM20 I1/NET098:F6281 BIASP:F6282 I1/NET0182:F6283 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MPM13 I1/NET098:F6229 BIASP:F6230 I1/NET0182:F6231 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MNM10@7 I1/NET098:F6614 I1/NET098:F6615 GND:F6616 GND nmos_1p2_ps SA=5.07 SB=2.76 ad=1.058p as=1.058p l=0.3u nrd=0.
052 nrs=0.052 pd=4.97u ps=4.97u w=4.5u
XI1/MNM10@8 I1/NET098:F6620 I1/NET098:F6619 GND:F6618 GND nmos_1p2_ps SA=5.84 SB=1.99 ad=1.058p as=1.058p l=0.3u nrd=0.
052 nrs=0.052 pd=4.97u ps=4.97u w=4.5u
XI1/MNM10@9 I1/NET098:F6624 I1/NET098:F6623 GND:F6622 GND nmos_1p2_ps SA=6.61 SB=1.22 ad=1.058p as=1.058p l=0.3u nrd=0.
052 nrs=0.052 pd=4.97u ps=4.97u w=4.5u
XI1/MPM39 I1/NET0310:F5997 GND:F5996 VDD:F5995 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM41 I1/NET0310:F6725 GND:F6724 VDD:F6723 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM36 I1/NET098:F6398 BIASP:F6399 I1/NET0310:F6400 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MPM37 I1/NET098:F6190 BIASP:F6191 I1/NET0310:F6192 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MNM10@10 I1/NET098:F6628 I1/NET098:F6627 GND:F6626 GND nmos_1p2_ps SA=7.38 SB=0.45 ad=1.058p as=2.025p l=0.3u nrd=0
.052 nrs=0.1 pd=4.97u ps=9.9u w=4.5u
XI1/MPM57 I1/NET0310:F5893 GND:F5892 VDD:F5891 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM40 I1/NET0310:F6036 GND:F6035 VDD:F6034 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM34 I1/NET098:F6372 BIASP:F6373 I1/NET0310:F6374 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MPM50 I1/NET098:F6476 BIASP:F6477 I1/NET0310:F6478 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
XI1/MPM30 I1/NET0310:F5906 GND:F5905 VDD:F5904 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM48 I1/NET0310:F6062 GND:F6061 VDD:F6060 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=0.45p as=0.45p l=0.13u nrd=0.45 nrs=0.45
 pd=2.9u ps=2.9u w=1u
XI1/MPM29 I1/NET098:F6333 BIASP:F6334 I1/NET0310:F6335 VDD PMOS_1P2 SA=0.45 SB=0.45 ad=1.8p as=1.8p l=0.2u nrd=0.112 nr
s=0.112 pd=8.9u ps=8.9u w=4u
@
                                                                                                  23831,1       99%
```

Very complicate with parasitic RC component

Chip Design Process

1. Circuit Design
2. Schematic simulation
3. Layout
4. Verification
5. Post-layout simulation with parasitic RC
6. Tape out
7. Chip on Board & Probing
8. Measurement



Chip Design Process

- Circuit Design
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- Verification
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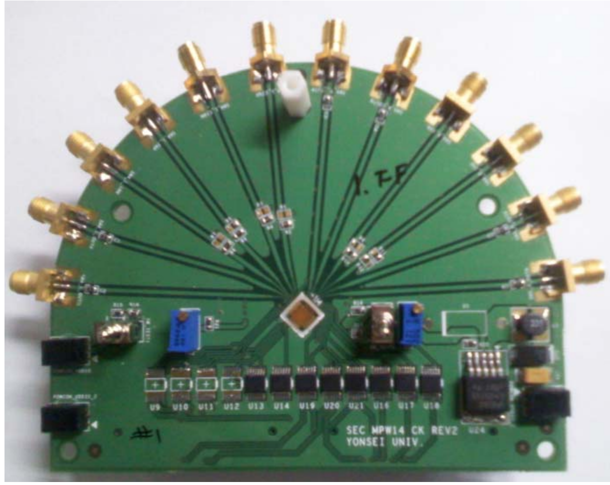
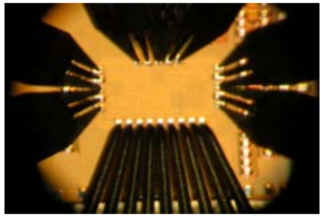
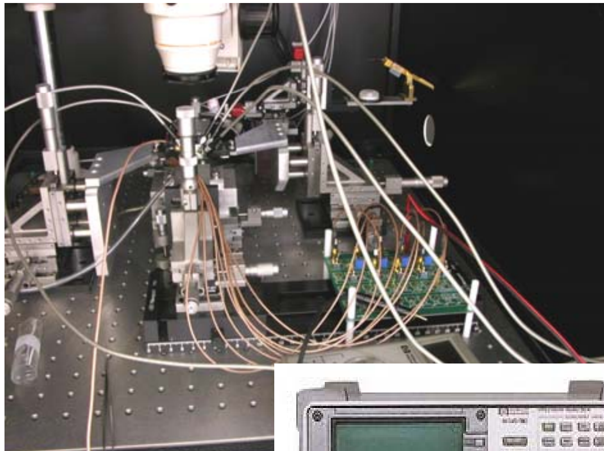
Chip on Board

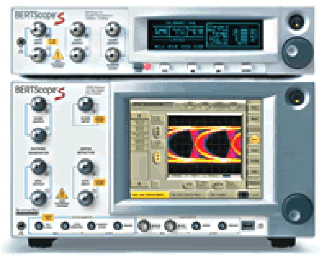


Probing



Measurement Setting





Much Faster Serial Links ?

Transmitter

- Serializer
- Phase-Locked Loop (PLL)

Receiver

- Equalizer
- Clock & Data Recovery (CDR)
- Deserializer

…1010110011…

…1010110011…

Large loss at high frequencies !!

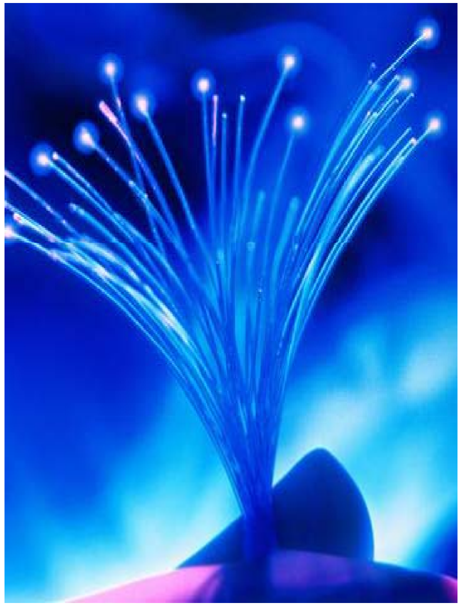
Much Faster Serial Links ?

Transmitter

- Serializer
- Phase-Locked Loop (PLL)

Electrical-to-optical (E/O) conversion

…1010110011…



Receiver

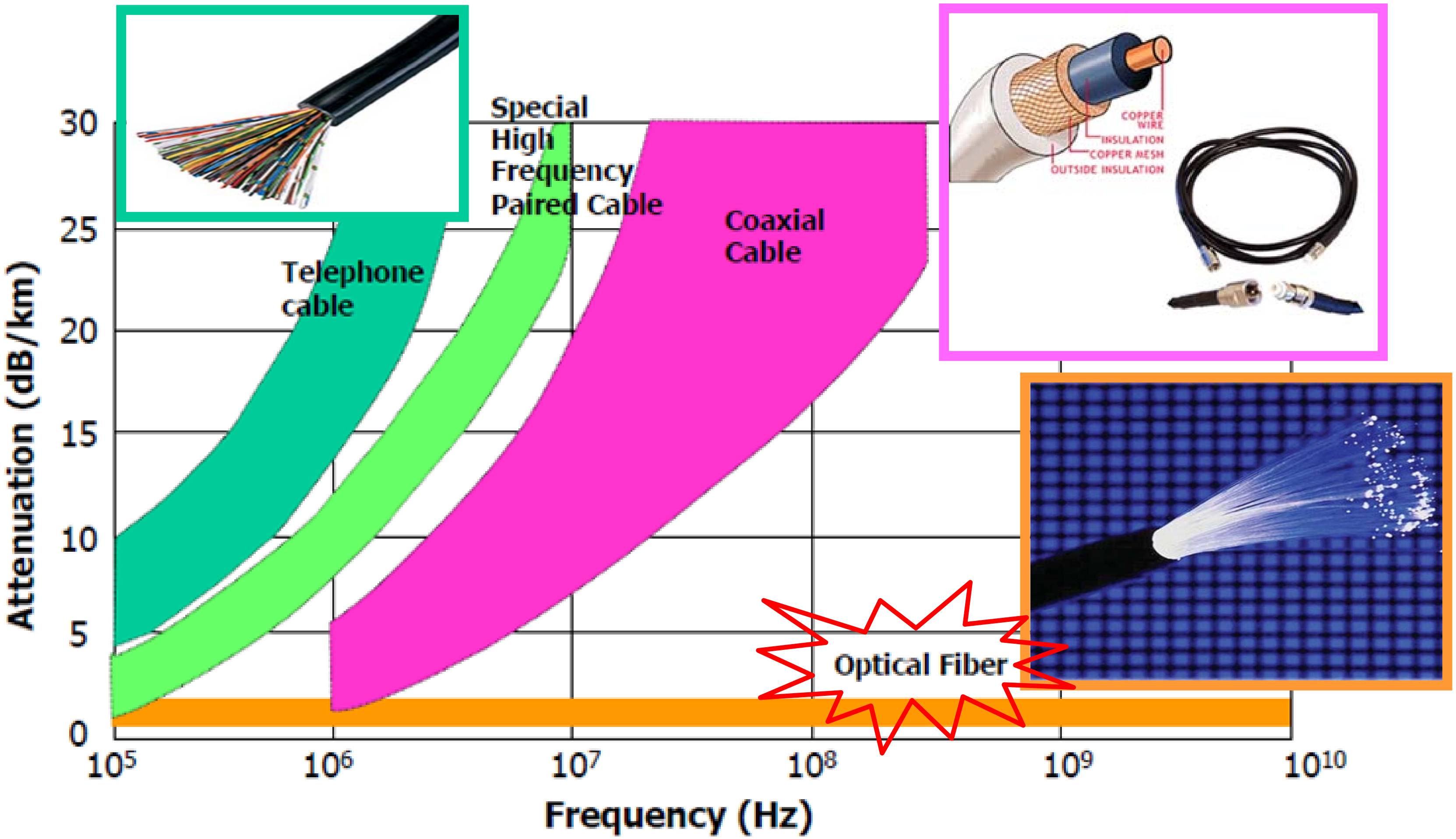
- Equalizer
- Clock & Data Recovery (CDR)
- Deserializer

Optical-to-electrical (O/E) conversion

…1010110011…

Use light over fiber !!

Loss of the Communication Cables



Very small loss even for very high frequencies!!!

The Nobel Prize in Physics 2009

Charles K. Kao

• *Director of Engineering of Standard Telecommunication Laboratories, Harlow, UK, and Vice chancellor, Chinese University of Hong Kong. Retired 1996*

PROC. IEE, Vol. 113, No. 7, JULY 1966

Dielectric-fibre surface waveguides for optical frequencies

K. C. Kao, B.Sc.(Eng.), Ph.D., A.M.I.E.E., and G. A. Hockham, B.Sc.(Eng.), Graduate I.E.E.

Synopsis

A dielectric fibre with a refractive index higher than its surrounding region is a form of dielectric waveguide which represents a possible medium for the guided transmission of energy at optical frequencies. The particular type of dielectric-fibre waveguide discussed is one with a circular cross-section. The choice of the mode of propagation for a fibre waveguide used for communication purposes is governed by consideration of loss characteristics and information capacity. Dielectric loss, bending loss and radiation loss are discussed, and mode stability, dispersion and power handling are examined with respect to information capacity. Physical-realisation aspects are also discussed. Experimental investigations at both optical and microwave wavelengths are included.

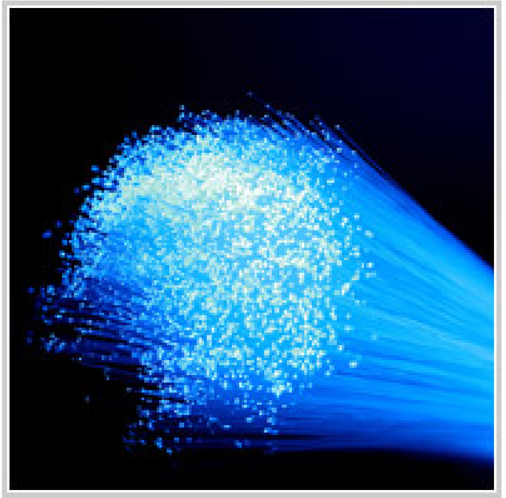
"For groundbreaking achievements concerning the transmission of light in fibers for optical communication"

Top Record for Long-Distance Communication

Future internet speeds – download a DVD in 0.0023 seconds

Posted in Main on March 3rd, 2008 by Pingdom

Researchers at Bell Labs have managed to transfer optical data at the incredible rate of 16.4 Tbps over a 2,550 km distance (1,584 miles).



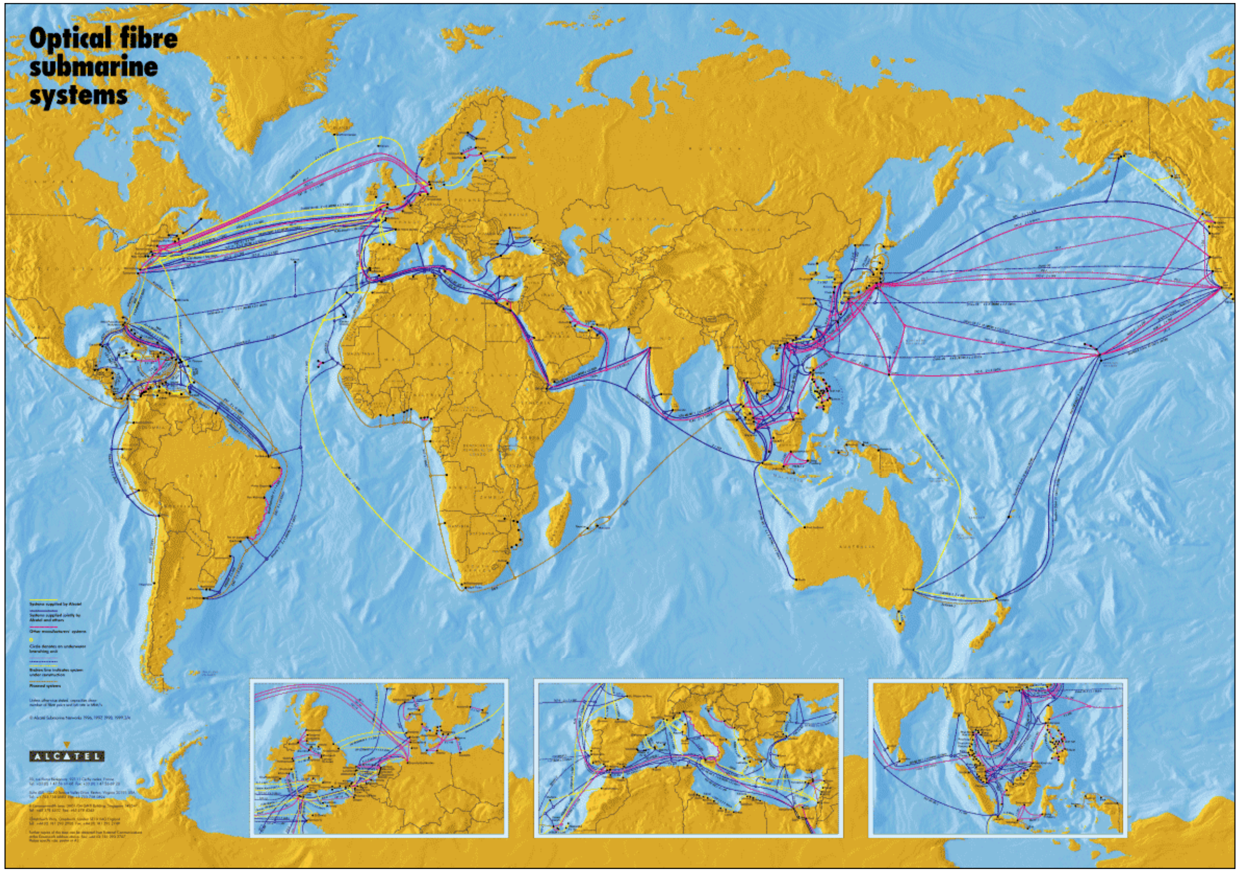
That is **2.05 terabyte (2,050 gigabyte) per second**, which is leaps and bounds ahead of what normal network equipment can currently handle.

What 16.4 Tbps transfer speeds are capable of

To give you some perspective of how blazingly fast such a connection is, here are some examples of how long it would take to transfer some common storage media over it:

- One DVD (4.7 gigabyte) – **2.3 milliseconds**
- One Blu-ray Disk (50 gigabyte) – **24.4 milliseconds**
- One 500 gigabyte hard drive – **244 milliseconds**

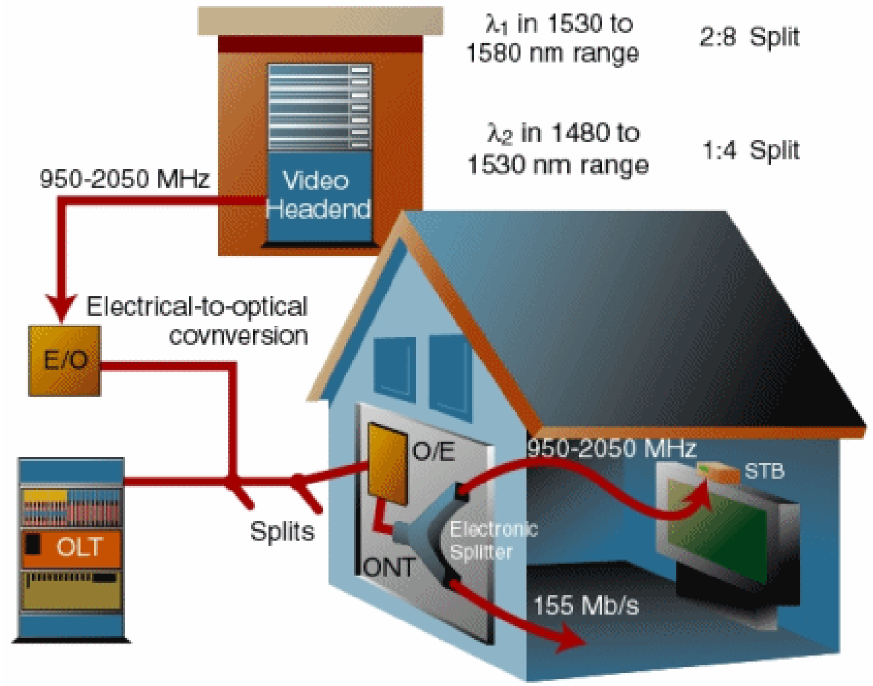
Long-Distance Optical Communication



- ***Optical fiber underwater system***
  - ***- Domestic: optical cable 198,640 km***
  - ***- Oversea: 0.4 billion km (earth – the moon 628 times round trip)***

Access Network Optical Communication

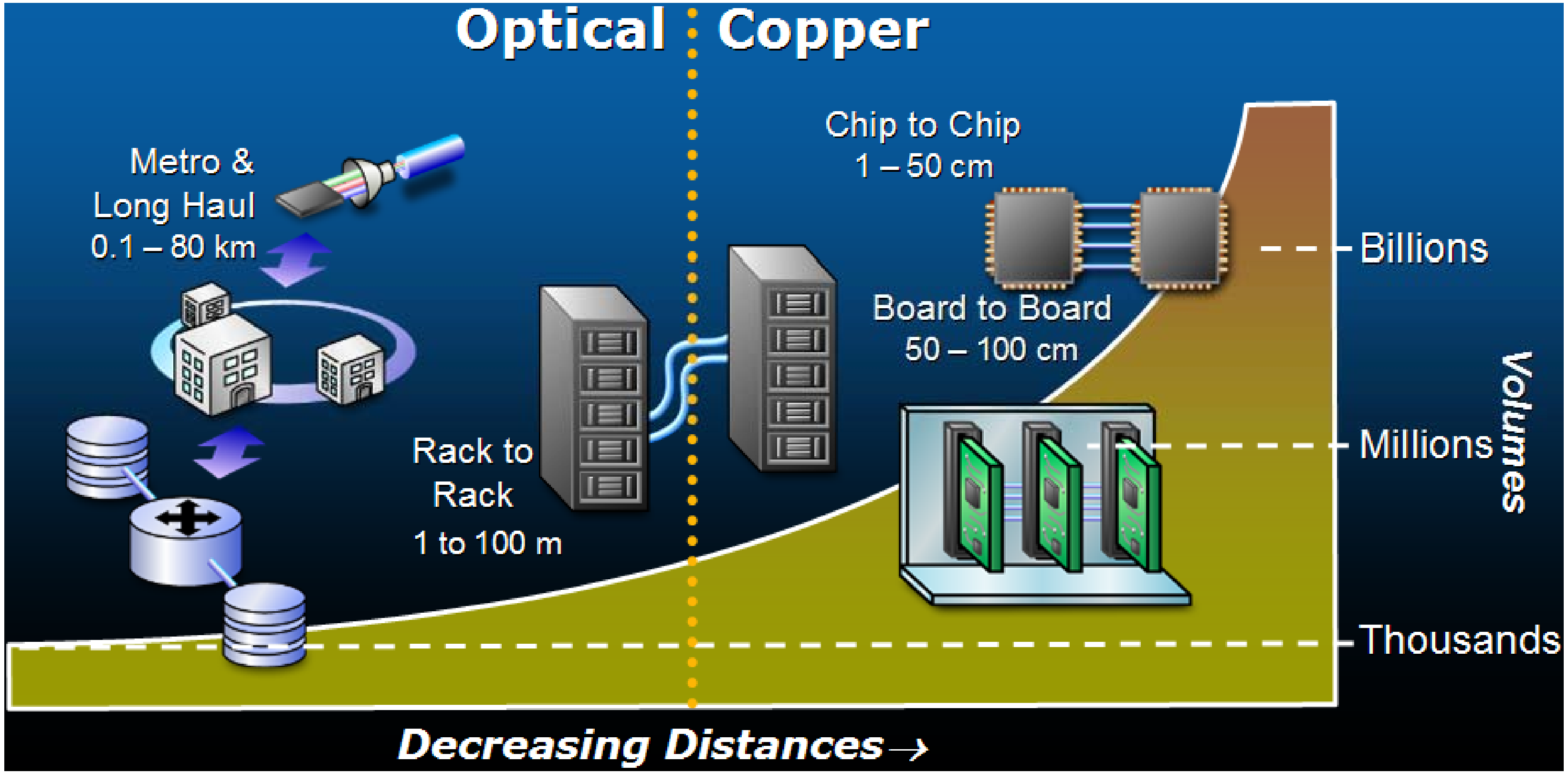
- FTTx: Fiber-to-the-Home (FTTH), Curb (FTTC)…



OLT: Optical Line Terminal
ONT: Optical Network Terminal
STB: Set-Top Box

- ***More bandwidth for more services …***
  - HDTV with interactive programs, multiple TV sets or PCs
  - VOD movies and programs streaming or download
  - On-line video games or download
  - Simultaneous and symmetrical usage

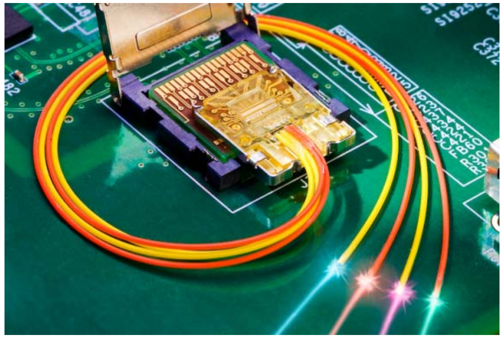
Communication & Interconnection System

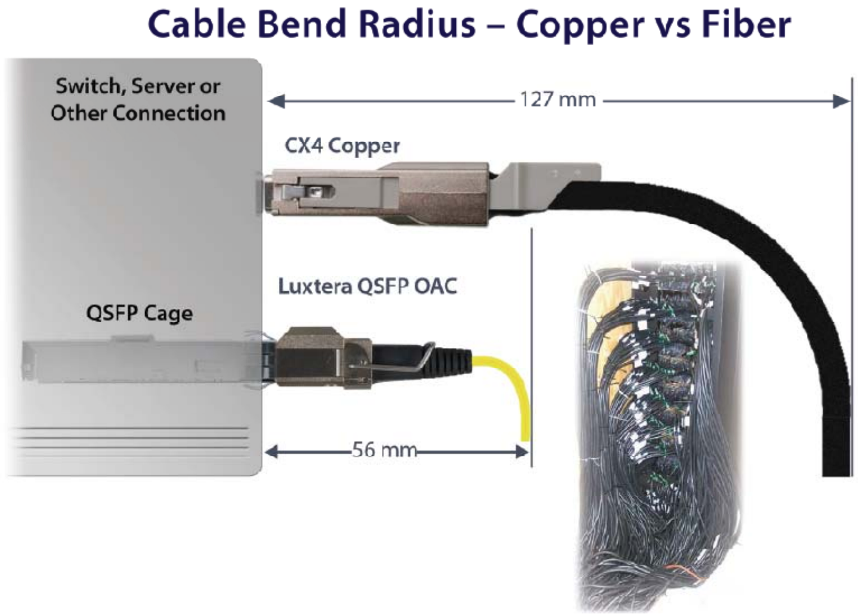


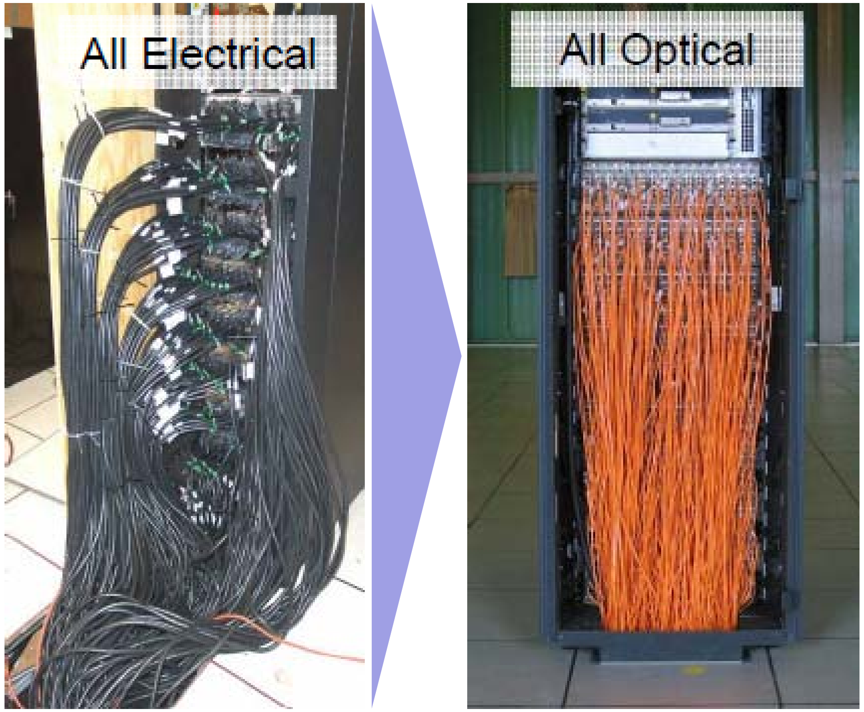
- **Long-distance: Optical Communication**
- **Short-distance: Electrical Interconnect**
- ***But the boundary is moving!***

Board-to-Board Optical Interconnect

- ***Luxtera (Blazar)***
  - 40-Gb/s full-duplex active optical cable transceiver
  - 10.3125 Gb/s (max.) per channel
- ***Intel (Light Peak)***
  - 10-Gb/s dual-channel transceiver







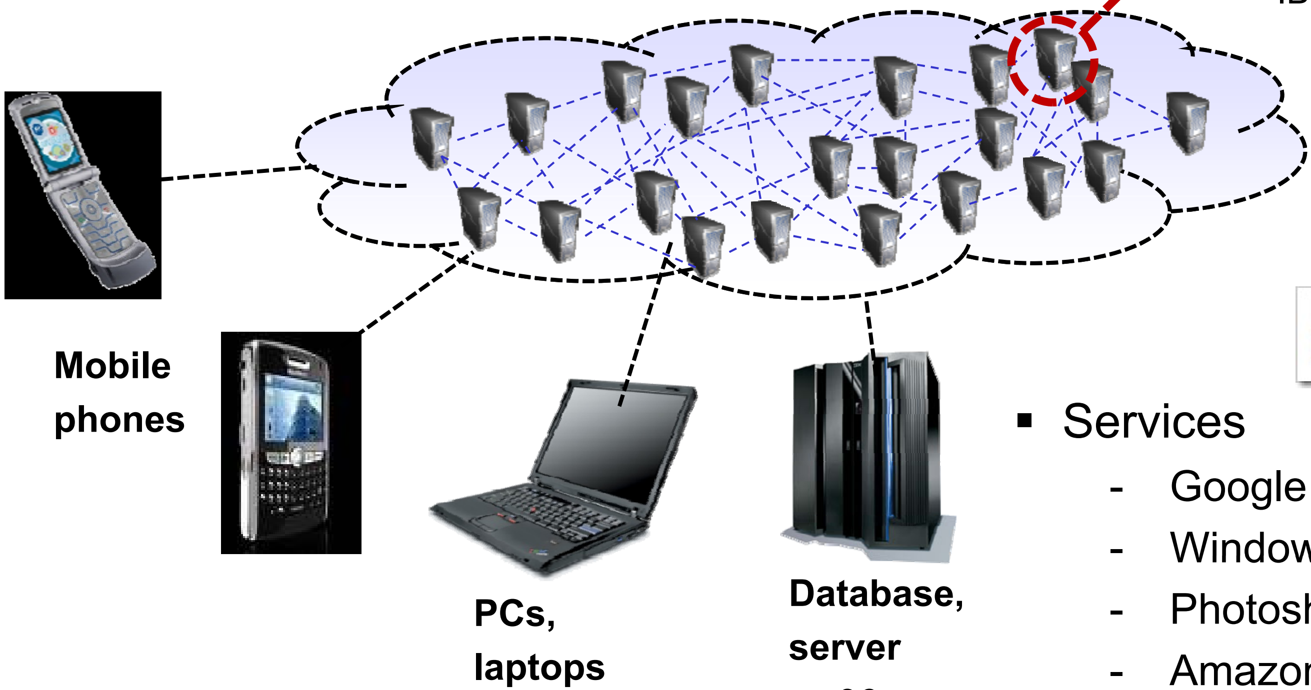
"Optical fibers much thinner and lighter than copper"

Applications: Cloud Computing

"The cloud is a smart, complex, powerful computing system in the sky that people can just plug into."
Marc Andreessen

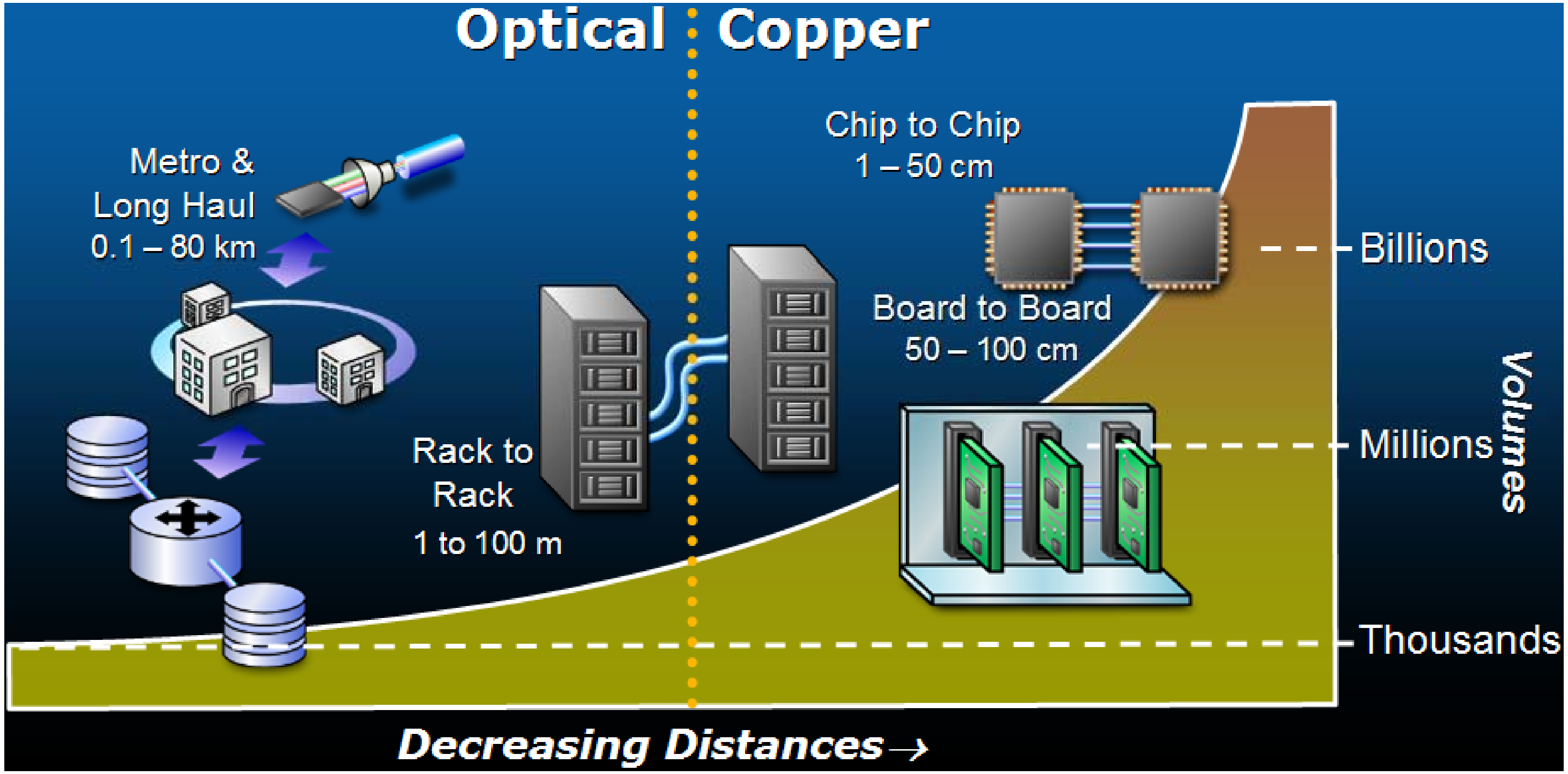
IBM cloud computing data center
(1,994 of servers)

- Application development
  - Google, IBM, Intel, HP, Microsoft etc..



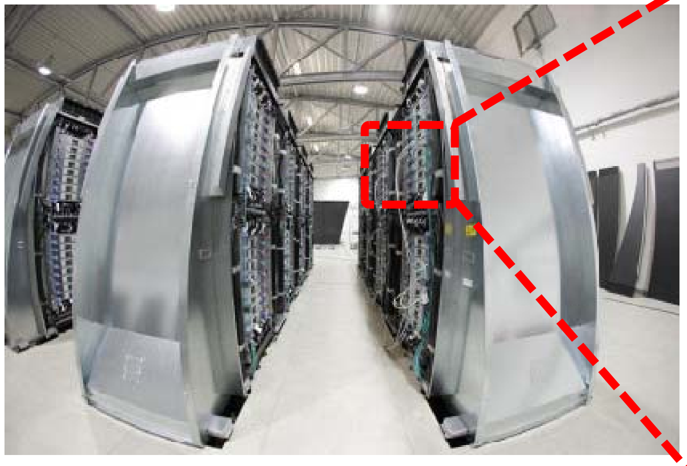
- Services
  - Google calendar
  - Windows live skydrive
  - Photoshop on-line
  - Amazon web service …

Communication & Interconnection System

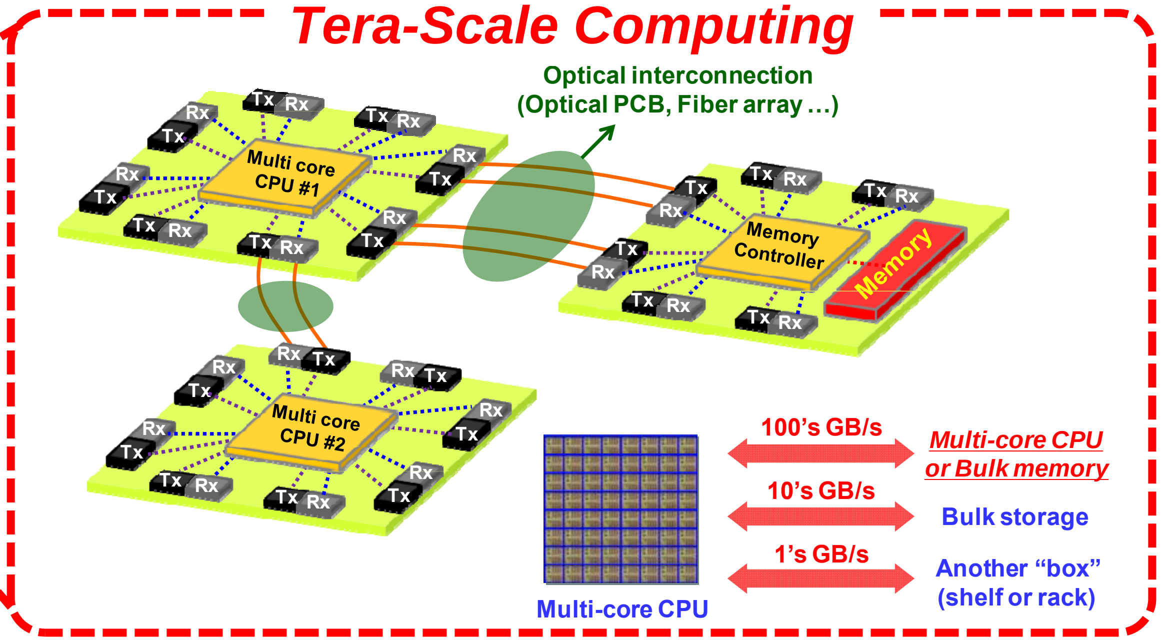


- **Long-distance: Optical Communication**
- **Short-distance: Electrical Interconnect**
- ***But the boundary is moving!***

Next Step: Chip-to-Chip interconnect ?

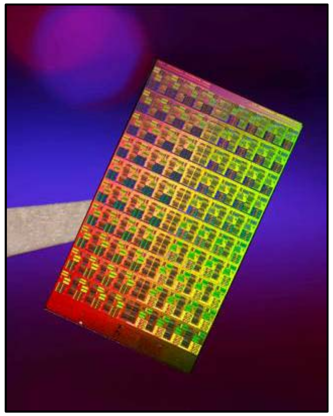


IBM cloud computing data center
(1,994 of servers)



- Single ➔ Multi ➔ **Many-Core μProcessors**
- Tera-scale many-core processors
  ➔ aggregate I/O rates ↑
- CPU-CPU, CPU-Memory bandwidth
  ➔ 2x performance per 2 years
- **100 Gb/s** memory BW in 2012-2013

Intel Teraflop Research Chip



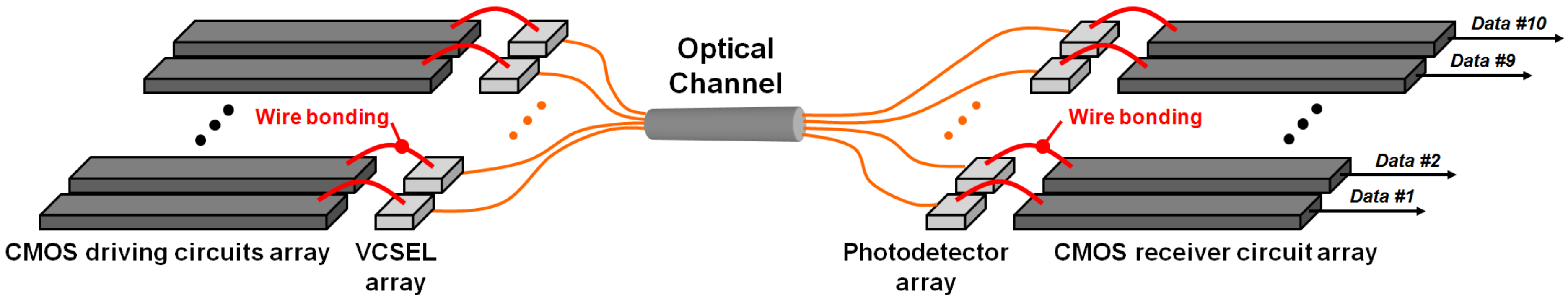
- 80 processor cores
- 100 million transistors
- $275mm^2$

S. Vangal *et al*, "An 80-Tile Sub-100W TeraFLOPS Processor in 65nm CMOS," *JSSC*, 2008.

Challenges ?

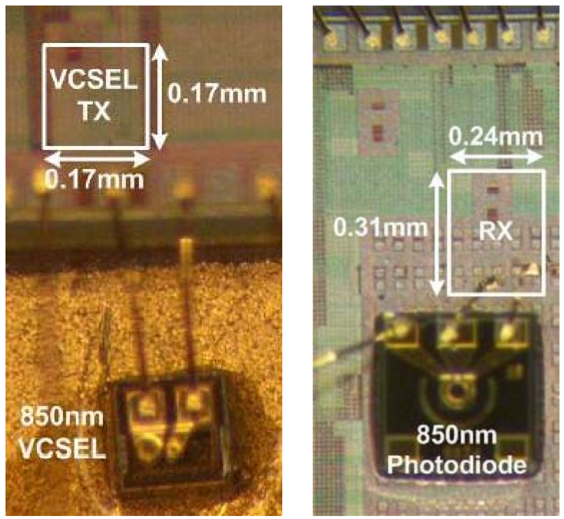
- Conventional optical receiver system

CMOS driving circuits / VCSEL *PD / CMOS receiver circuits*



- **Increasing cost**
  - High-performance photodetector
  - Special fabrication process
  - Packaging solution using wire bonding

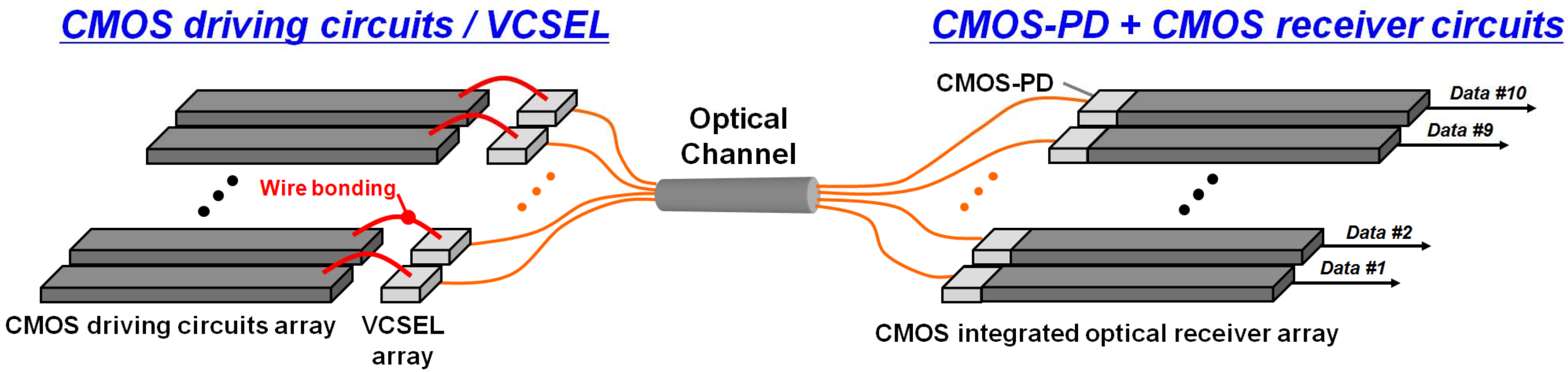
- **Decreasing reliability/yield**
  - Usage of additional material
  - High temperature process



I. Young *et al*, "Optical I/O Technology in Tera-scale Computing," *ISSCC*, 2009.

Monolithic Solution at Yonsei HSCS

- Photonics integrated with standard CMOS technology

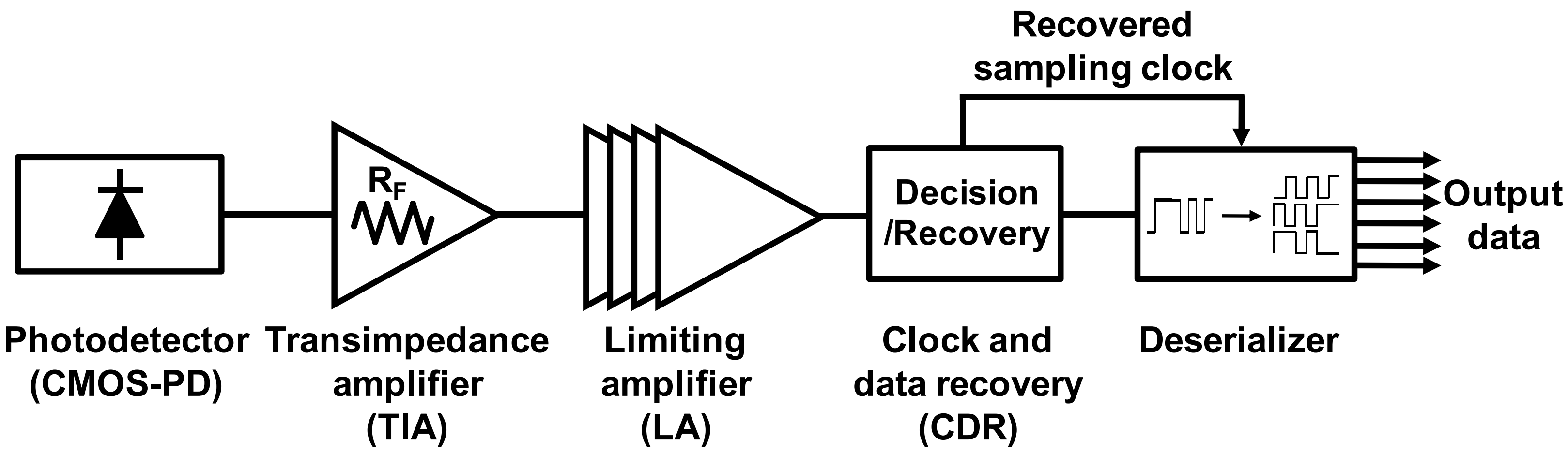


Monolithic integration with photodetector and CMOS circuits

- Low fabrication cost
- High integration level
- Better performance (jitter, crosstalk, EMI)
- More reliable/higher yield process than wire bonding
- Compatibility with μP/logic process

Research Topic at HSCS

- High-speed monolithic CMOS optical receiver

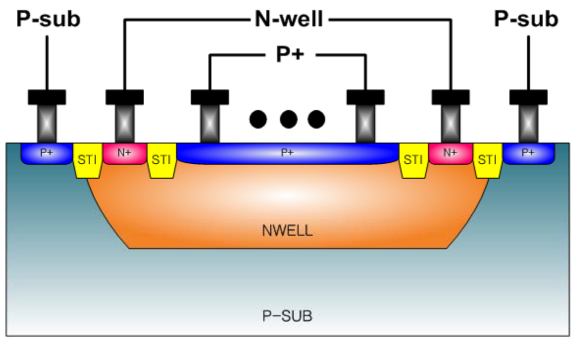


Device physics + ***Circuit design***

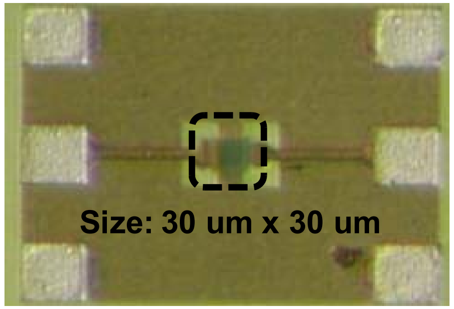
- Photodetector (PD): optical-to-electrical conversion
- Transimpedance amplifier (TIA): current-to-voltage conversion
- Limiting amplifier (LA): signal amplification
- Clock and data recovery (CDR): data decision and system clock extraction
- Deserializer: serial to parallel signal conversion

Our Previous Works

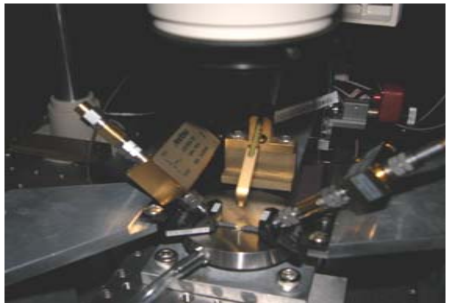
Device physics research



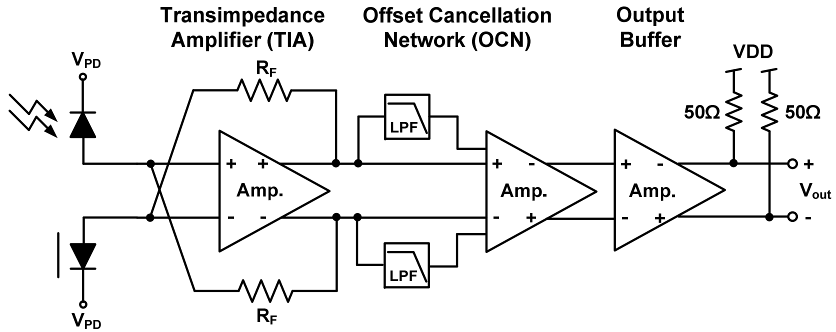
Chip photograph



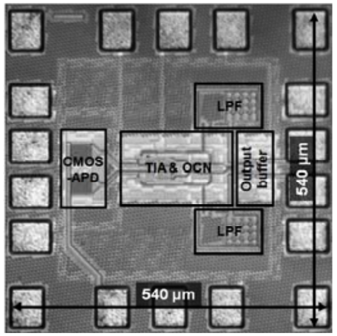
Measurement Setup



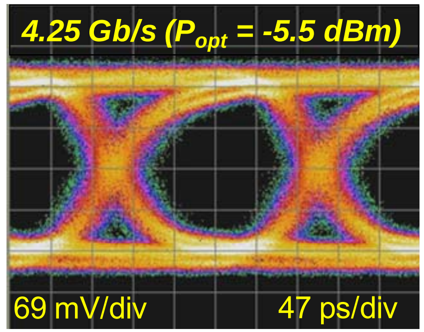
Circuit design research

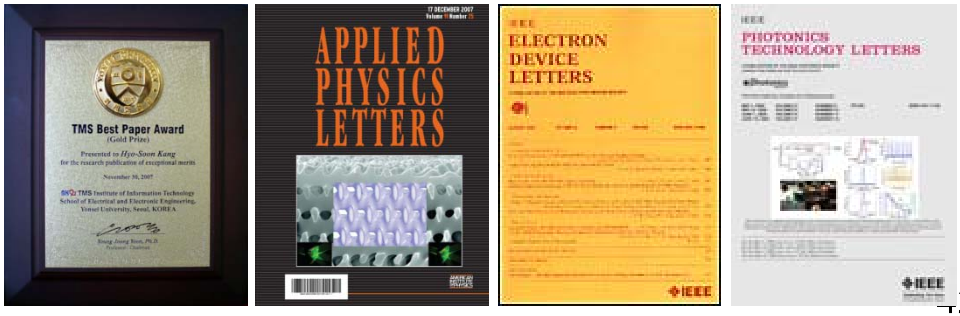


Chip photograph



Eye-diagram



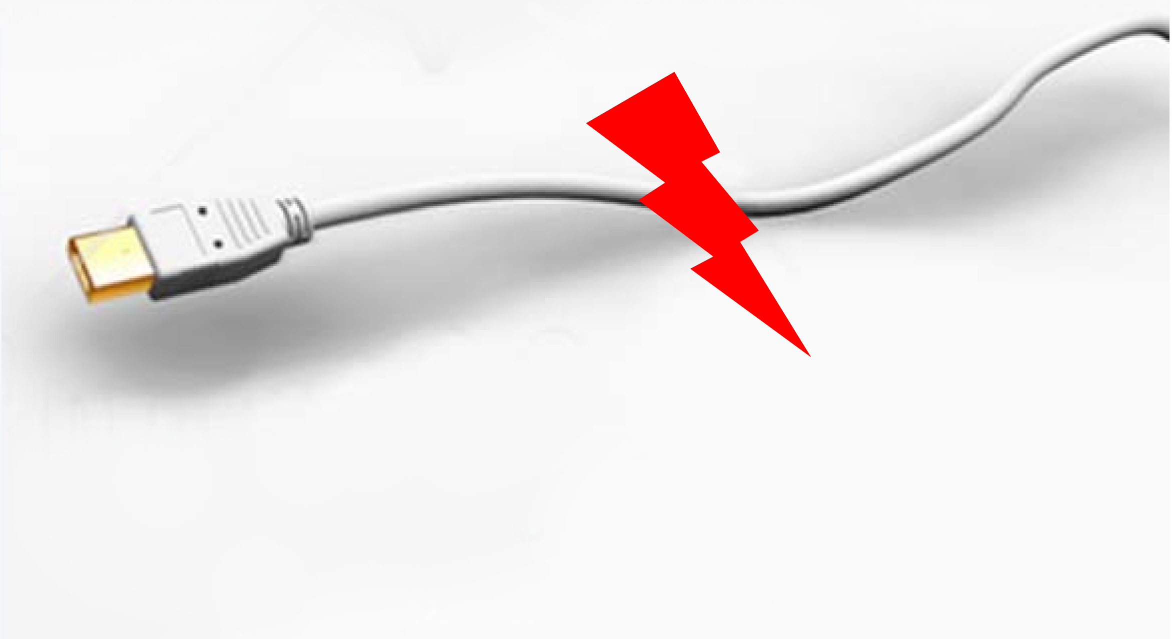


- TMS Best paper Award (Gold Prize), 2007
- Applied Physics Letters (APL), Vol. 90, No. 15, 2007
- IEEE Electron Device Letters (EDL), Vol. 29, No. 10, 2008
- IEEE Photonics Technology Letters (PTL), Vol. 21, No. 20, 2009

Wire or Wireless?

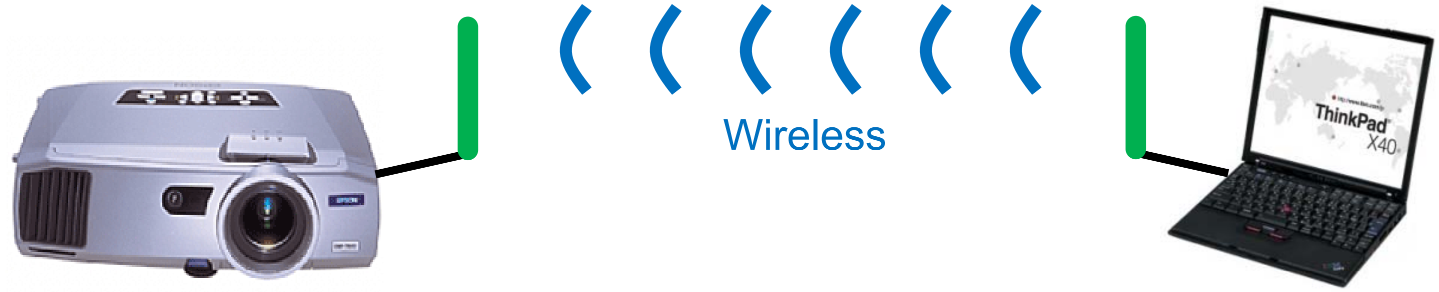
- Wire Communication

  - *Wireless Communication*



Data Capacity in Wireless Communications

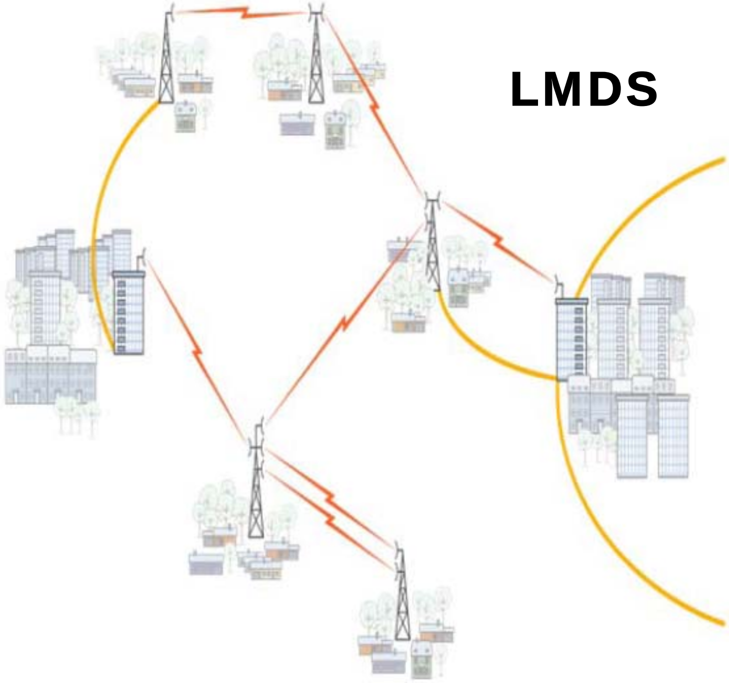
- Data capacity in recent wireless communications?



Standard	Frequency	Data capacity	State
Bluetooth	2.4-2.4835 GHz	1 Mbps	Commercialized
Wibro(4G)	2.3~2.4 GHz	24.8 Mbps	Commercialized
		1 Gbps	Now in standardization
WLAN (802.11n)	5 GHz	600 Mbps	Commercialized
UWB	3.1-10.6 GHz	480 Mbps	Commercialized
Millimiter-wave WPAN (802.15.3c)	**60 GHz**	**> 3 Gbps (up to 6 Gbps)**	**Now in standardization**
Millimiter-wave WLAN (802.11ad)	**60 GHz**	**> 1 Gbps**	**Now in standardization**

Millimeter-Wave Wireless Communications

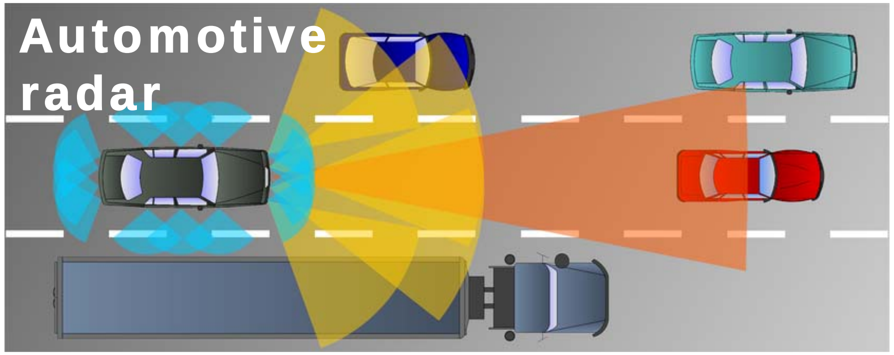
- Local Multipoint Distribution Services (LMDS)
  - Metropolitan Area Network (MAN): Fixed point-to-multipoint
  - 26, 29 GHz (licensed band) / 2 – 5 km
- Ka-band Very Small Aperture Terminal (VSAT)
  - Satellite communications: 12 – 18 GHz → 26 – 40 GHz
  - Typical use in EU: 30 GHz (384 kb/s)



- D.Koether, WSB-1, IMS 2008 Workshops

Millimeter-Wave Wireless Communications

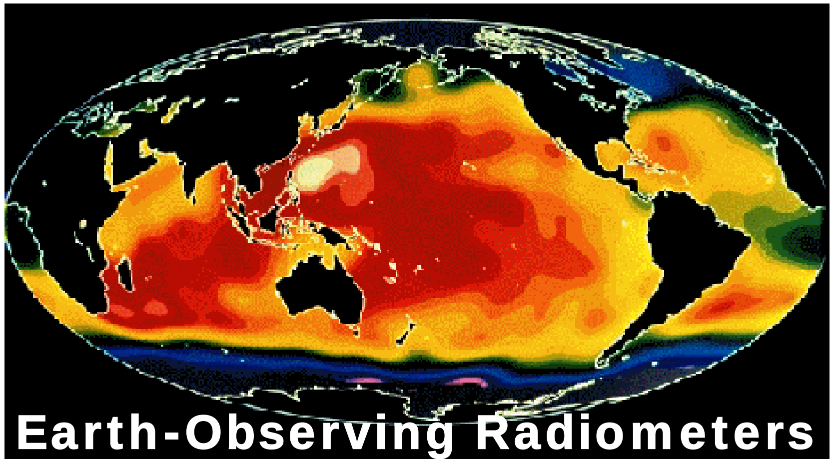
- Automotive radar
  - 19 / 24 / 66 / 77 GHz
- Passive mm-wave imaging
  - 35 / 94 / 140 / 220 GHz (radiation windows)
  - Airport security, medical diagnostics
  - Comparable with infrared systems
- 60GHz high-data rate communications



- D.Koether, WSB-1, IMS 2008 Workshops

Millimeter-Wave Wireless Communications

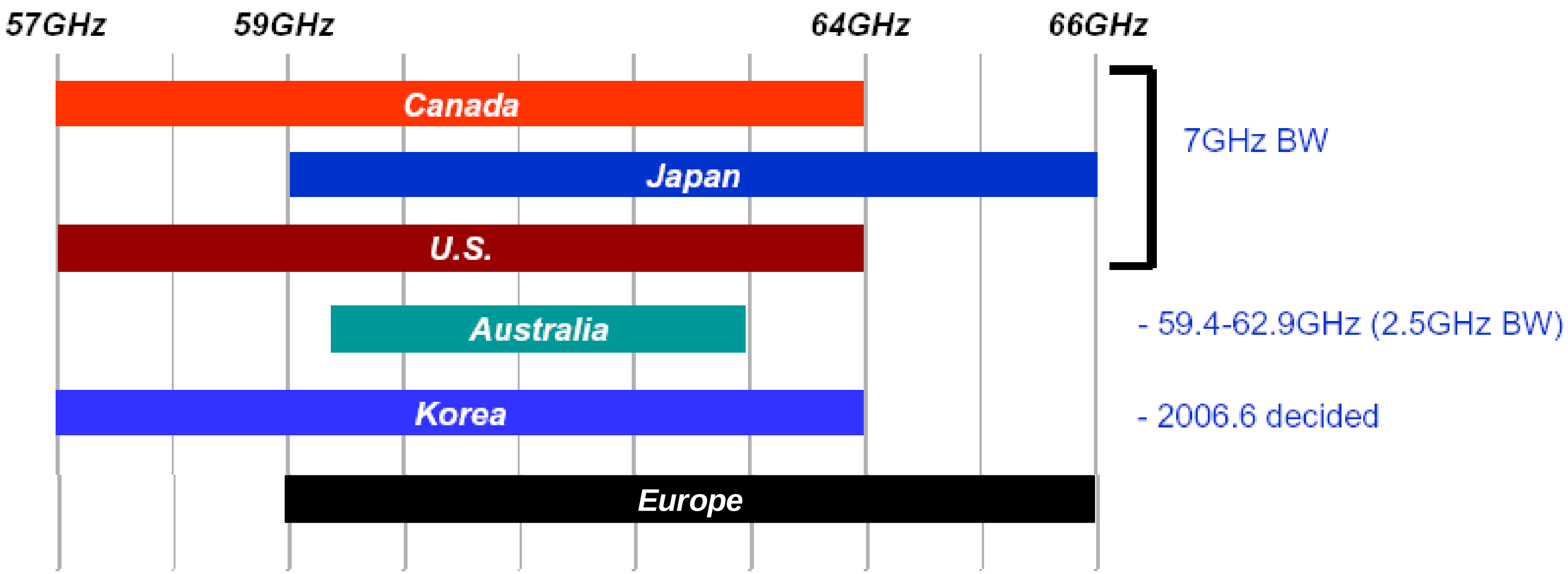
- Earth-Observing Radiometers
  - Absorption/emission behavior of molecules in the atmosphere
  - Temperature, humidity, pressure, wind, and density
  - 118 GHz → Oxygen for a temperature profile
  - 183 GHz → Water vapor for a humidity profile
- Radio Telescope
  - Searching for sources of natural radio interference in the sky
  - Communicating with outer-space (Deep Space Communications)
  - 0.1-20 GHz (Do not know exact frequencies)


Earth-Observing Radiometers


Radio Telescope

Characteristics of 60GHz Communications

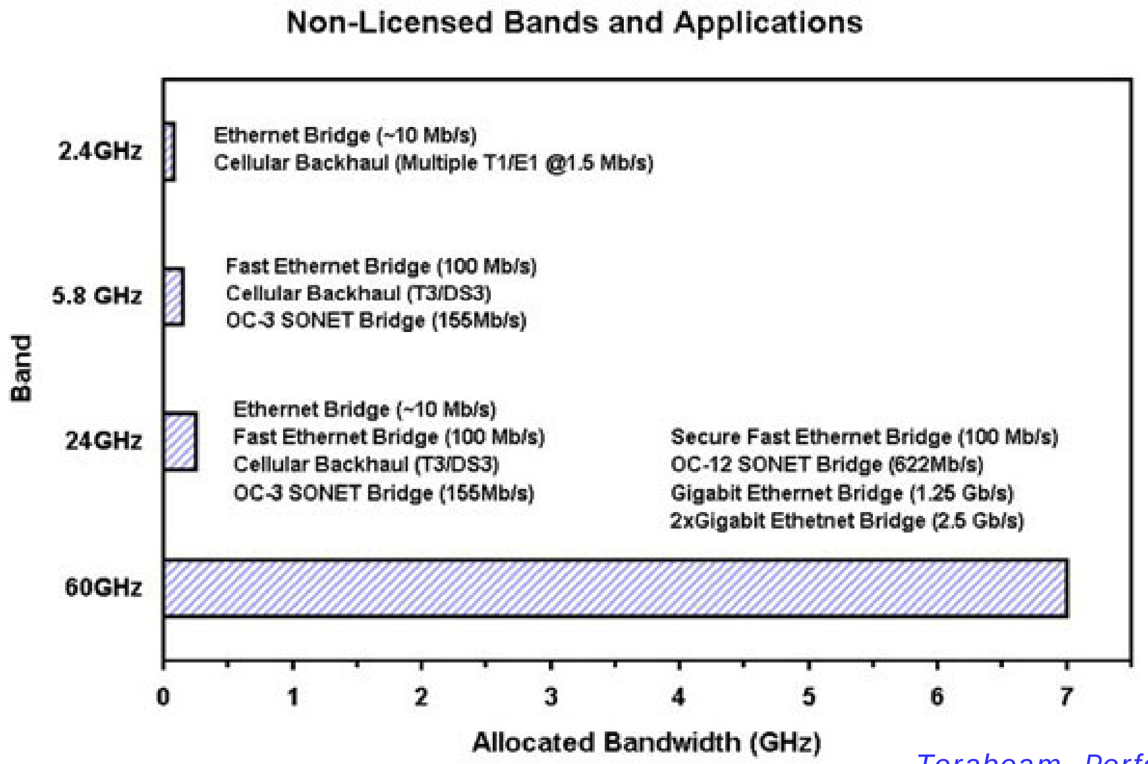
- 7GHz continuous bandwidth as an unlicensed band
  - Operators do not have to buy a license
  - World-wide band → World-wide market



- Terabeam, Performance characteristics of 60-GHz comm. Systems.

Characteristics of 60GHz Communications

- 7GHz continuous bandwidth as an unlicensed band
  - Operators do not have to buy a license
  - World-wide band → World-wide market
  - High-data rates with the widest unlicensed band



- Terabeam, Performance characteristics of 60-GHz comm. Systmes.

Characteristics of 60GHz Communications

- Path loss and antenna gain
  - Path loss increases with frequency
    (decreases with wavelength)

$$L_{path} = \frac{P_t}{P_r} = \frac{1}{G_r G_t}\left(\frac{4\pi R}{\lambda}\right)^2$$

From Friis transmission equation

  - Solution: high-gain small-size antenna

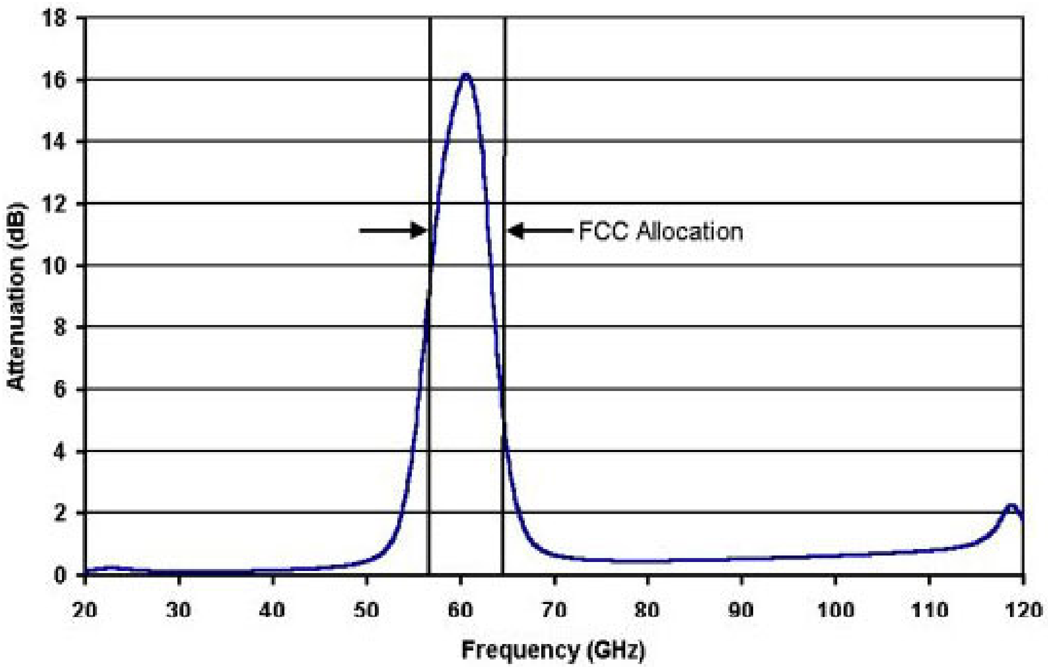
$$G_{Ant} = \frac{4\pi A}{\lambda^2}$$

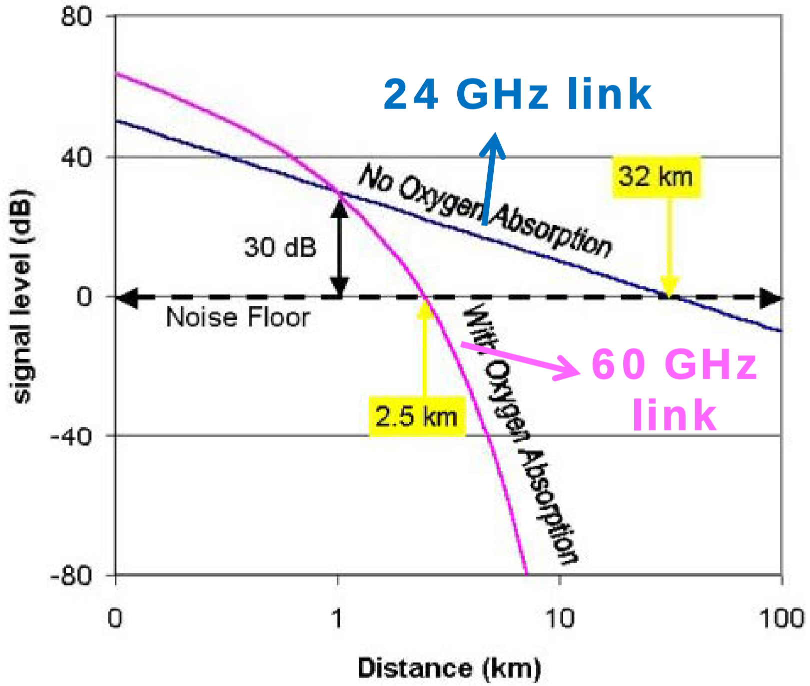
For same gain,
frequency↑ → dimension↓

- Terabeam, Performance characteristics of 60-GHz comm. Systmes.

Characteristics of 60GHz Communications

- High atmospheric absorption at 60 GHz
  - 98% of energy absorbed by O_2 over a 1-km path
  - Unsuitable for long-haul wireless applications
  - Ideal for short-distance and high-security transmission

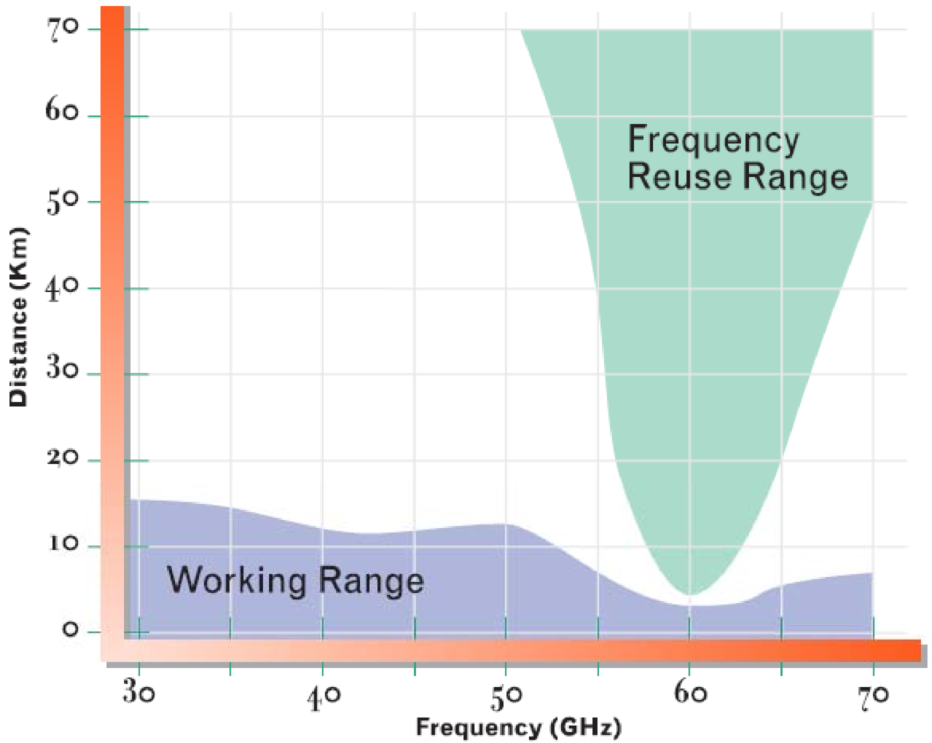




- Terabeam, Performance characteristics of 60-GHz comm. Systmes.

Characteristics of 60GHz Communications

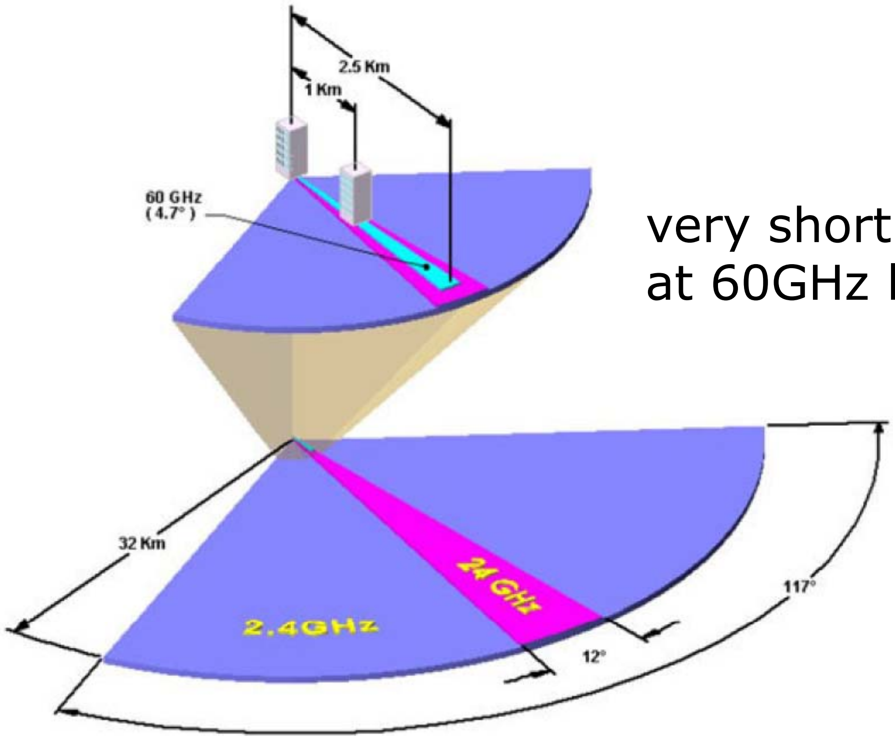
- Frequency Reuse
  - Possible to deploy numerous radio terminals that operate on the same frequency in very dense configurations
  - Eliminating the probability of interference (≤1.2km)



Source: FCC [1]

Characteristics of 60GHz Communications

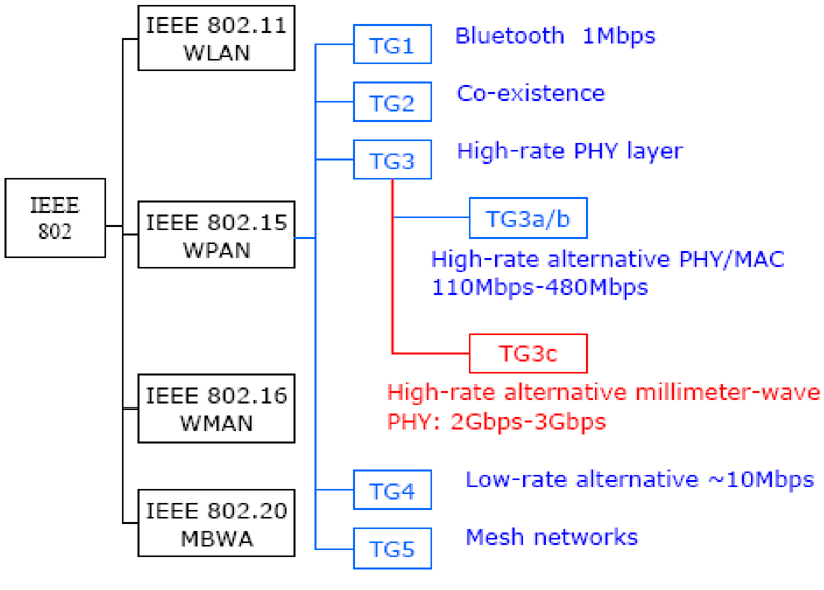
- High atmospheric absorption at 60 GHz
  - 98% of energy absorbed by O_2 over a 1-km path
  - Unsuitable for long-haul wireless applications
  - Ideal for short-distance and high-security transmission
  - High frequency re-use



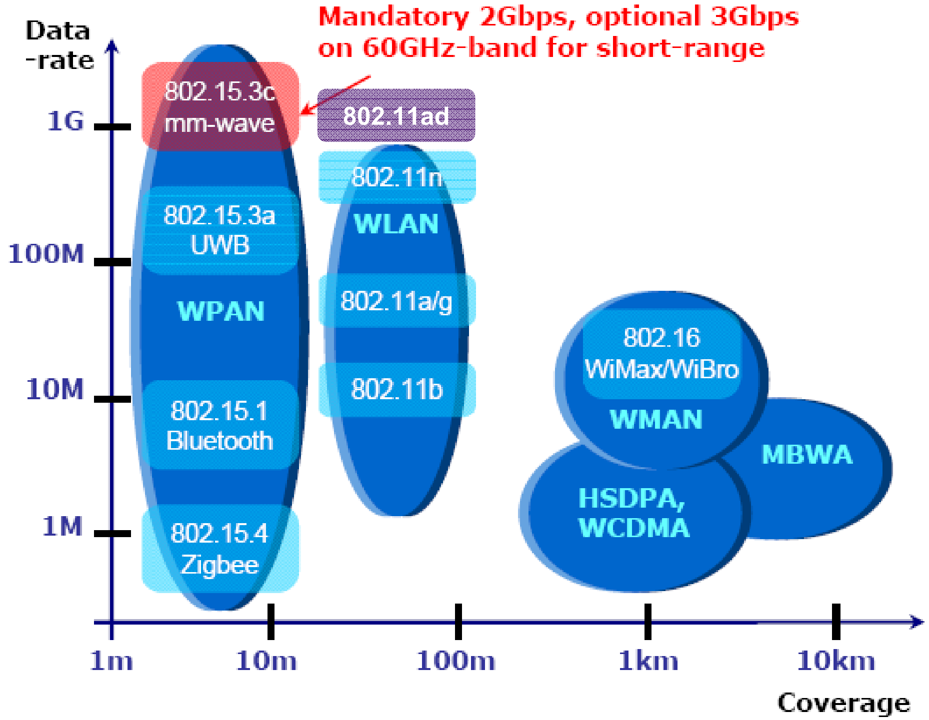
very short radiation range at 60GHz link

- Terabeam, Performance characteristics of 60-GHz comm. Systmes.

Standardization Activities – IEEE 802.15.3c



WLAN: Wireless Local Area Network
WPAN: Wireless Personal Area Network
WMAN: Wireless Metropolitan Area Network
MBWA: Mobile Broadband Wireless Access



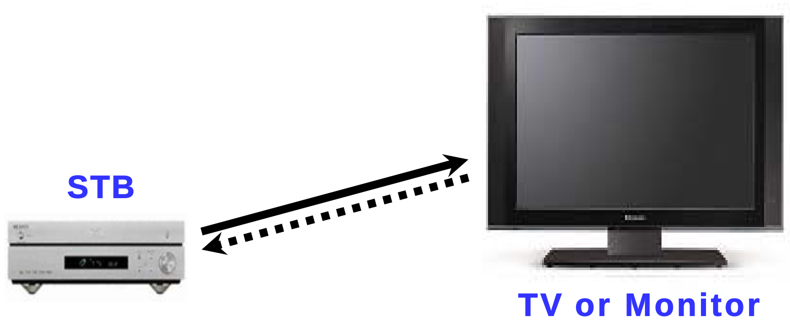
IEEE 802.15.3c for high-rate WPAN

- 1.5Gbps mandatory and 6Gbps optional for TG3c
- Call for Intents: more than 26 companies and institutes (Intel, IBM, Philips, IHP, FT, NiCT, NTT, Panasonic, Samsung, ETRI, LG, Motorola, …)

Target Applications

UM1: Uncompressed Video Streaming (Audio / Visual mode)

- OFDM Asymmetric link



Environment	Throughput MAC SAP	Data Rate	Distance
LOS/NLOS Residential	1.49 Gbps for 1080i, 24bit, 60Hz 2.98 Gbps for 1080p, 24bit, 60Hz	~3.807Gbps	10m

- IEEE 802.15 TG3c Usage model: 15-06-0369-008-003c

Target Applications

Distance: 10 m (beamforming)

XCANVAS의 무압축 전송방식 기술

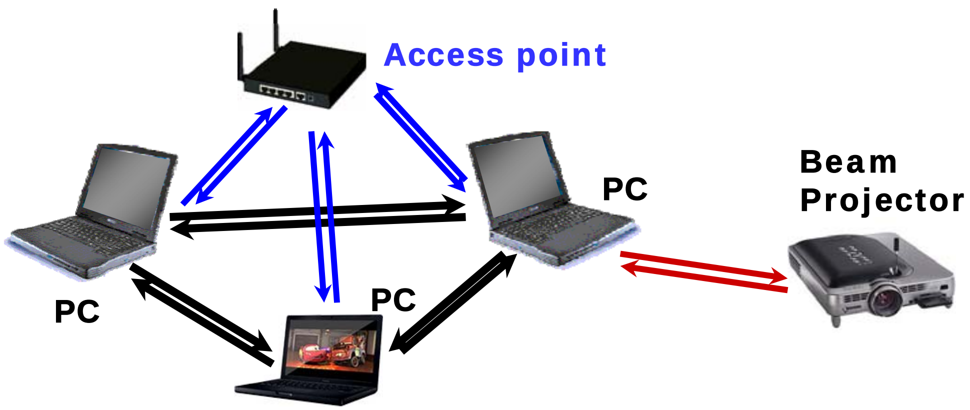
LG electronics

	XCANVAS
Format	Si-Beam **CMOS 130nm**
압축방식	무압축 방식
화질	화질 저하 없음
무선으로 인한 장애	전혀 없음
결론	세계 최초 무압축 전송 방식으로 선명한 화질 그대로 전달

Target Applications

UM4: Conference Ad-Hoc (High-speed interface mode)

- OFDM Symmetric link with low latency

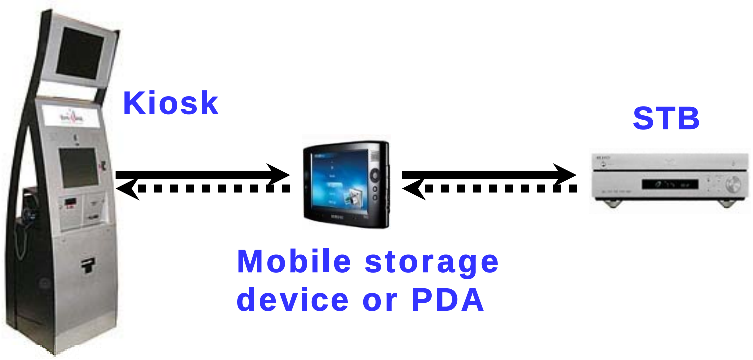


Environment	Throughput MAC SAP	Data Rate	Distance
LOS/NLOS Office	1.75 Gbps Ethernet traffic	~5.67Gbps	5m

Target Applications

UM5: Kiosk File-Downloading (Single-carrier mode)

- Single carrier burst-mode with lower cost



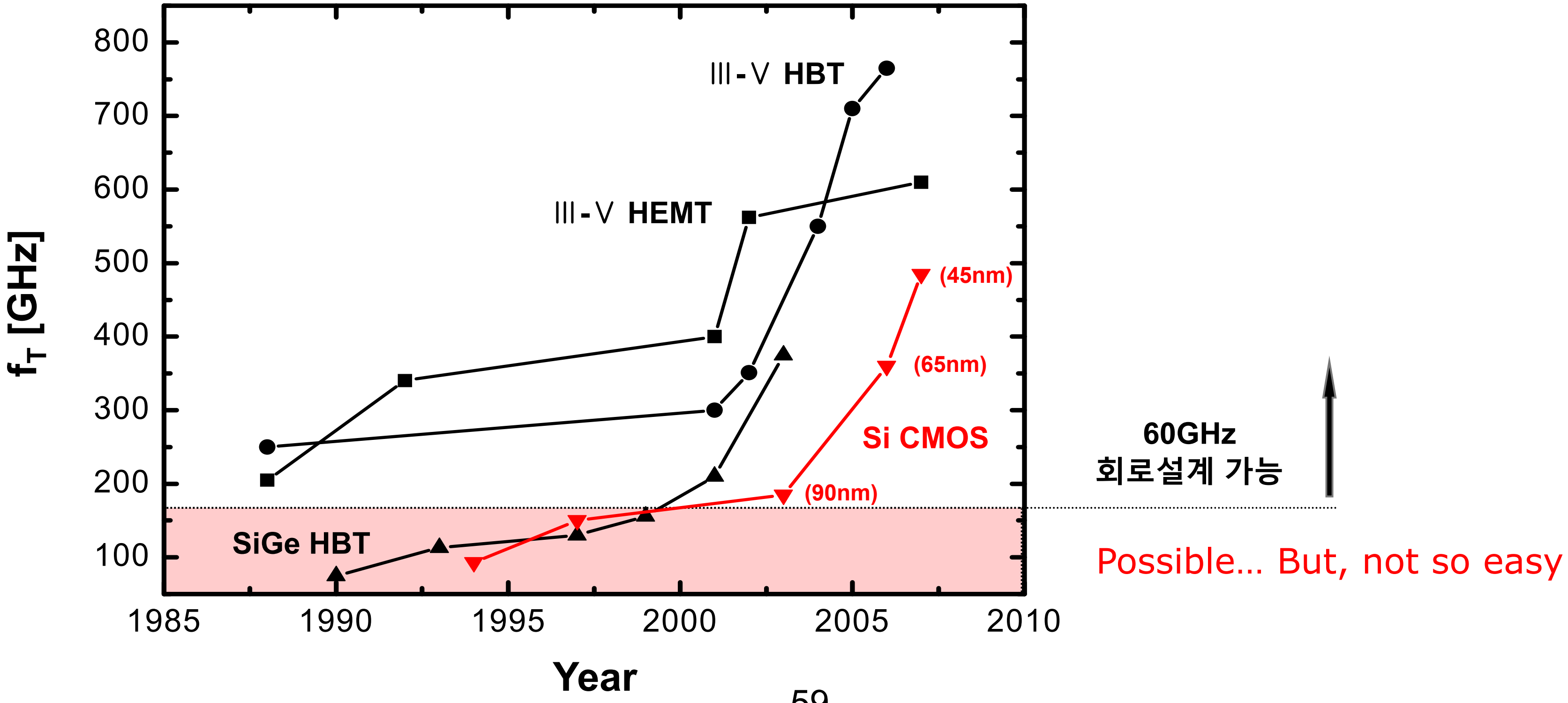
Environment	Throughput MAC SAP	Data Rate	Distance
LOS Office	1.5Gbps burst 2.25Gbps burst	~5.18Gbps	1m

Issues of 60GHz WPAN Standard

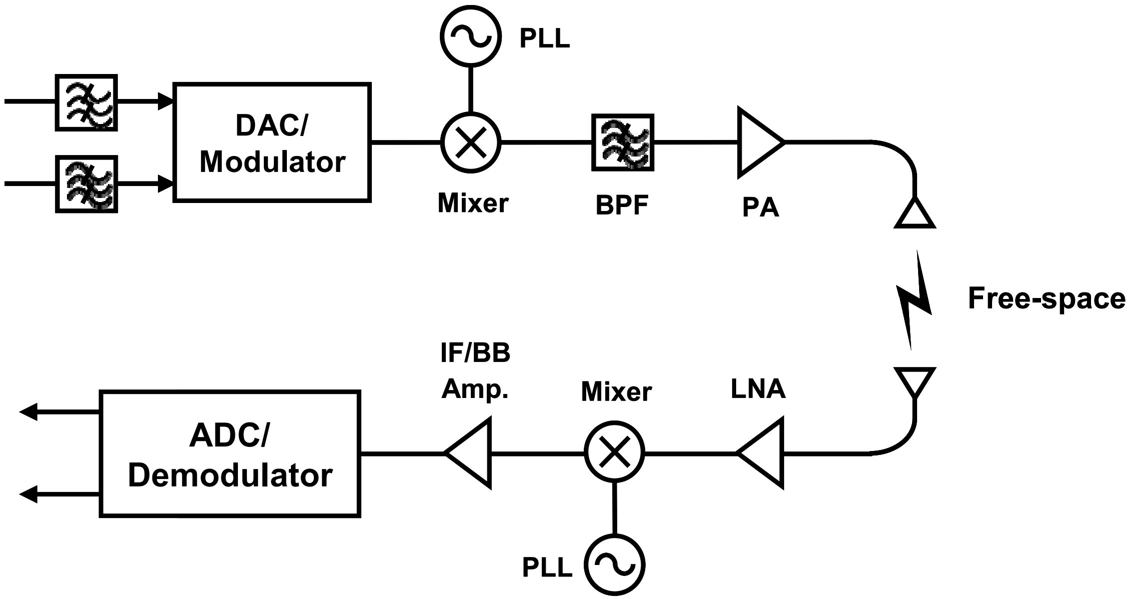
- Millimeter-wave circuits had been implemented with compound semiconductors
  - High-speed, but expensive and bulky

- 60GHz WPAN transceiver requires
  - Compact
  - Low-cost

→ Should be realized with Silicon RF-IC



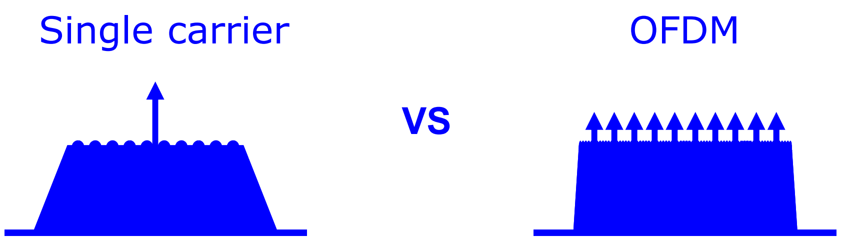
Issue of 60GHz WPAN Standard – RF Impairments



Hard to implement due to

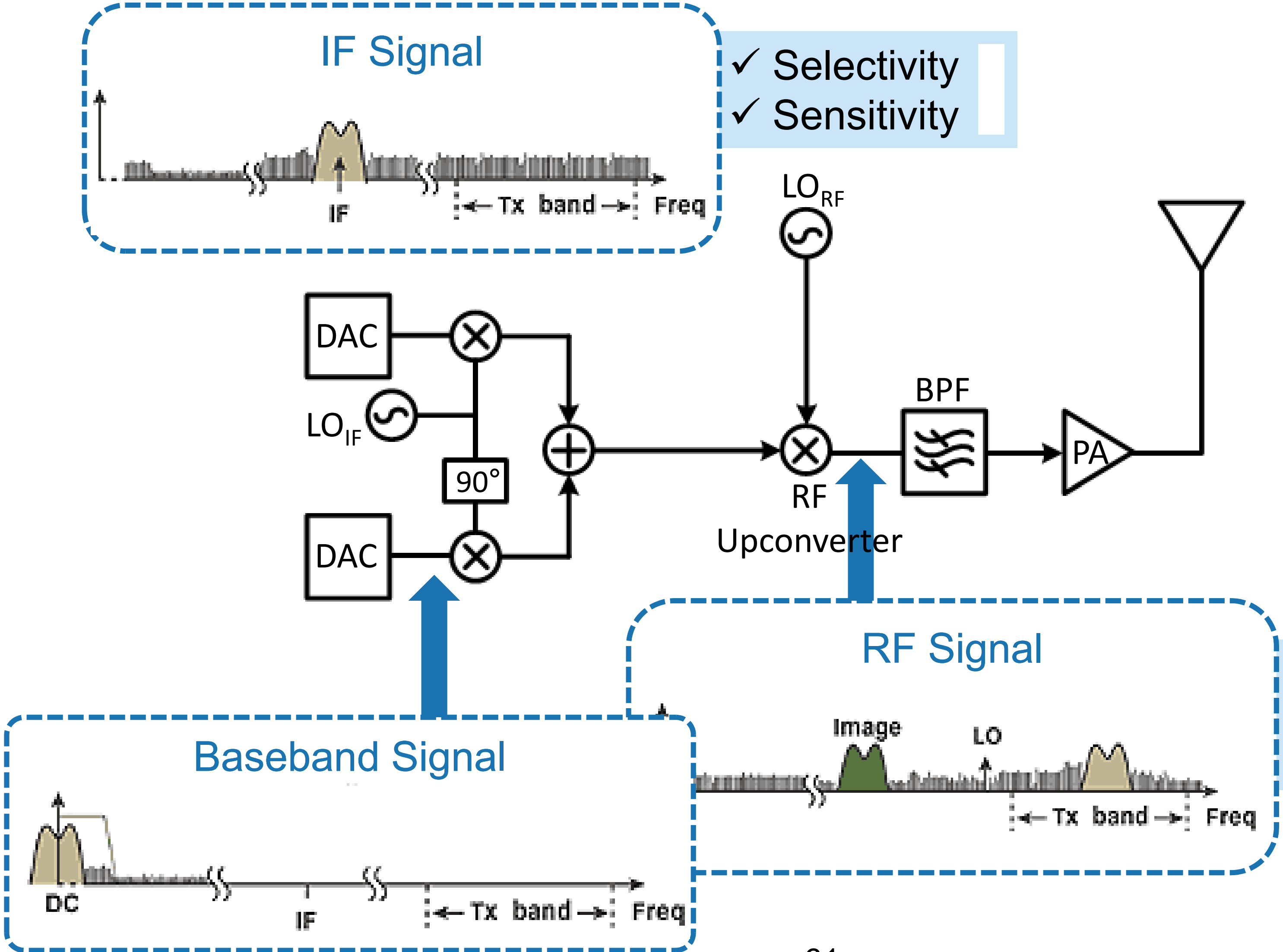
- High frequency operation (60GHz)
  - higher noise figure of LNA
  - higher phase noise (jitter) of PLL
  - lower power gain of transistor
- Wide bandwidth (2GHz)
  - higher channel noise (No=kTB)
  - difficult impedance matching
  - requires high-speed modem/ADC

So, 60GHz WPAN standard is mainly biased on RF part (e.g. OFDM or Single Carrier ?)



- In 2.5/5GHz WLAN/UWB, OFDM is clearly better choice
- But, not in 60GHz

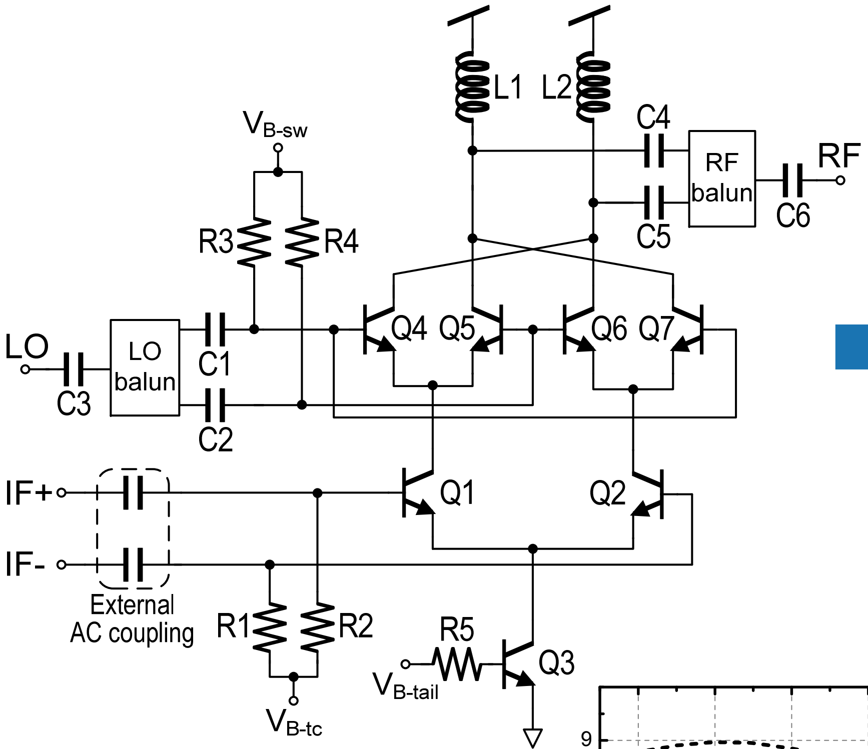
RF Building Blocks-Transmitter

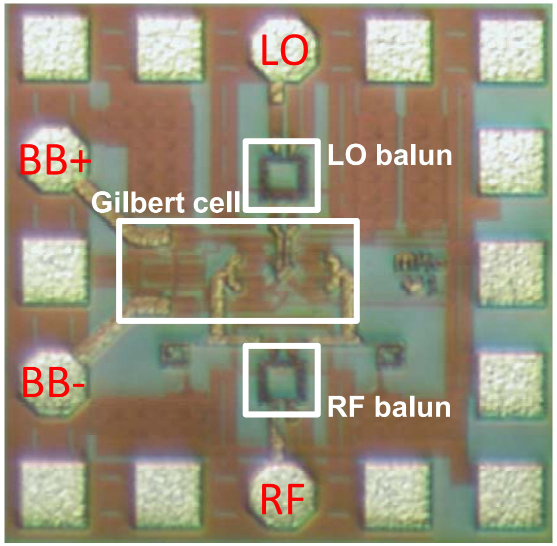


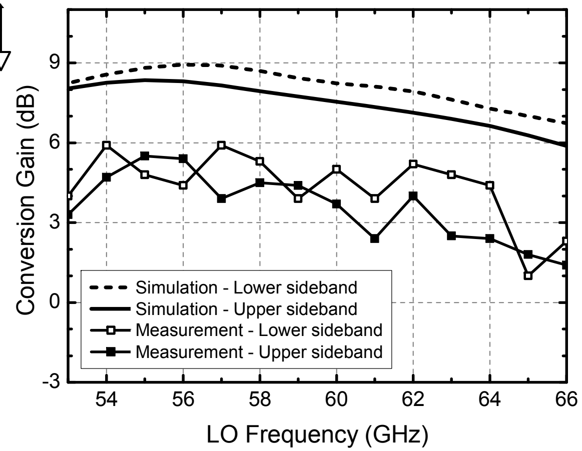
- ✓ Selectivity
- ✓ Sensitivity

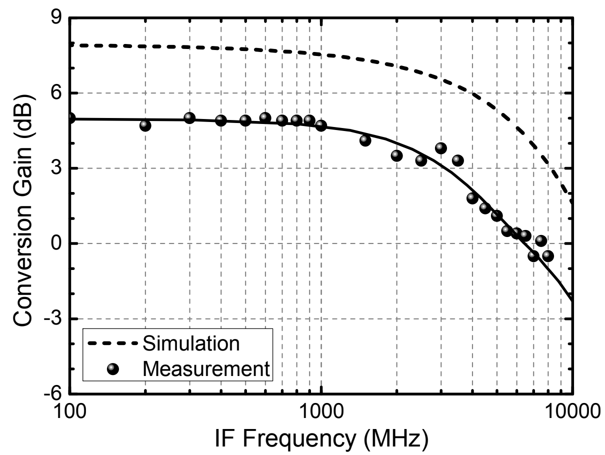
- ✓ Mixer: freq. Conversion
- ✓ LO: Clean CW

SiGe 60GHz Up-Mixer

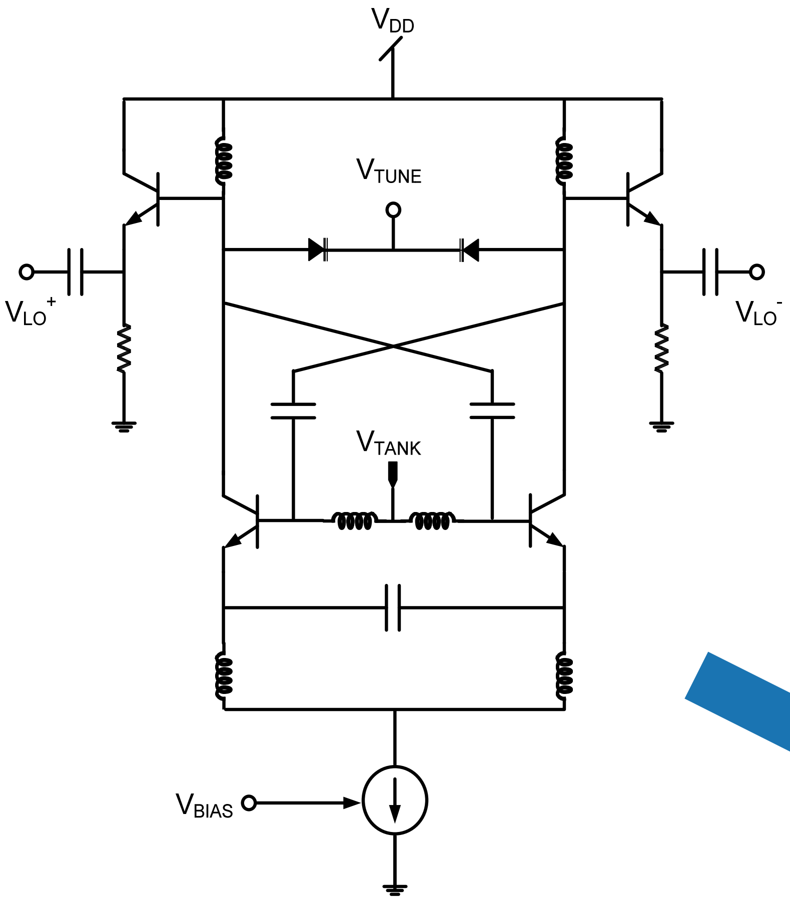


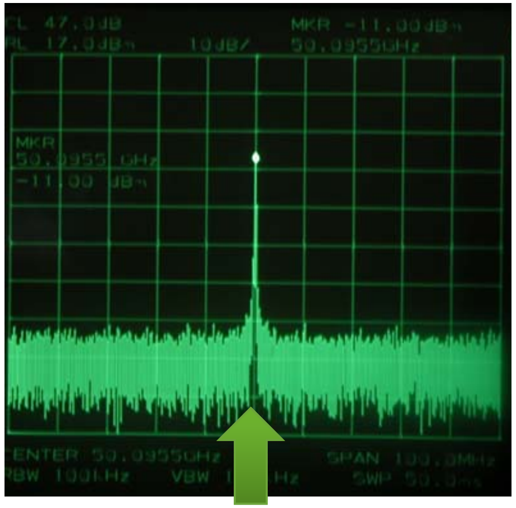




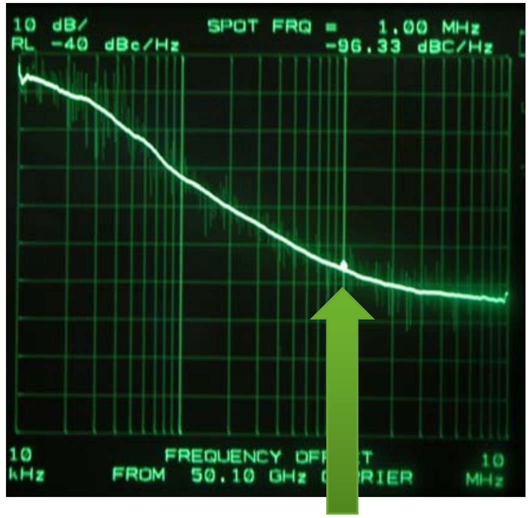


SiGe 60GHz Cross-Coupled VCO

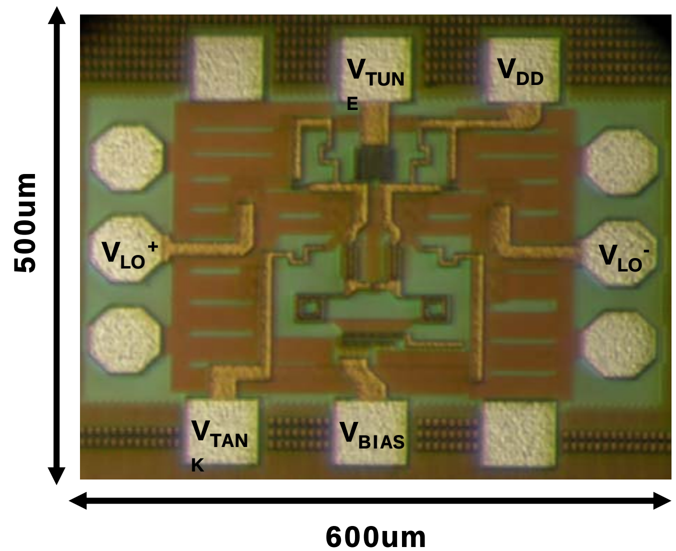




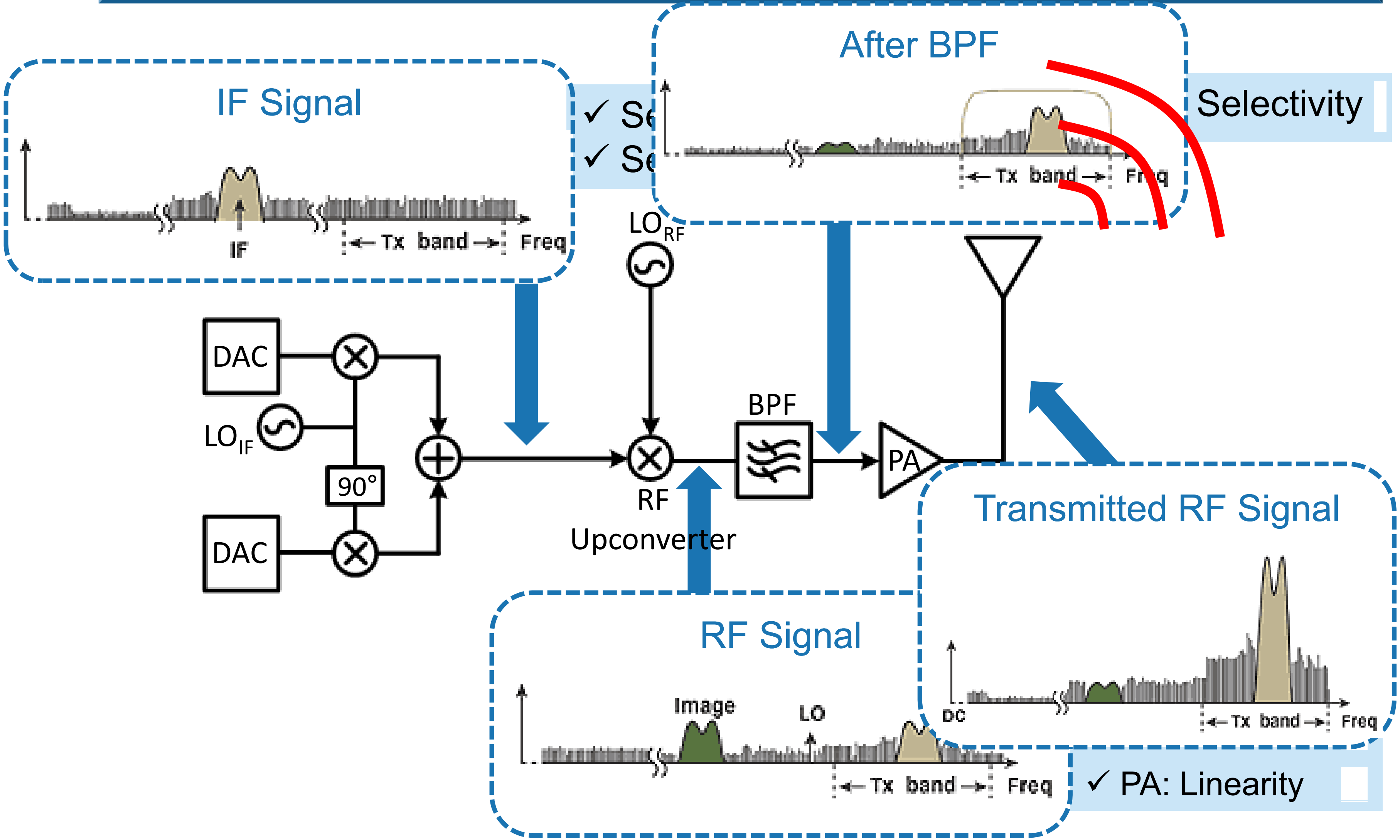
Frequency Tuning Range :
48.66~50.1GHz (1.44GHz)



Phase noise : -90 ~ -95dBc/Hz
@ 1MHz offset

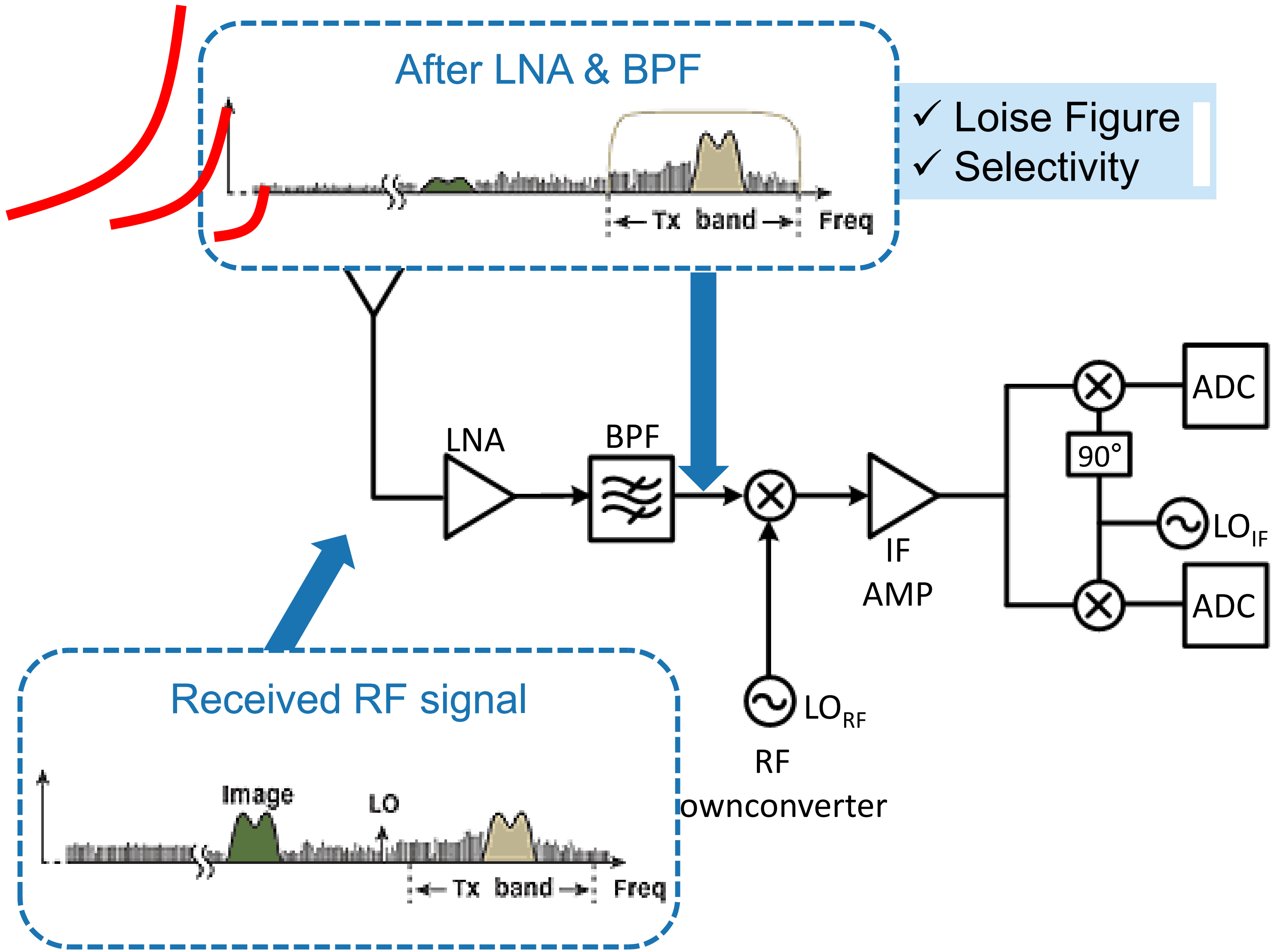


RF Building Blocks-Transmitter



RF Building Blocks-Receiver

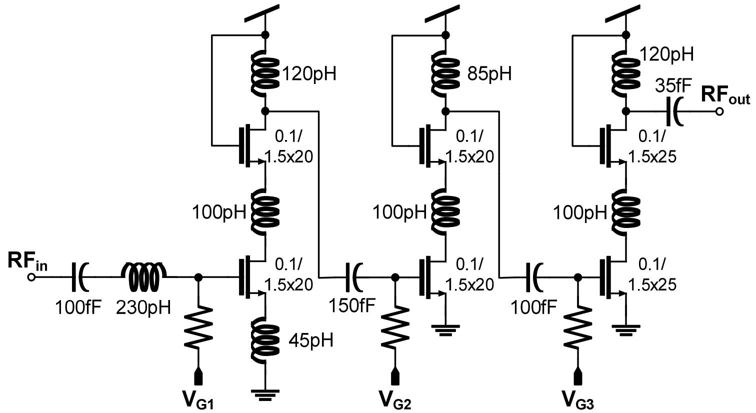
- ✓ Loise Figure
- ✓ Selectivity

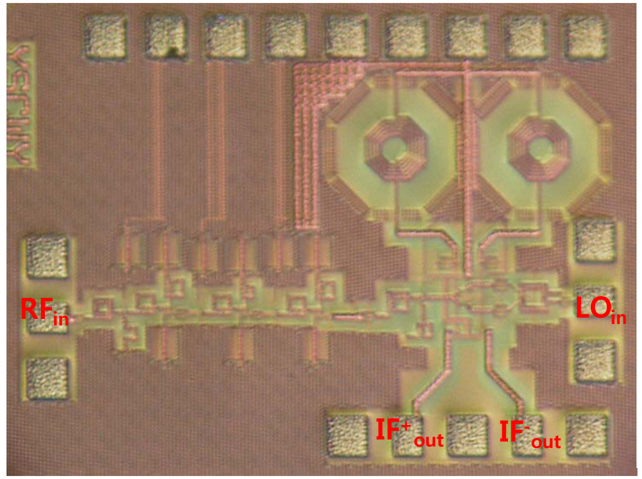


CMOS 60GHz Integrated Receiver (LNA & Mixer)

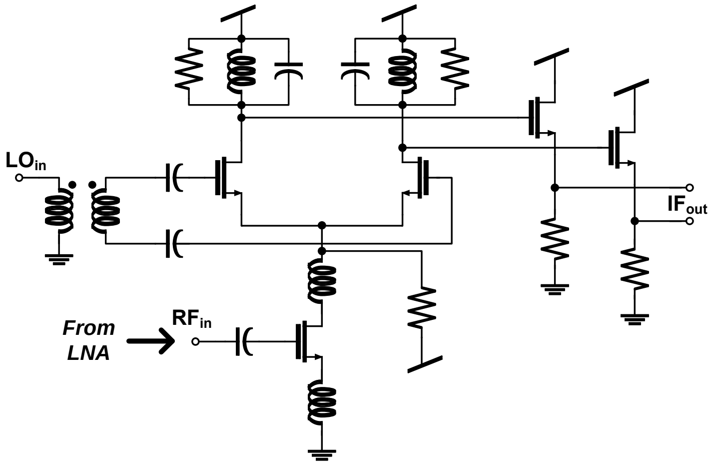
- 60GHz Receiver (LNA + Mixer) in TSMC 90nmm CMOS process

<3-Stage Cascode LNA>



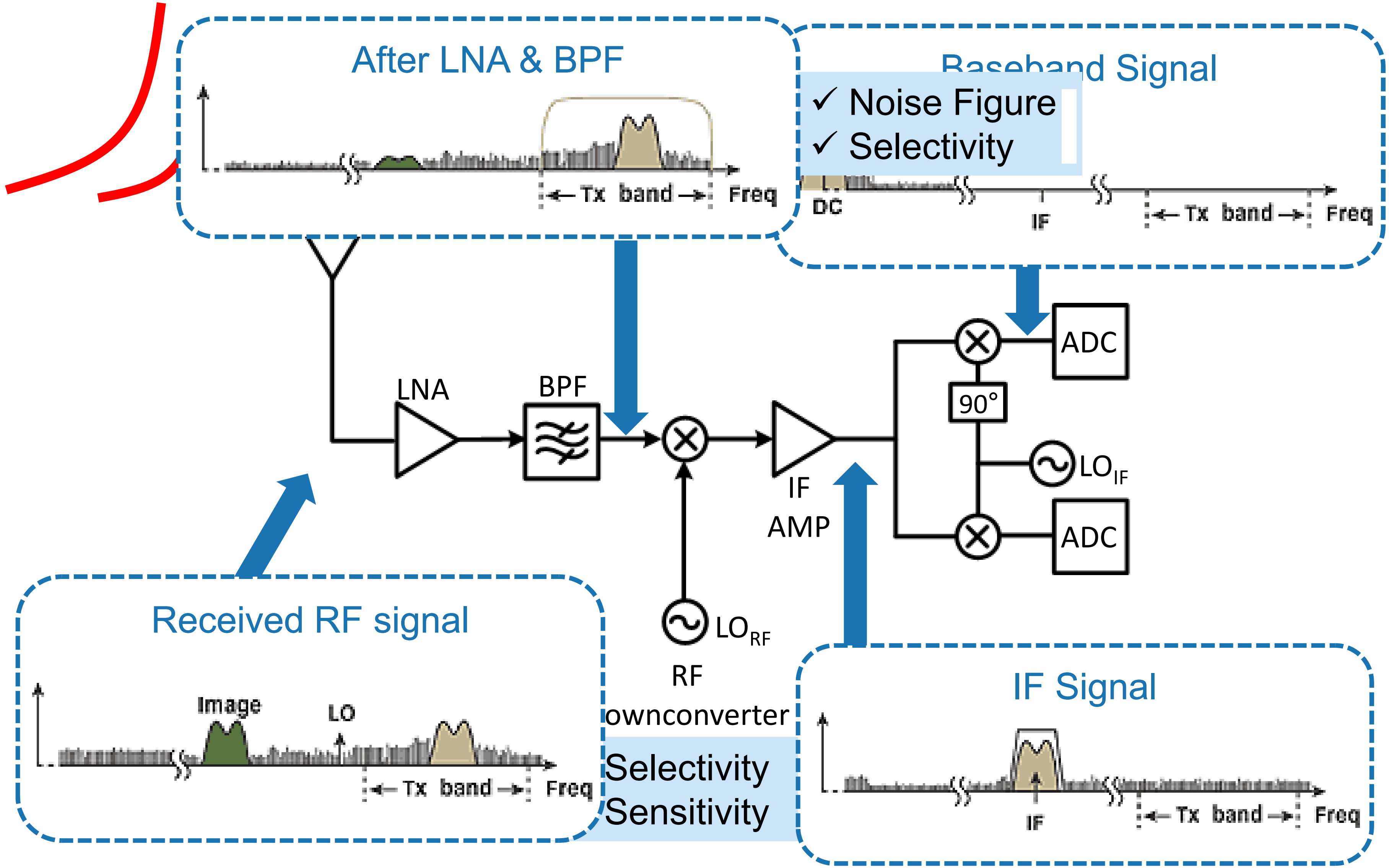


<Single-balanced Mixer>

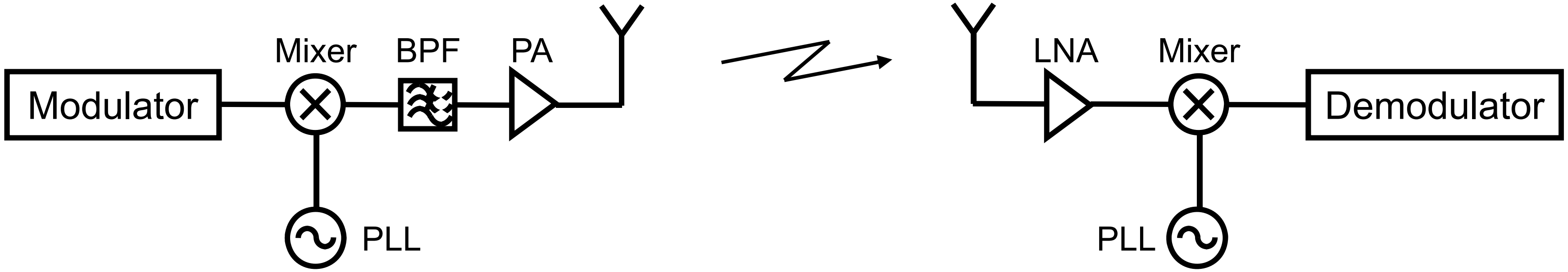


RF Freq (GHz)	IF Freq (GHz)	Gain (dB)	NF (dB)
55 ~ 65.8	3.1 ~ 5.8	15	8.14 ~ 8.32
IP1dB (dBm)	**IIP3 (dBm)**	**Power (mW)**	
-19.8	-10.2	59.5 @VDD=1.5V	

RF Building Blocks-Receiver



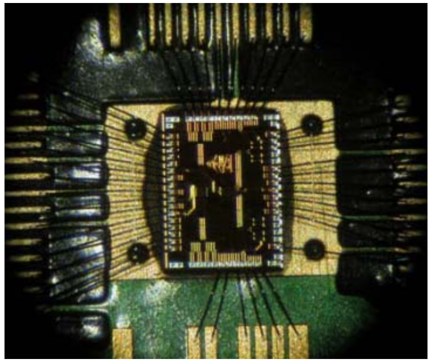
Silicon-Based Integrated 60GHz Transceivers



- 60GHz passive components in CMOS / BiCMOS
- 60GHz up-conversion mixer in BiCMOS
- 60GHz VCO in BiCMOS
- 60GHz receiver (LNA & mixer) in CMOS
- 60GHz VCO in CMOS
- 1.6Gb/s QPSK demodulator in CMOS

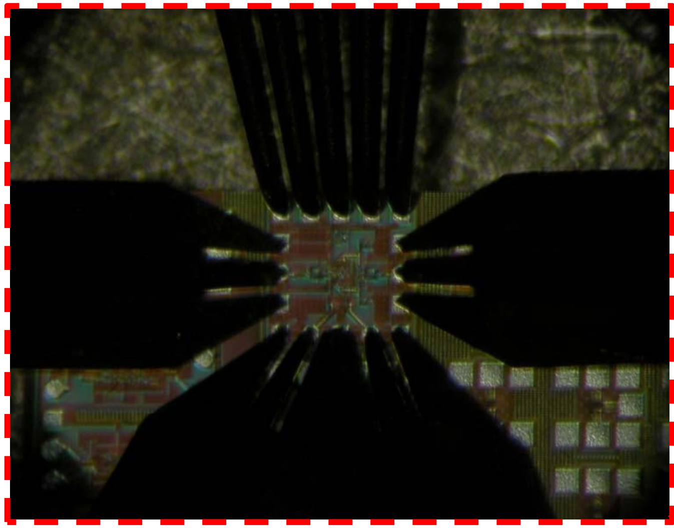
Experimental Setup for 60GHz ICs

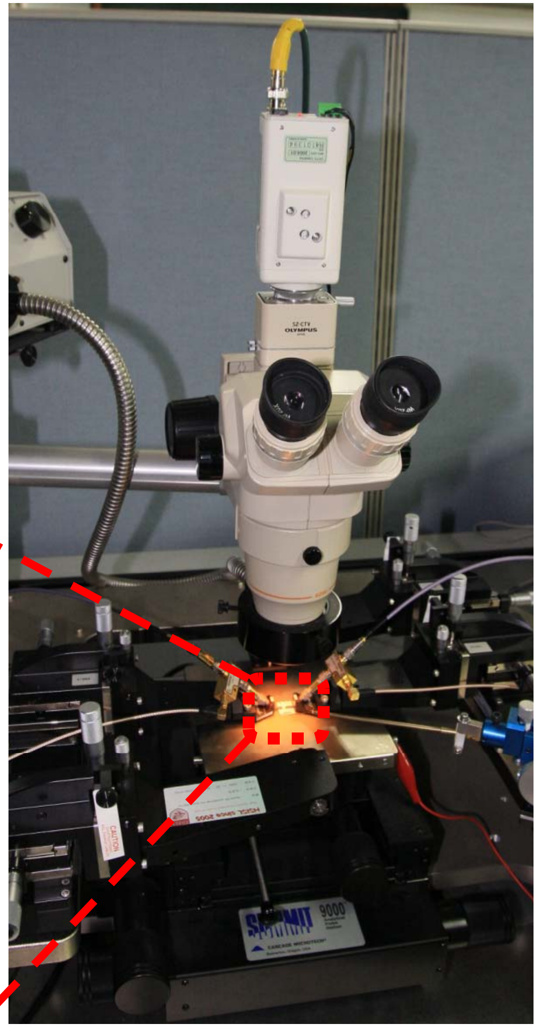
< Wire-Bonding Setup >



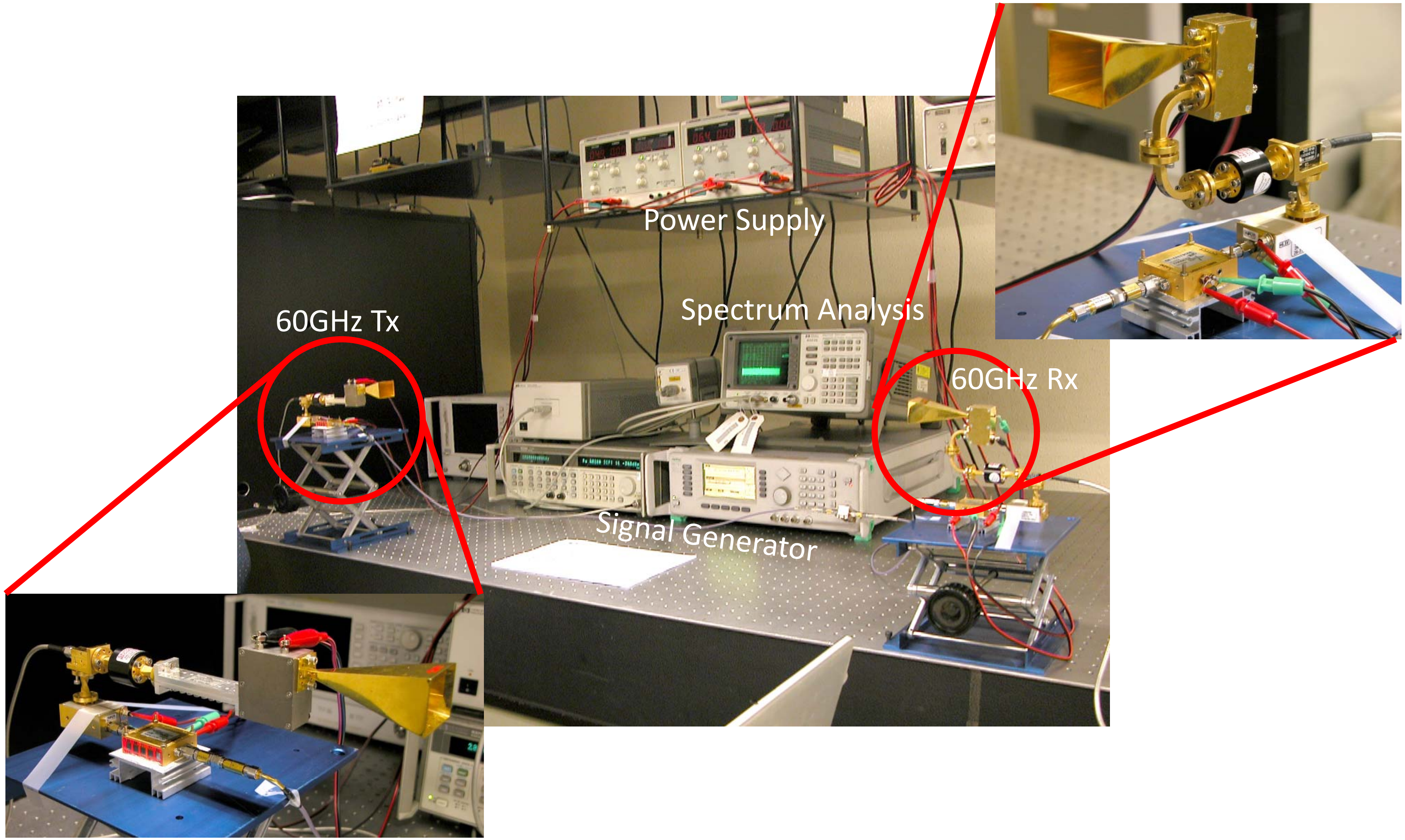
► Parasitic inductance of bond wires severely affects overall circuit performances in 60 GHz.

< On-Wafer Probing Setup >

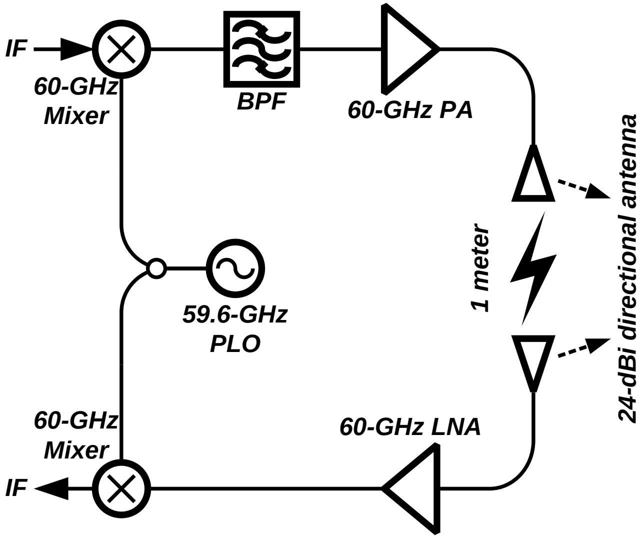


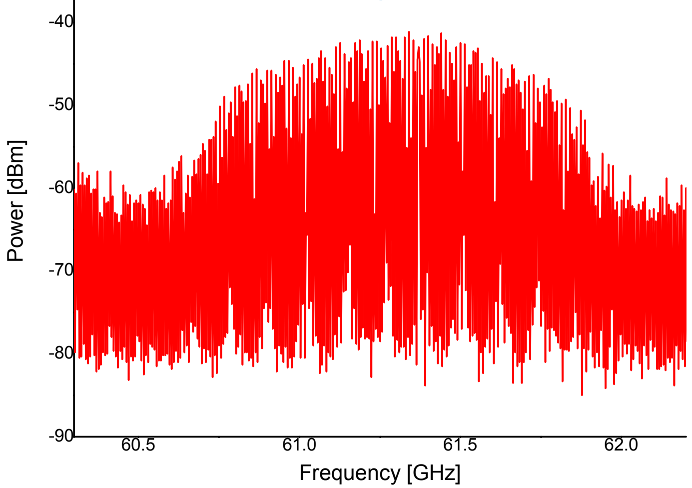


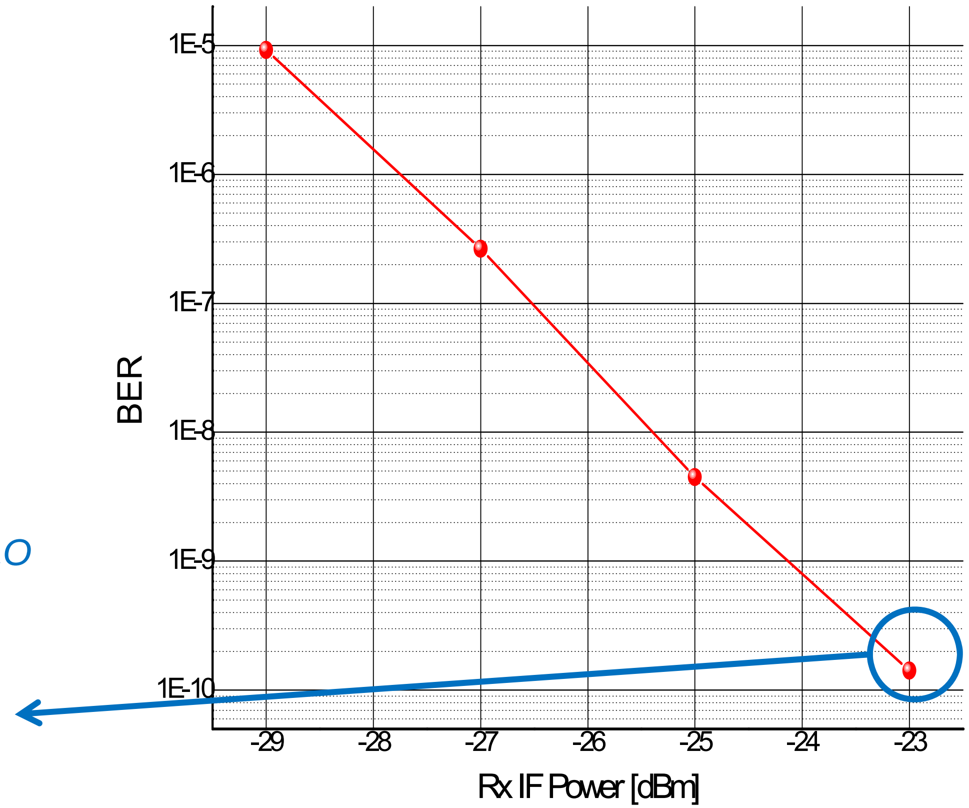
60GHz Link Demonstration



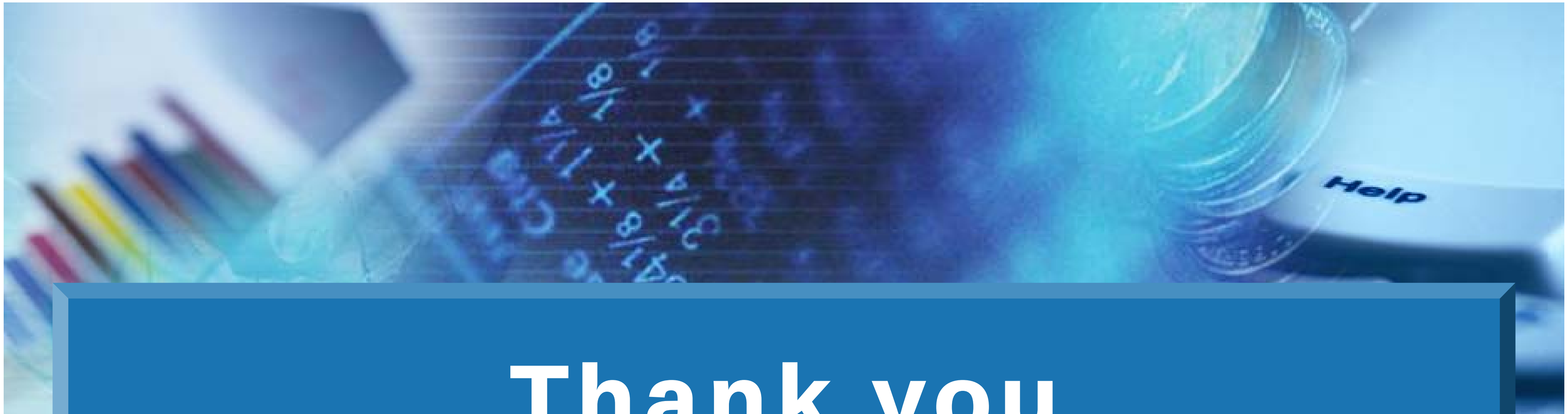
60GHz Link Demonstration







BER < 10^{-9} with 1.6Gb/s QPSK in 60GHz link



Thank you

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