2008 EU-Japan
Cooperation Forum
on ICT Research

FUJITSU

Cooperative Activities of Fujitsu with European Institute/Universities in Photonic Network Technologies

March 4th, 2008

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FUJITSU LABORATORIES LTD.

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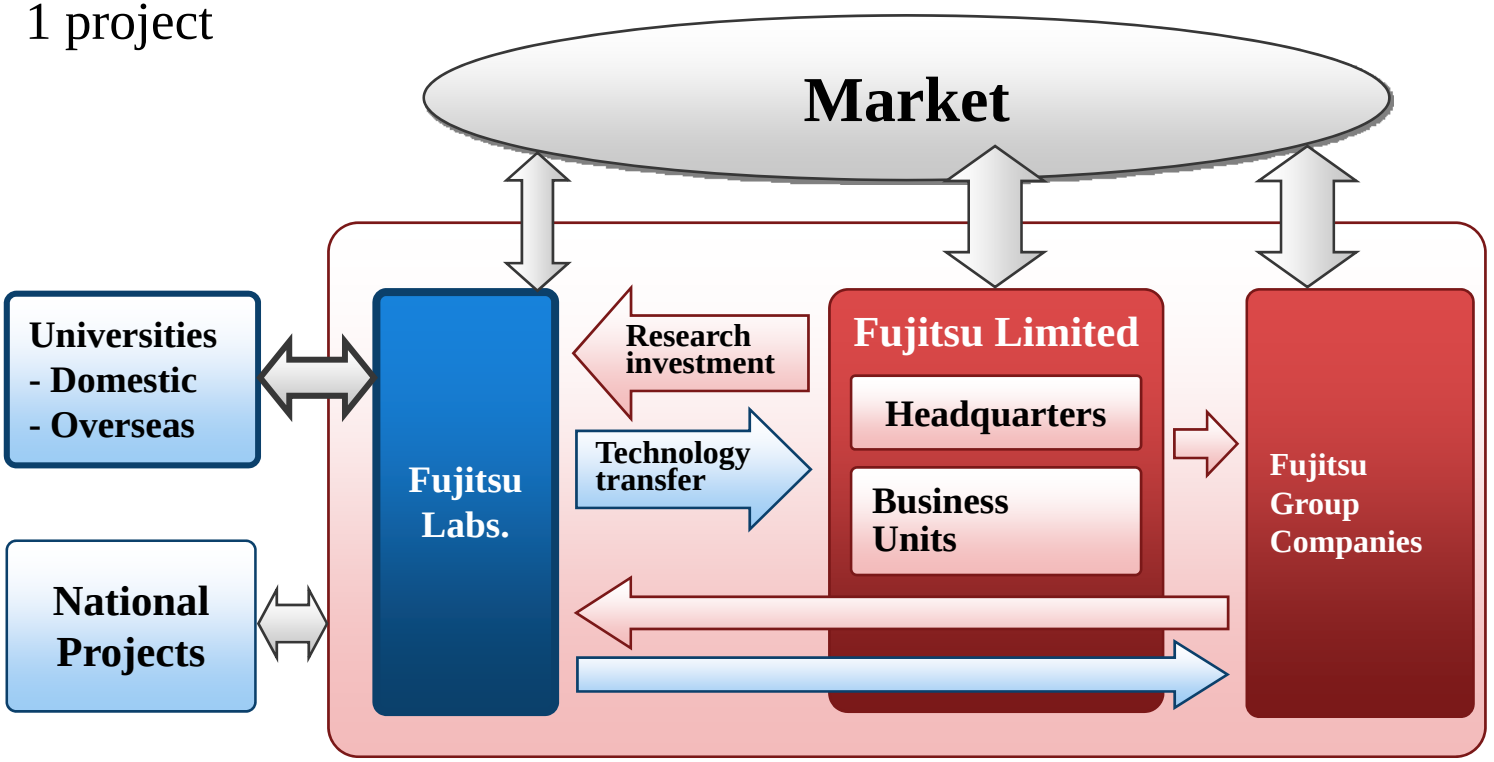
Contents

1. Fujitsu Laboratories and Technology Value-Chain
2. Cooperative activities in Photonic Network Technology
   - Heinrich-Hertz Institut, Fraunhofer Gesellschaft
   - Technical University of Eindhoven, the Netherlands
   - Technical University of Copenhagen, Denmark
3. Summary

Brief Introduction of Fujitsu Laboratories Ltd.

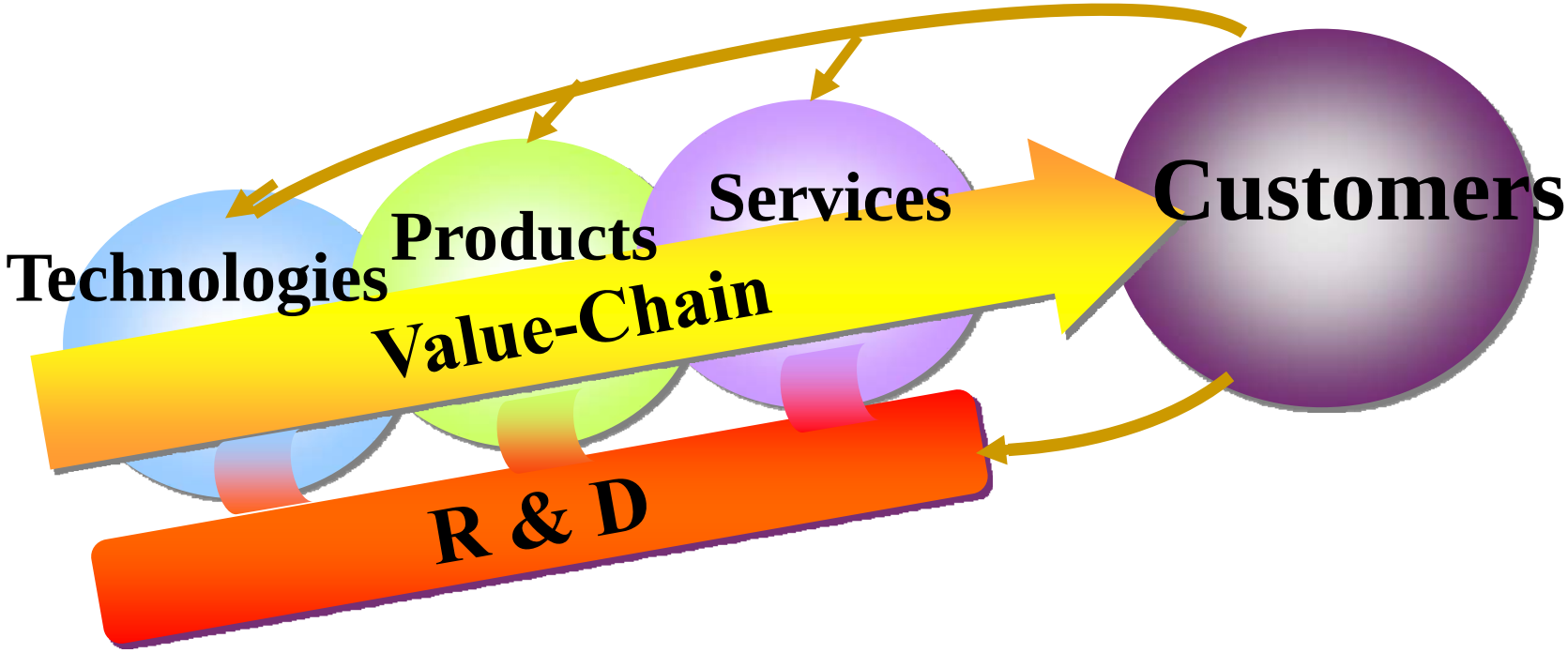
- as the basis of my talk -

- Established: November 1968
- Employees: Approx. 1,500 in Japan
  Approx. 180 at overseas labs (Europe, US, China)
- Organization: 8 laboratories
  5 centers
  1 project
- Framework



Promotion of Value-Chain from Enterprise R&D

By the value-chain connecting technology (including devices), products (platform) and services through R&D, we are promoting to provide sophisticated solutions to customers who are aiming new business models.



Collaboration is diversifying and increasing

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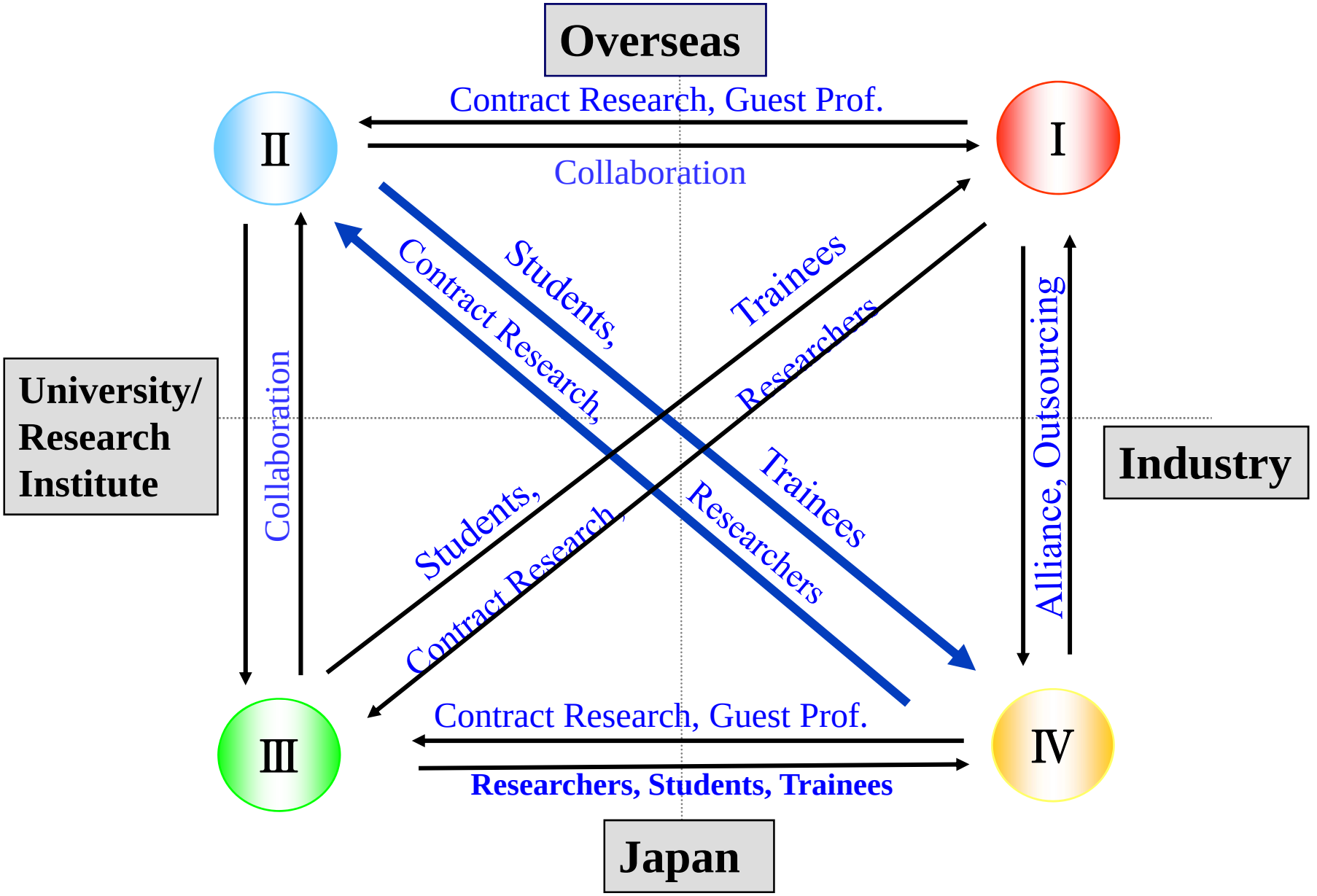

Key to the successful partnership:

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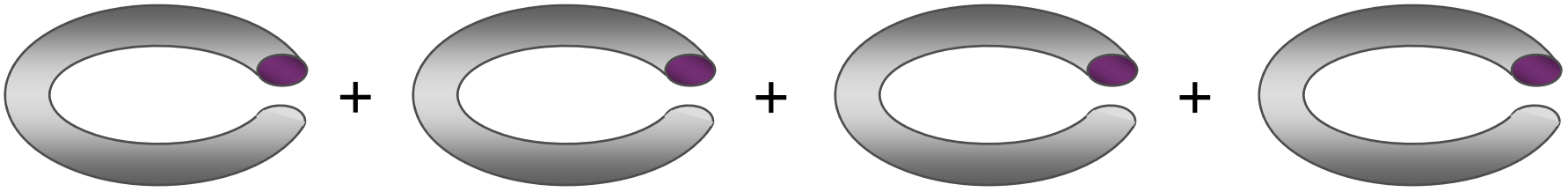
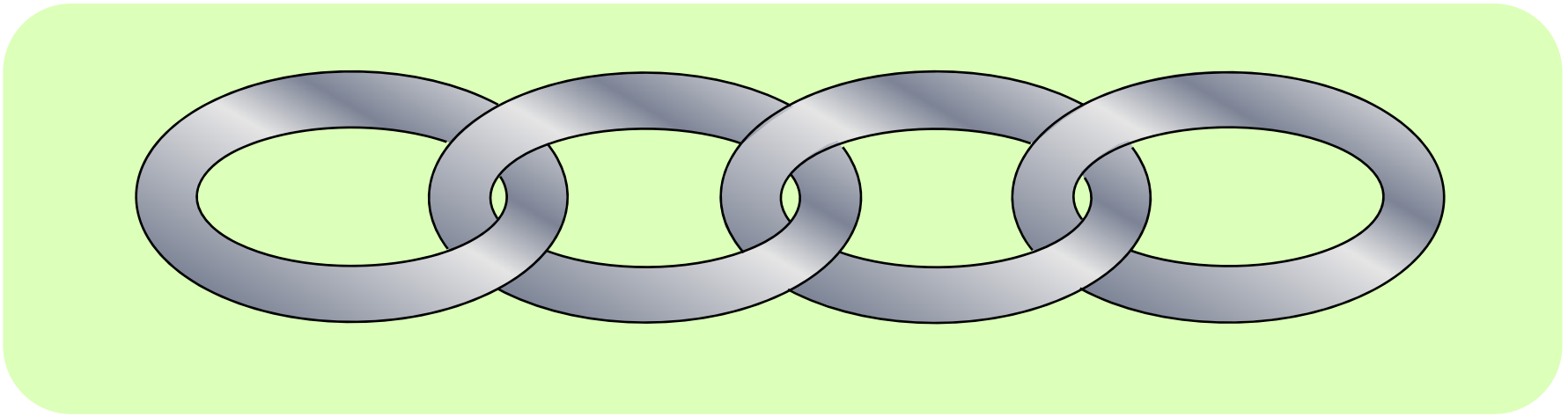
Connect the Technology Value-Chain Globally



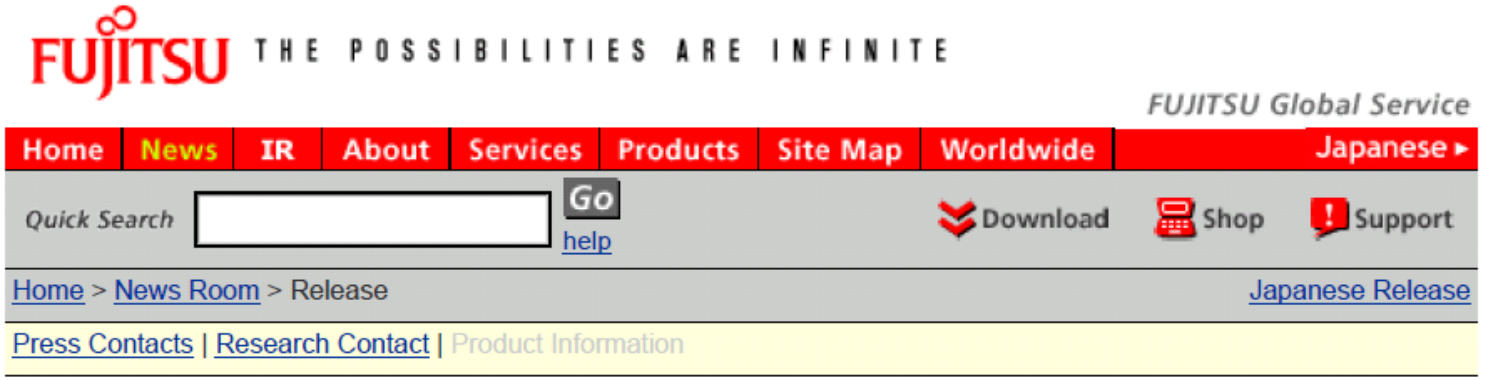
Education + Research + Development + Product/ Service



Collaboration with Heinrich-Hertz Institut (HHI) / FhG.

- Objective: To challenge frontier technologies
  gathering expertise and resources of both laboratories
- Research subject: Ultra-high speed optical signal processing
- Enjoying fruitful collaboration since 2001
  - **To bring the world-class strengths together:**
    HHI: Ultra-high speed transmission technologies
    Fujitsu: Optical signal processing technologies
  - **To set the objective extremely high:**
    Gold medal in Olympic game or Formula-1
  - **To exchange researchers for face-face discussion:**
    Young researchers: longer period (months)
    Leaders: frequent visit
  - **To jointly use expensive facilities for experiments**

Press-release of Collaboration at the Starting in 2001



FUJITSU THE POSSIBILITIES ARE INFINITE

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2001-0179E
Fujitsu Laboratories Ltd.

Fujitsu Laboratories and Heinrich-Hertz-Institut Collaborate in Research on Super High-Speed Optical Signal Processing Technology

Kawasaki, September 27, 2001 - Fujitsu Laboratories Ltd. today announced that it has begun full-fledged collaborative research with Germany's Heinrich-Hertz-Institut (HHI) in optical signal processing technology, a field essential to the future development of optical communications and photonic networks. The project will focus on signal processing that seeks to take advantage of light's ultra-high-speed characteristics without having to convert it into electronic signals. The goal is to develop new super high-speed optical signal processing technology within five years that will break through the barriers now being faced by existing technology.

Results: Conference Publication of Collaboration Activities

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	Authors	Conferences	Title
1	R. Ludwig, et al.	OFC 2008	All-optical Amplitude Noise Suppression of 107 Gb/s DPSK Signals Using a Parametric Fiber Switch in a 320 km Transmission Experiment
2	F. Futami, et al.	OFC 2007	All-optical Amplitude Noise Suppression of 160-Gb/s OOK and DPSK Data Signals Using A Parametric Fiber Switch
3	M. Galili, et al.	OFC 2007	All-optical Combination of DPSK and OOK to 160 Gbit/s DQPSK Data Signals
4	C. Schmidt-Langhorst et al.	ECOC2006 PDP	160 Gbit/s All-optical OOK to DPSK In-Line Format Conversion
5	H. G. Weber et al.	ECOC2005 PDP	Single-channel 1.28 Tbit/s and 2.56 Tbit/s DQPSK Transmission
6	V. Marembert, et al.	CLEO 2005	Investigations of Fiber Kerr-Switch: Nonlinear Phase Shift Measurements and Optical Time-Division Demultiplexing of 320 Gbit/s DPSK Signals
7	S. Watanabe, et al.	ECOC2004 PDP	Novel Fiber Kerr-Switch with Parametric Gain: Demonstration of Optical Demultiplexing and Sampling up to 640 Gb/s
8	V. Marembert, et al.	ECOC2004 PDP	Single-channel 640 Gbit/s DPSK Transmission over a 160 km Fibre Link
9	S. Watanabe	ECOC 2004 Symposium	Technologies for 160 Gbit/s Optical 3R-Regeneration
10	R. Ludwig, et al.	ECOC 2004 Symposium	160 Gbit/s DPSK-Transmission - Technologies and System Impact
11	C. Boerner, et al.	ECOC 2004	160 Gbit/s Clock Recovery in a 3R-Regenerating Wavelength Converter
12	S. Ferber, et al.	OFC 2004	160 Gb/s Regenerating Conversion Node
13	S. Watanabe, et al.	OFC 2003 PDP	160 Gbit/s Optical 3R-Regenerator in A Fiber Transmission Experiment
14	C. Schubert, et al.	ECOC 2002	Improved performance of a 160 Gb/s fiber-based all-optical switching using rectangular gating pulses
15	C. Schmidt, et al.	ECOC 2002	320 Gb/s All-Optical Eye Diagram Sampling using Gain-Transparent Ultrafast-Nonlinear Interferometer (GT-UNI)
16	R. Ludwig, et al.	OECC 2002 PDP	160 Gbit/s 3R-Regenerating Wavelength Converter
17	C. Schmidt, et al.	CLEO 2002	Optical Q-factor monitoring at 160 Gb/s using an optical sampling system in an 80 km transmission experiment
18	C. Schmidt, et al.	OFC 2002	Complete optical sampling system with broad gap-free spectral range for 160 Gbit/s and 320 Gbit/s and its application in a transmission system

OFC; Optical Fiber Communications Conference, ECOC; European Conference on Optical Communications

160 Gb/s Optical 3R-Transmission (OFC2003)

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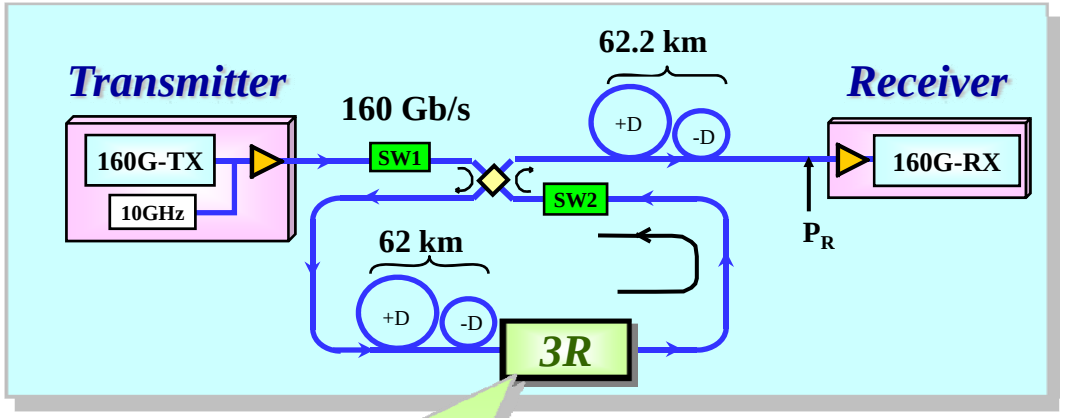
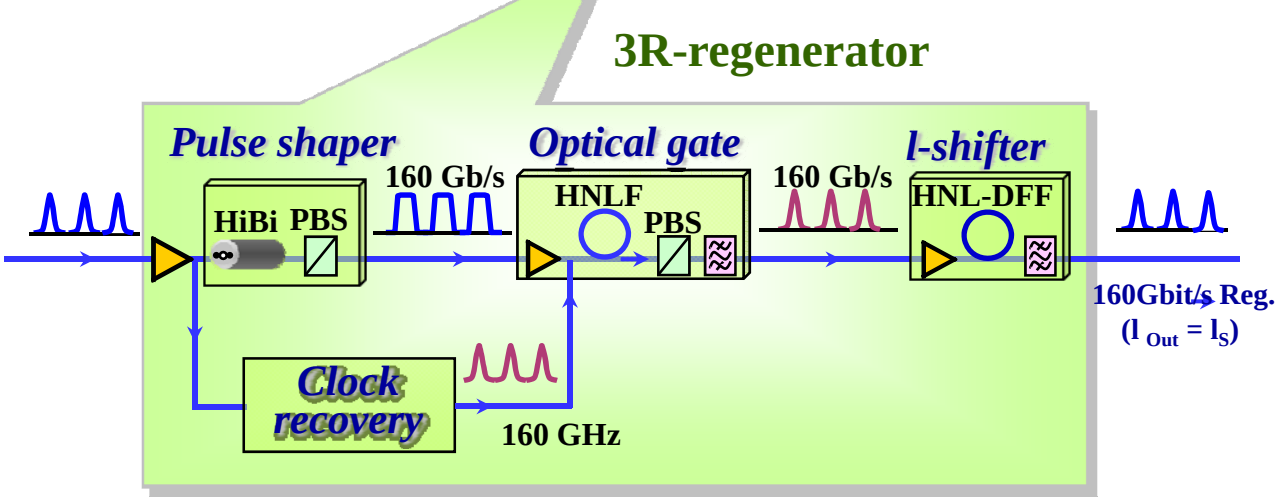
Fraunhofer Institut Nachrichtentechnik Heinrich-Hertz-Institut

- Restoration of distorted signal waveform (regeneration) by optical 3R (Re-amplifying, Re-Shaping, and Re-timing).

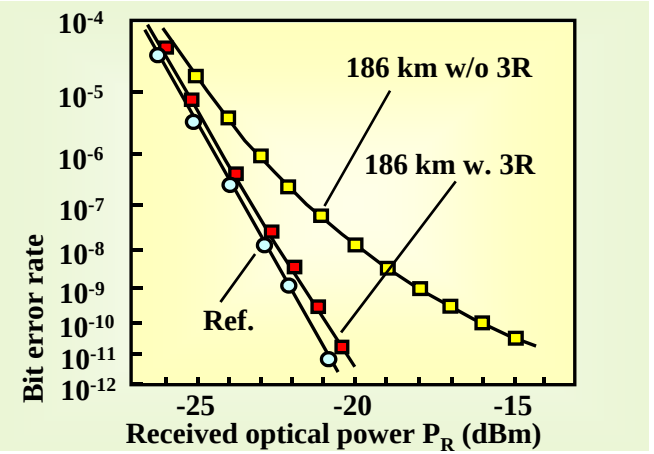
Setup



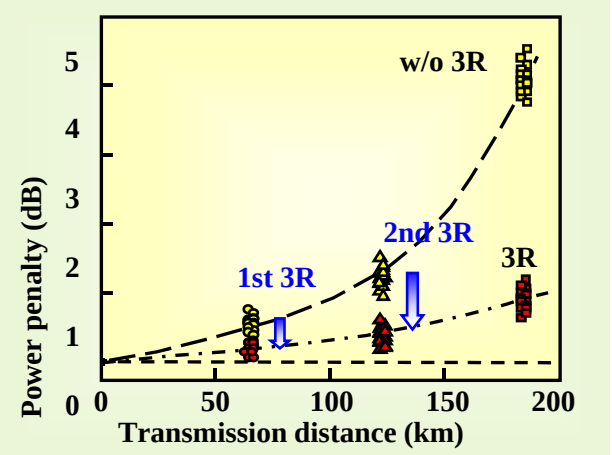


◆ **Optical gating by fiber switch, and jitter reduction by pulse shaping**

BER characteristics



Improvement by 3R



Single Channel 1.28/2.56 Tb/s Transmission (ECOC2005)

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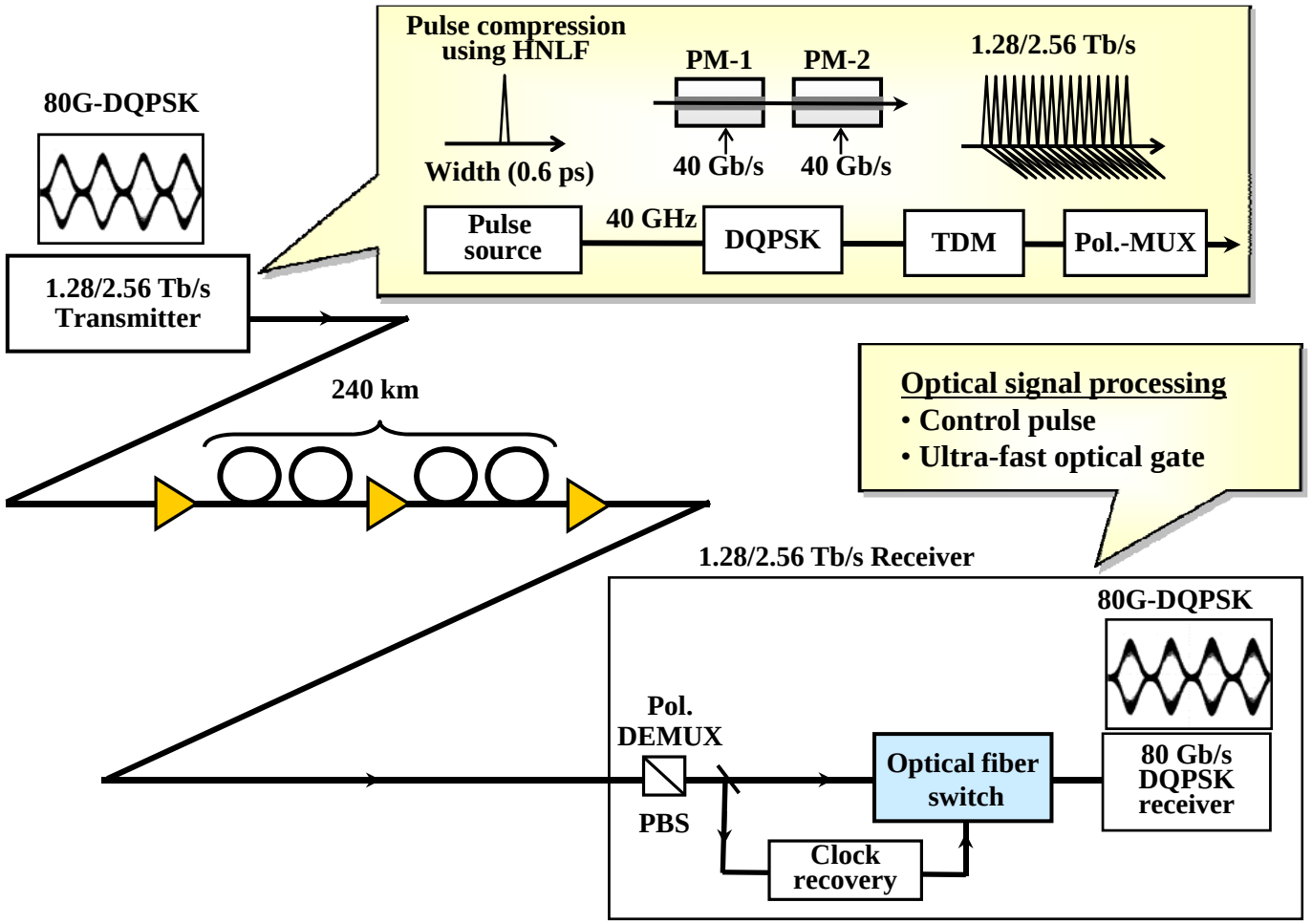
Fraunhofer Institut Nachrichtentechnik Heinrich-Hertz-Institut

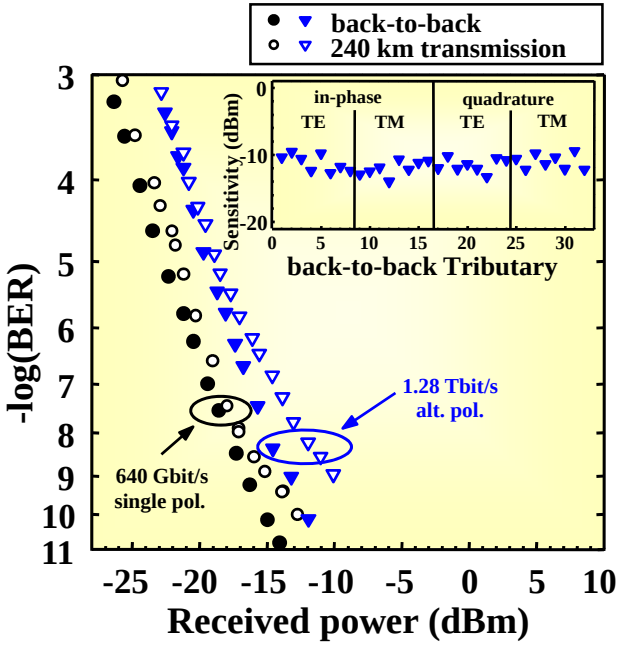
- **Single channel 1.28/2.56 Tb/s DQPSK transmission**
- **Ultra-large capacity data multiplexing by DQPSK, TDM and Pol.-MUX**
- **Optical signal processing and Tb/s switching using nonlinear fiber**



Mulitplexing (MUX) technologies

- DQPSK modulation
- Optical time division MUX (TDM)
- Polarization MUX

40 Gb/s ⇒ 2.56 Tb/s



From HHI Annual Report 2006/2007

PHOTONIC NETWORKS
AND SYSTEMS

2.5 TERABIT PER SECOND SINGLE CHANNEL DATA TRANSMISSION OVER 160 KM FIBER

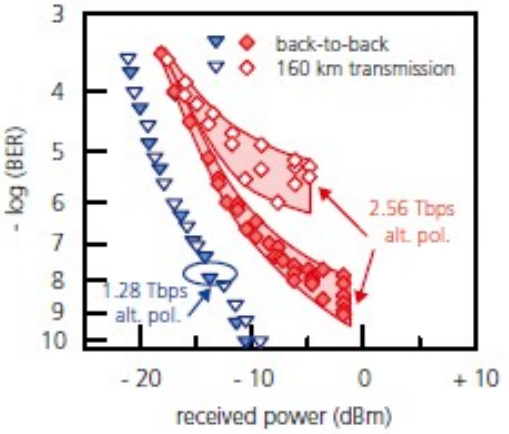
The use of optical time division multiplexing (OTDM) in combination with differential quaternary phase shift keying (DQPSK) modulation enables transmission at ultra-high data rates up to the world record transmission rate of 2.5 Tbps in a single wavelength channel. This was demonstrated by HHI in a 160 km transmission experiment together with Fujitsu Laboratories Ltd., Japan.

Der Einsatz der optischen Zeitmultiplextechnik (OTDM) in Verbindung mit differentieller vierstufiger Phasenmodulation (DQPSK) ermöglicht

this is a new record for single wavelength channel transmission.[1] In a DQPSK modulated signal, each symbol carries 1 out of 4 logical states which enables the encoding of two bits into one transmitted symbol. This enables a doubling of the data rate without changing the symbol rate or reducing the symbol rate for a given data rate. The latter can be used to increase the transmission distance which was also demonstrated by error free (bit error rate BER < 10^{-9}) 1.28 Tbps transmission over a record fibre length of 240 km.

Fig. 1 shows the experimental setup comprising the DQPSK transmitter and receiver as well as the transmission link. In the transmitter, a 10 GHz mode-locked solid state laser (MLSL) and a pulse compression unit provided a

including 300 m highly nonlinear fiber (HNLF) as optical gate. A mode-locked fibre laser (MLFL) provided the control pulses and was synchronized by a clock recovery unit which is commercially available from HHI.[2] Within the 80 Gbps DQPSK receiver, a delay-line interferometer (DLI) operated as the phase decoder.



Amplitude Noise Suppression by Parametric Fiber Switch

(OFC2008)

- Amplitude noise suppression of phase modulated (DPSK) signals by gain saturation of optical parametric amplification
- ~ 5 dB improvement of OSNR (Optical Signal-to-Noise Ratio)

Experimental setup

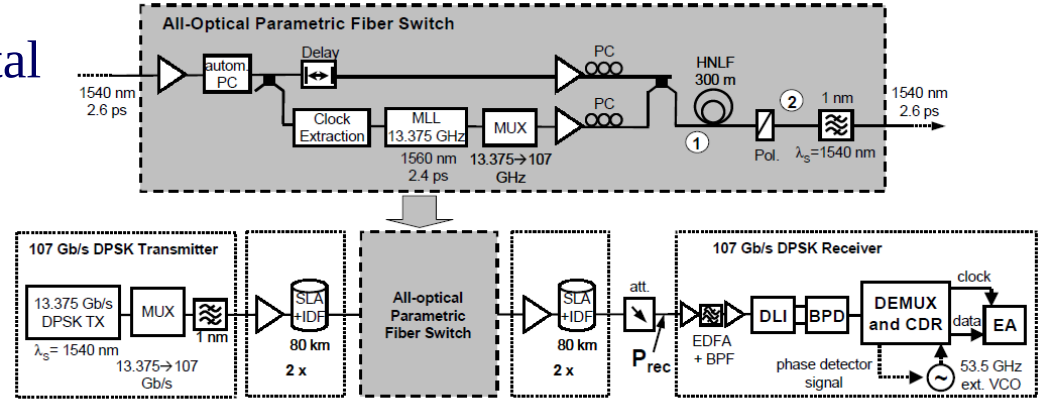


Fig. 1. Experimental setup

Results

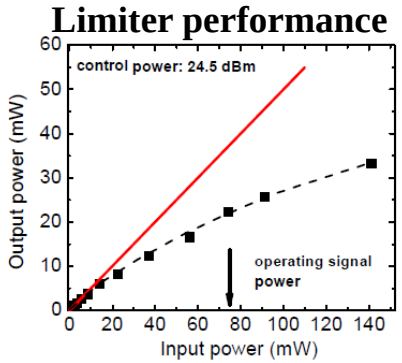


Fig. 2. Measured power transfer characteristics of the parametric fiber switch for 107 Gb/s DPSK

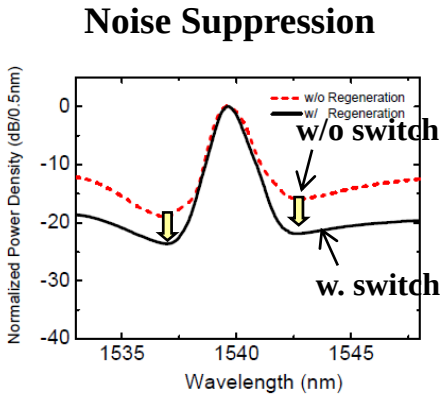


Fig. 3. Optical spectrum after the 320 km fiber link with and without regeneration

BER characteristics

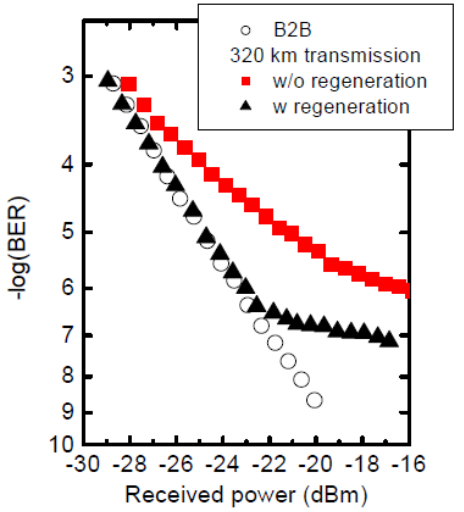


Fig. 4. BER performance for 107 Gb/s DPSK back-to-back (b2b) and after transmission over 320 km with (w) and without (w/o) mid-span regeneration

Collaboration with Technical University of Denmark (DTU)

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Collaborative activities with Prof. Palle Jeppesen

- Outside examiner of the thesis:
  - Ph. D. thesis in 1994
  - Ph. D. thesis in 2006
- Stayed as Guest Researcher and outside examiner of master thesis of two students (1997)
- Internship for two master-course students (1997)
- Visiting researcher scholarship program (VRSP) for a post-doctoral researcher (2007)

Guest professor at DTU in 2005

- Lectures on optical signal processing and collaboration with Prof. Jeppesen's group

Main results of collaboration

- Investigation on nonlinear optical fibers since 1997
- Simultaneous wavelength conversion of 32-WDM signals (ECOC'98-PDP)

(DTU; Danmarks Tekniske Universitet)

Multi-channel Wavelength Conversion (ECOC'98)

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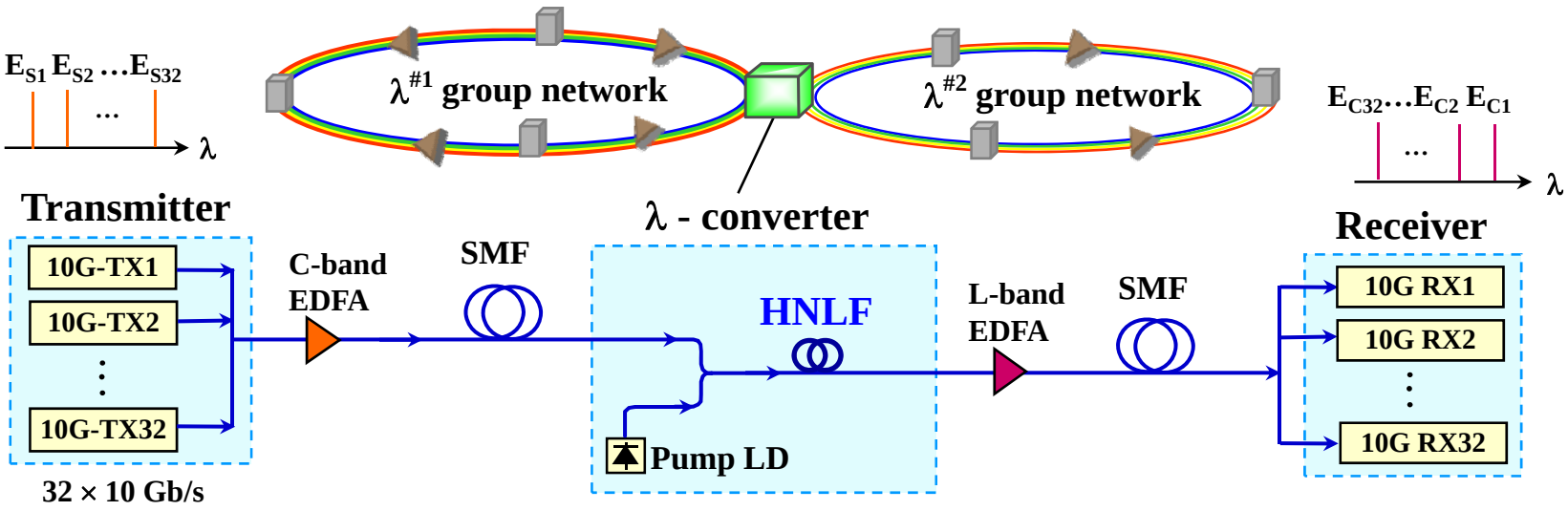
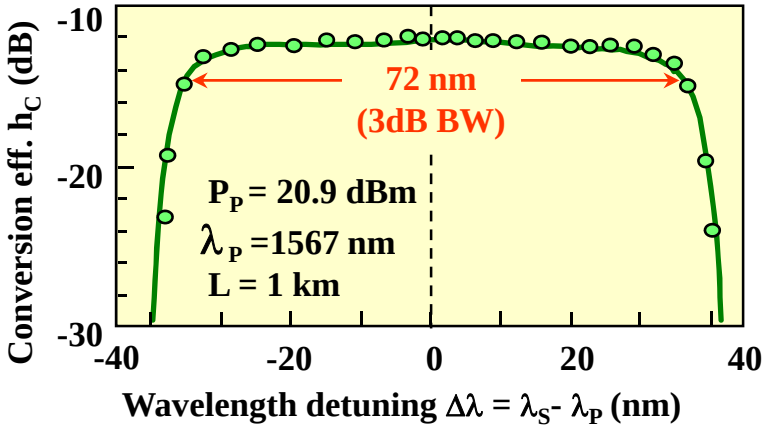
- Simultaneous multi signal λ conversion using fiber nonlinearity for flexible and expandable photonic network

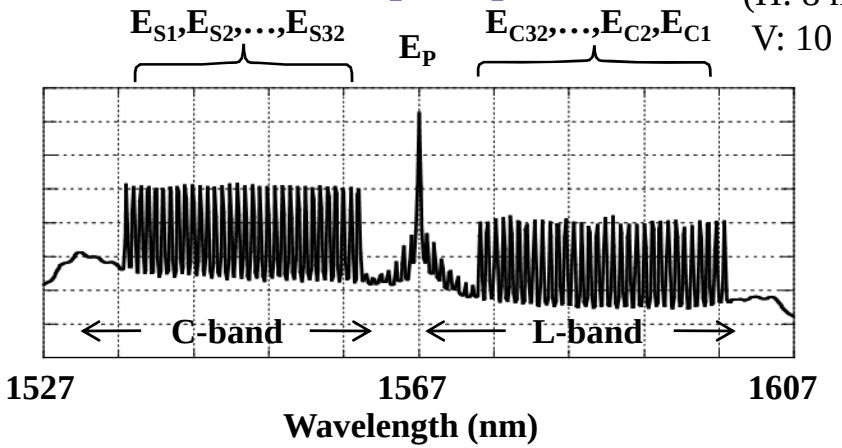


■ Bandwidth characteristics



■ λ-converter output spectrum

(H: 8 nm/div., V: 10 dB/div.)



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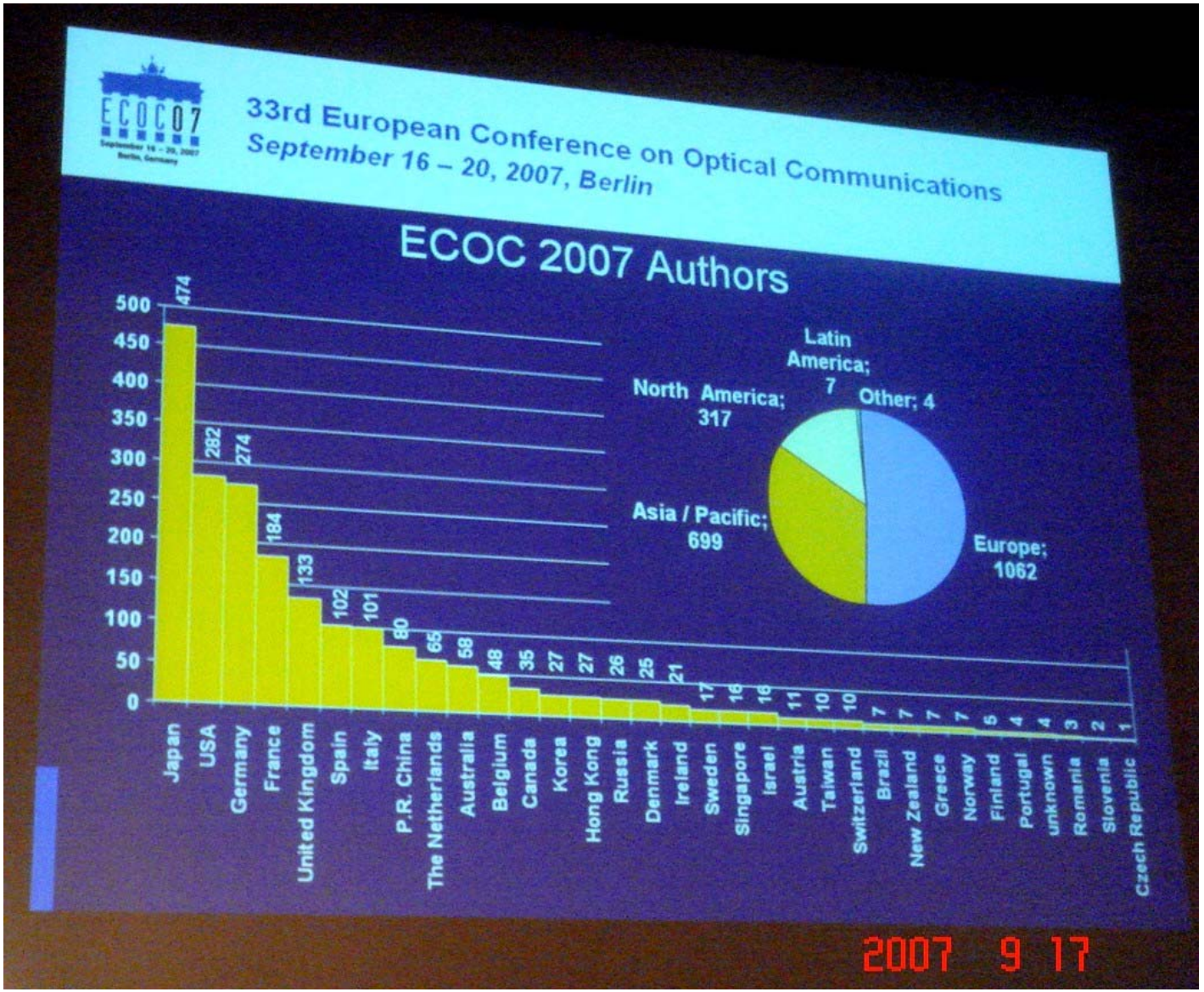
Internship and visiting researcher in Fujitsu Labs
- in Photonic Network Technology area -

- **Collaboration with Technical University of Eindhoven**
  - **The group of Prof. G.D. Khoe (COBRA)**
  - **Internship for a master course student in 1999 and 2002**
  - **Visiting researcher scholarship program (VRSP) for a post-doctoral researcher in 2005**
- **Collaboration with Technical University of Munich**
  - **Internship for a master course student in 1983, 1998 and 2003**

Author Statistics in ECOC2007

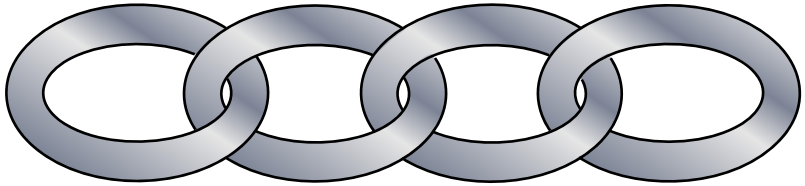


ECOC: European Conference on Optical Communications

Summary

- Cooperation activity with European university or research institute has been effective and fruitful for Fujitsu Labs.

- We will continue this promising relation and pursue to expand the front edge of photonic network technology, and connect the value-chain to bring the outcome to our society.



- While photonic networking technology is already serving to shorten the distance and time between Europe and Japan, we will pursue further more broadband, cost effective and power efficient technologies to the earth.

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Thank you !

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THE POSSIBILITIES ARE INFINITE