

ITU Workshop IP/Optical

Chitose, Japan, July 10, 2002



Session 6

WDM and DWDM

Franko Küppers
T-Systems
Technologiezentrum
Darmstadt, Germany

Experiences from Pilot Trials and Field Experiments at 40 and 160 Gbit/s/ λ



Outline

- **40G – First Field Experiment in 1998**
- **40G – Various Field Trials from 1998 to 2002 (including Raman, PolMux, and RZ/NRZ)**
- **40G – Pilot Trial in 2002 PhotonEx**
- **160G – First Field Experiment in 2000**
- **Conclusion – What's next?**

First Field Experiments in 1998

40 Gbit/s/ λ over 130 km SMF – Inv. CD+PMD



■ 4x10 Gb/s OTDM Tx in Darmstadt (TZ)

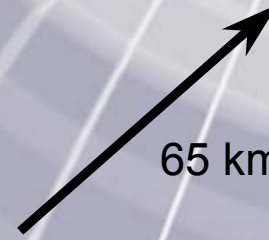
Rx with 40/10 Gb/s DEMUX Rx in Darmstadt (TZ) ■



65 km of SMF

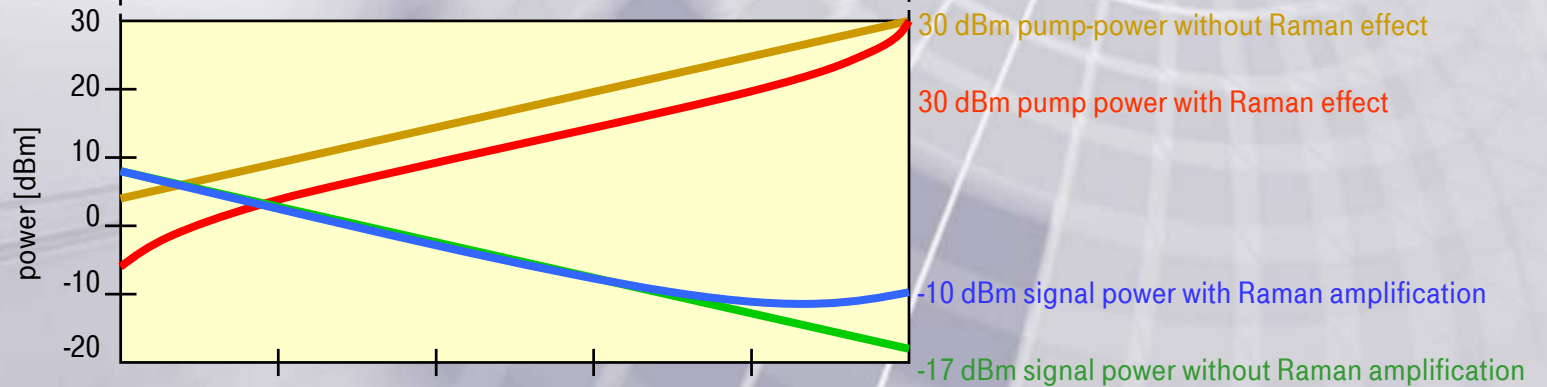


65 km of SMF



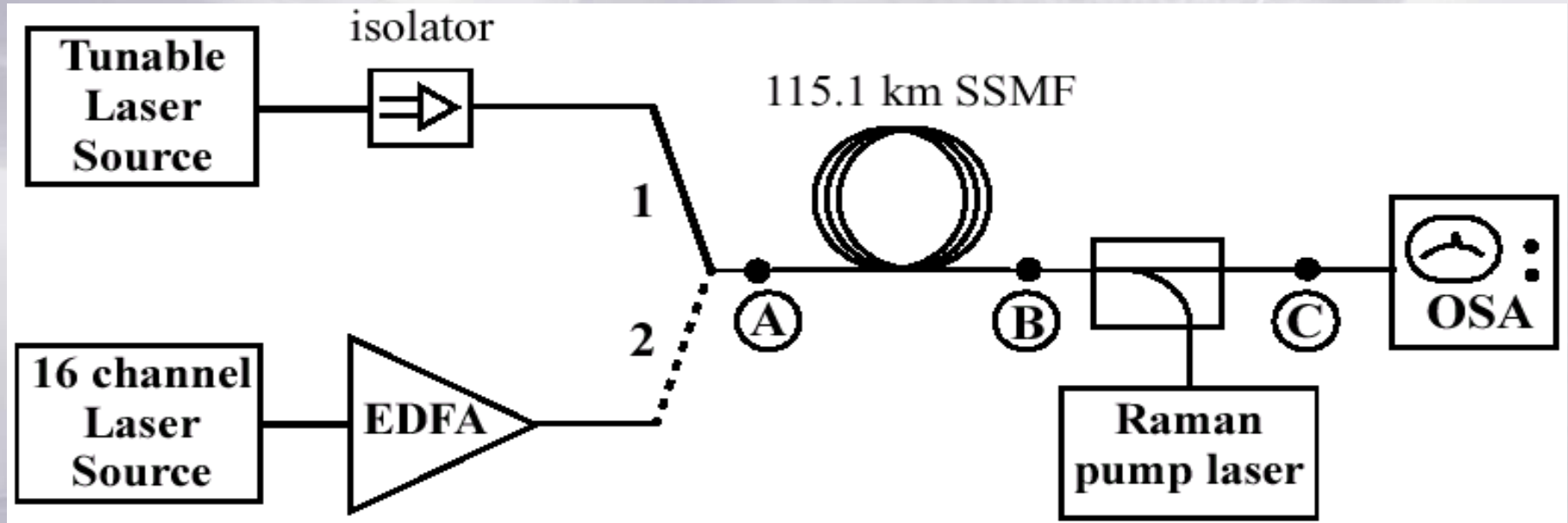
Distributed Raman Amplification

Basic Set-up



Distributed Raman Amplification

Raman Gain of Installed Fibers (I)

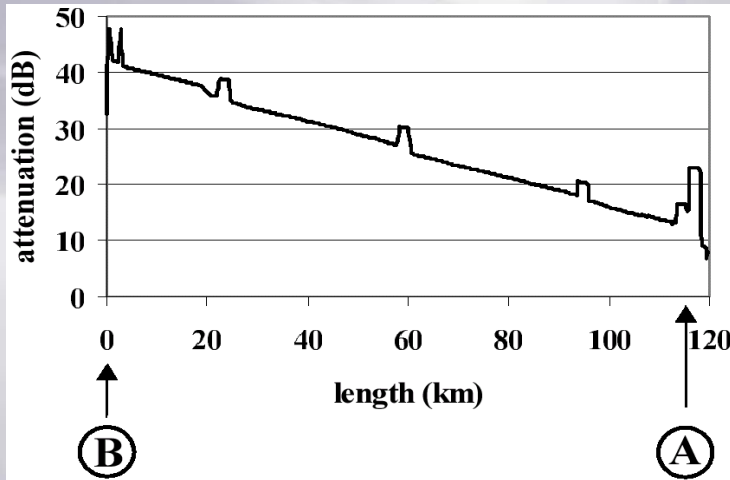


TLS: measurement of attenuation and Raman gain coefficient

16 ch.: measurement of Raman on-off-gain

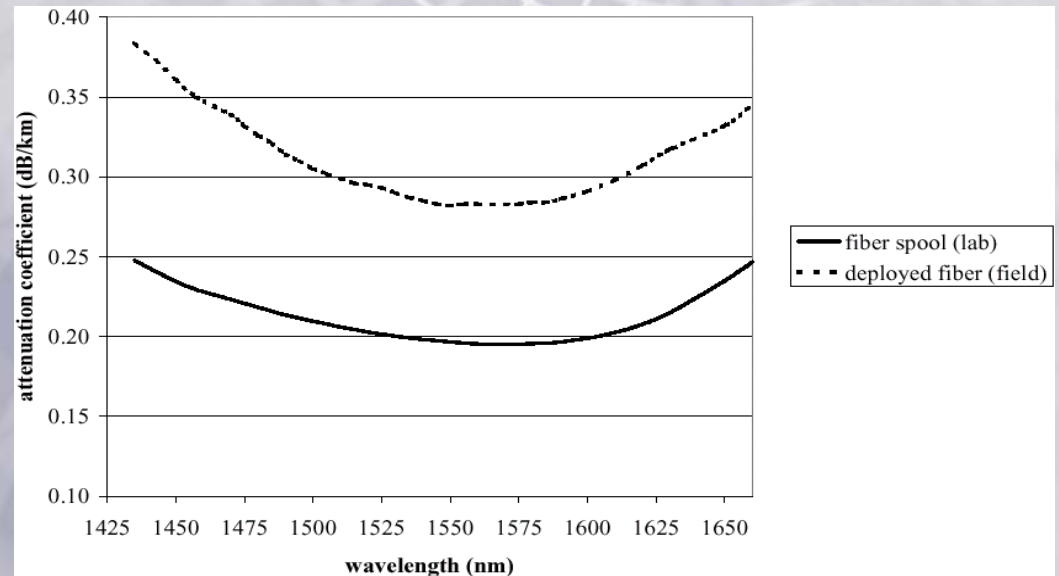
Distributed Raman Amplification

Raman Gain of Installed Fibers (II)



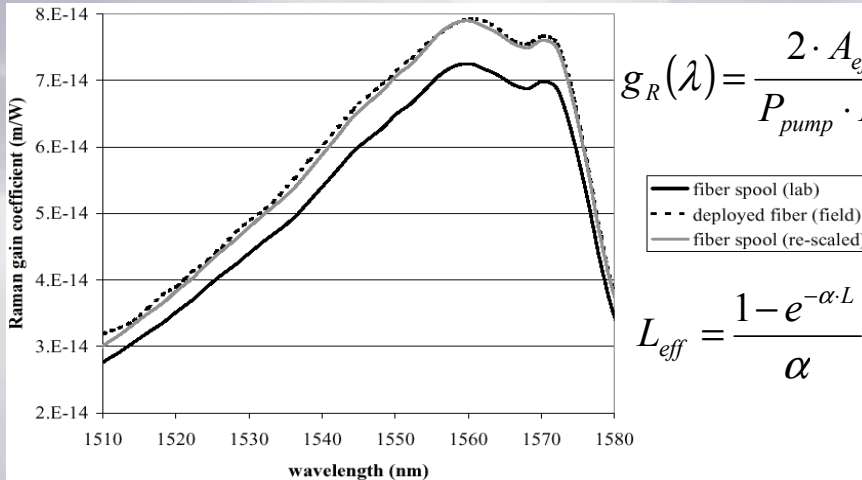
OTDR trace
with a total attenuation of 32 dB
and various splices

fiber spool (lab)
vs.
deployed fiber (field)

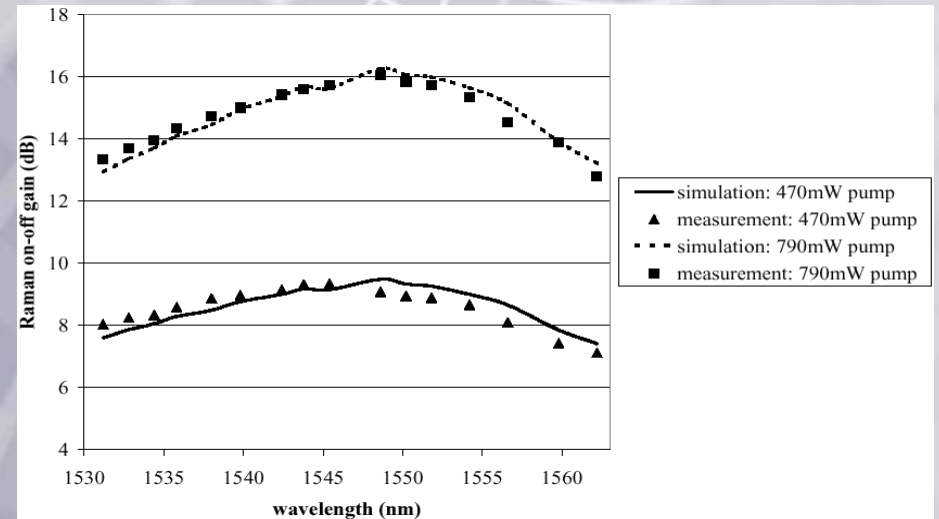


Distributed Raman Amplification

Raman Gain of Installed Fibers (III)



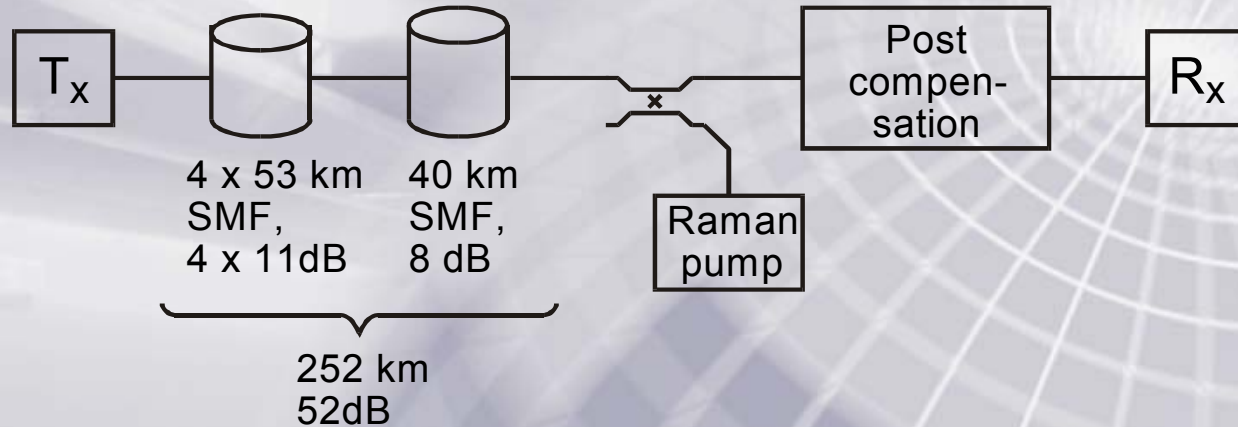
simulation vs. measurement of Raman on-off-gain
 16 signal λ , 4 pump λ , 2 pump powers



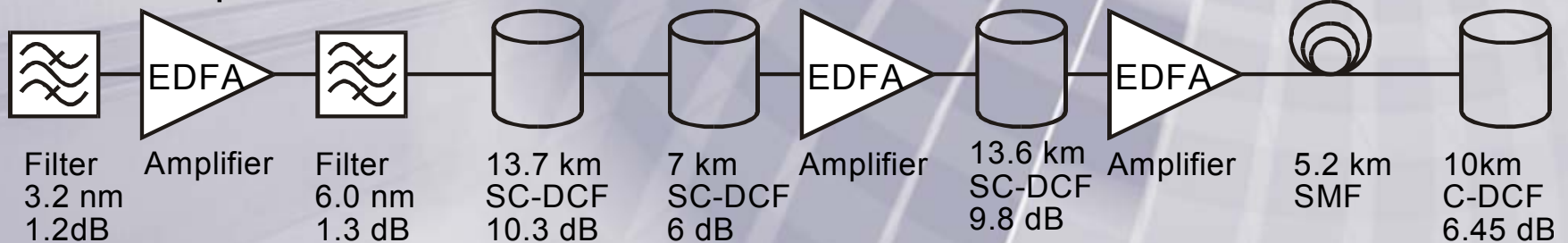
- Raman gain coefficient
- fiber spool (lab)
 - deployed fiber (field)
 - spool re-scaled

Distributed Raman Amplification

Unrepeated 40G over 252 km G.652 Fiber (I)

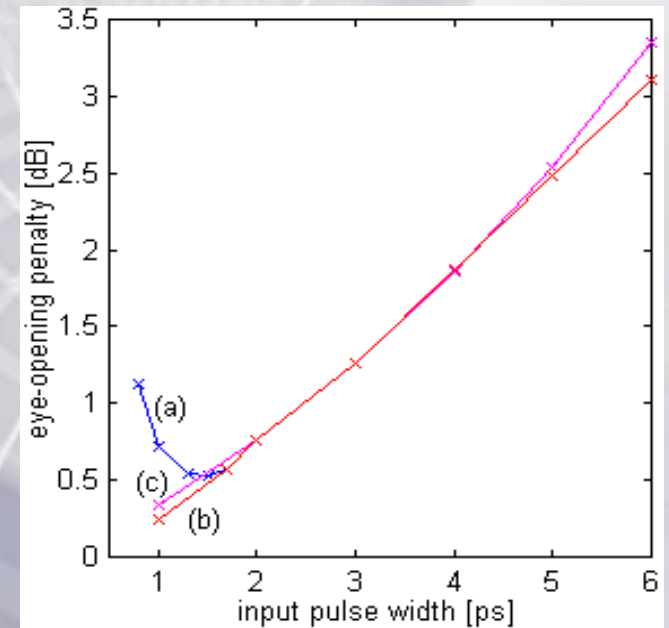
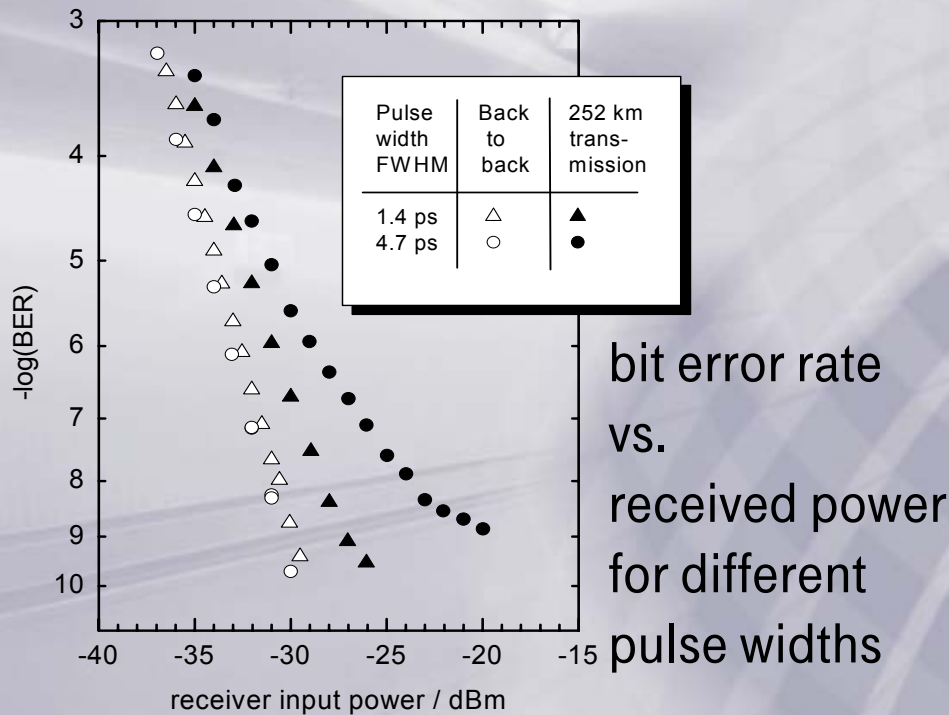


Post compensation:



Distributed Raman Amplification

Unrepeated 40G over 252 km G.652 Fiber(II)



- (a) 'normal' DCF, 1.6 W pump
- (b) SC-DCF, 1.6 W pump
- (c) SC-DCF, 0.8 W pump

Polarization Multiplexing

$16\lambda \times 2 \times 42.6$ Gbit/s over 116 km SMF (I)



16 cw laser sources

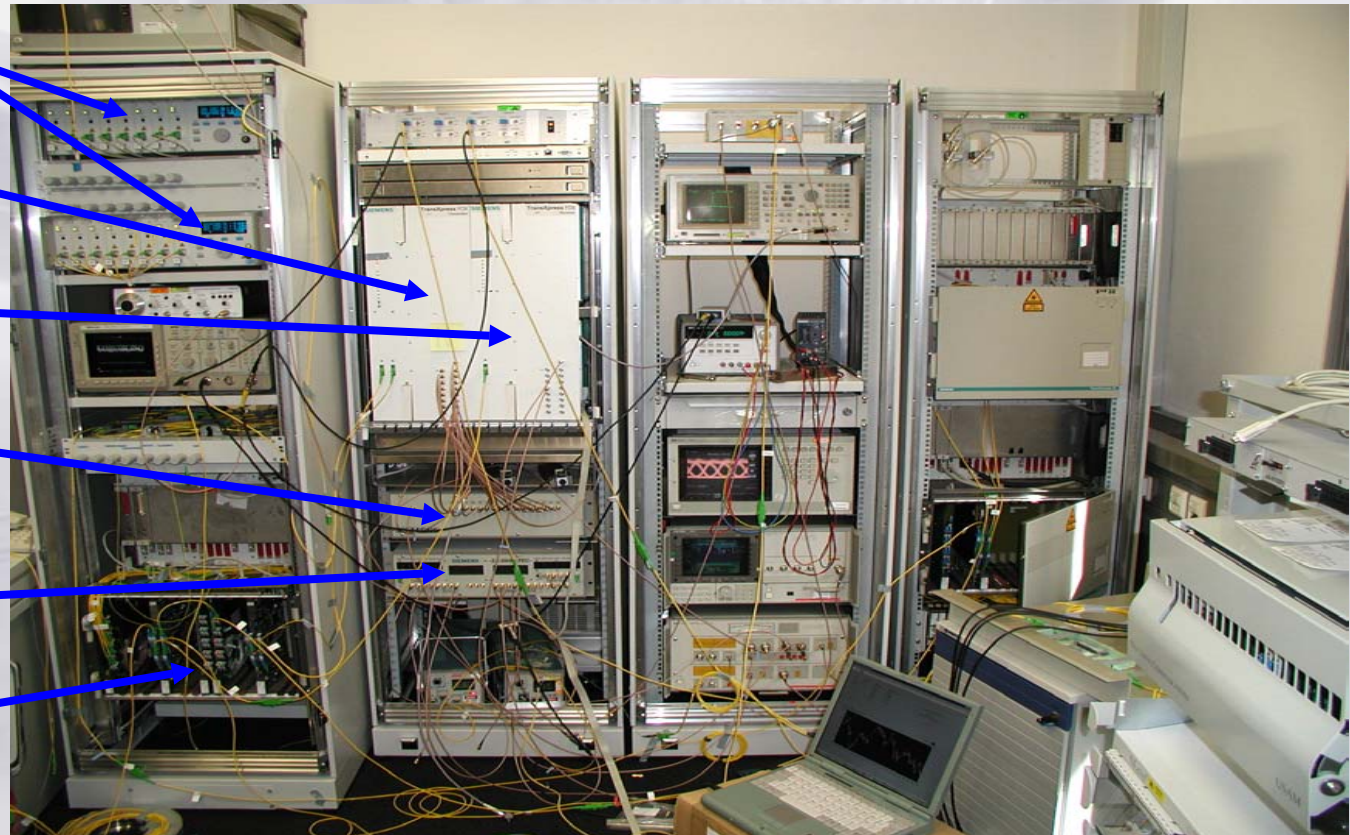
40 Gbit/s transmitter

40 Gbit/s receiver

16 x 2,488 Gbit/s ports

FEC encoder/decoder

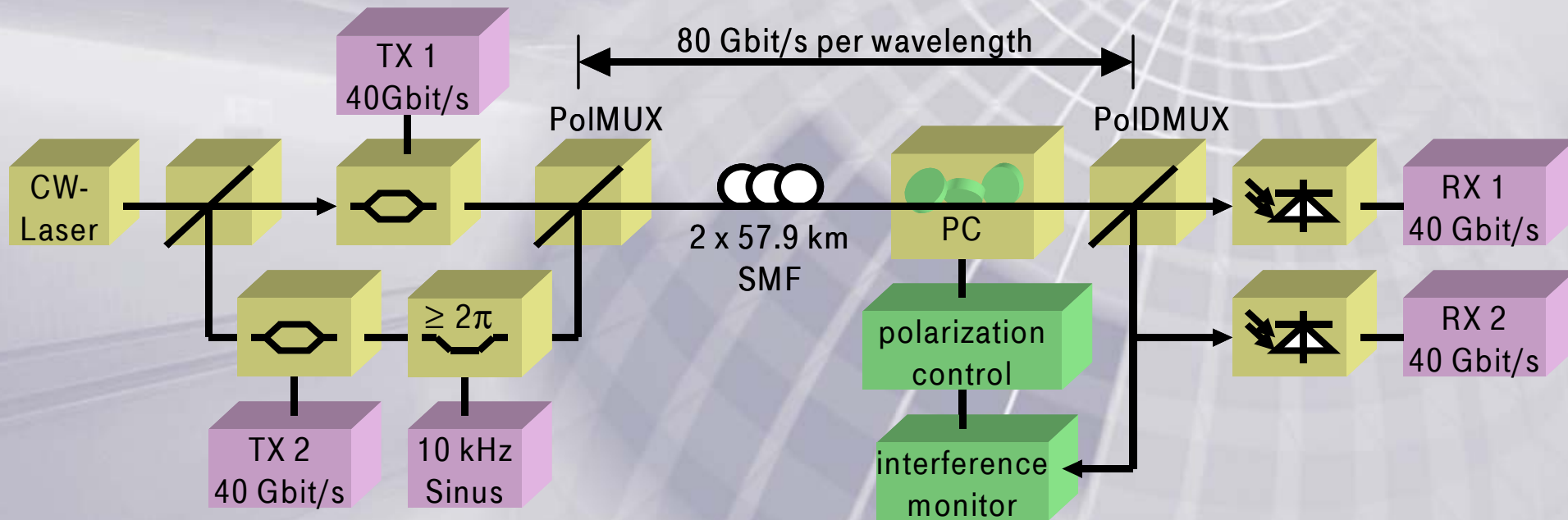
WDM multiplexer



Polarization Multiplexing

$16\lambda \times 2 \times 42.6$ Gbit/s over 116 km SMF (II)

- doubles capacity within the same wavelength band
- crosstalk due to PDL / PMD induced orthogonality distortions

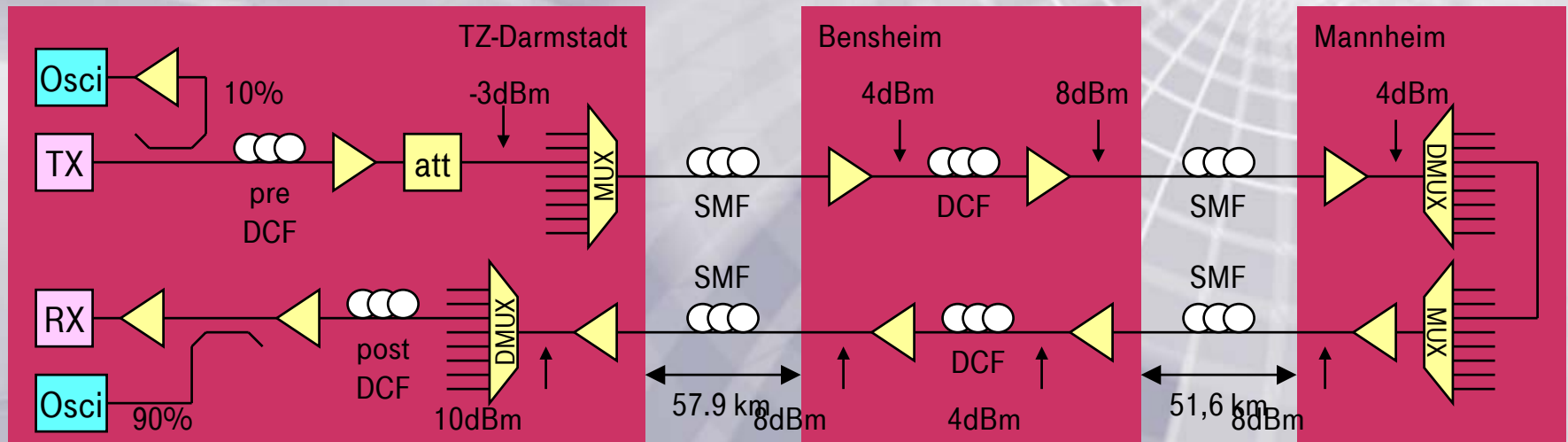


RZ / NRZ

219 km SMF Field Trial Set-up



comparison of NRZ and RZ (33 and 66% duty cycle)



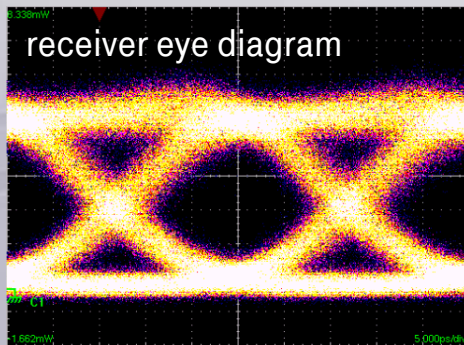
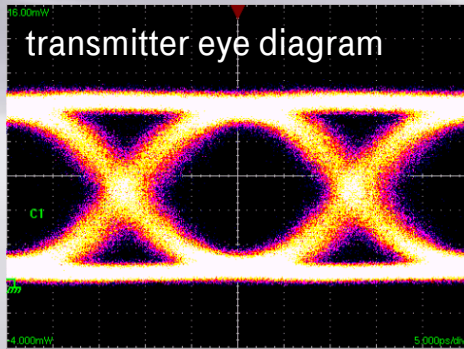
pre DCF: -120 ps/nm @ 1552 nm (-7,5 km SSMF)
post DCF: -167 ps/nm @ 1552 nm (-10 km SSMF) + TDC (300 ps/nm)
DCF in Bensheim: -90 km SSMF, 10 dB insertion loss
MUX-DMUX: spacing: 200 GHz, loss: 3 dB

RZ / NRZ

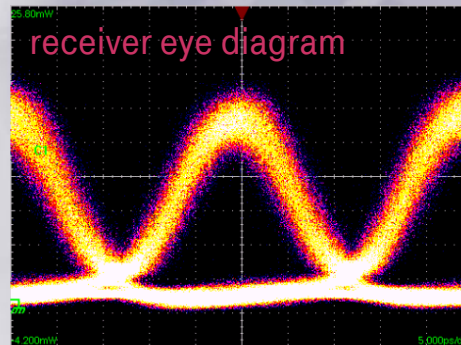
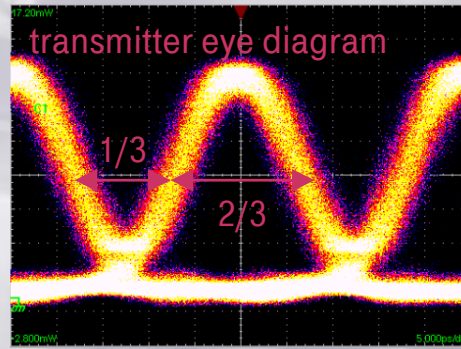
Eye Diagrams



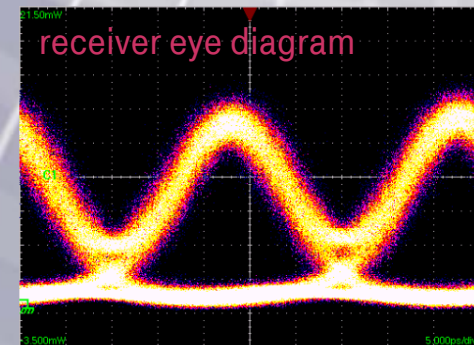
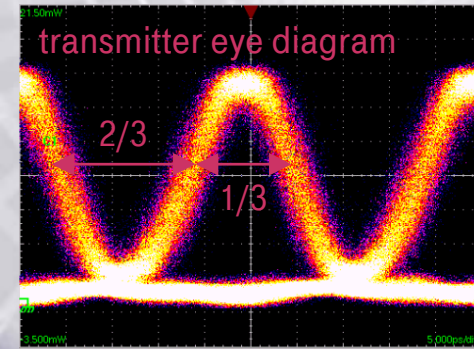
NRZ



RZ (66)

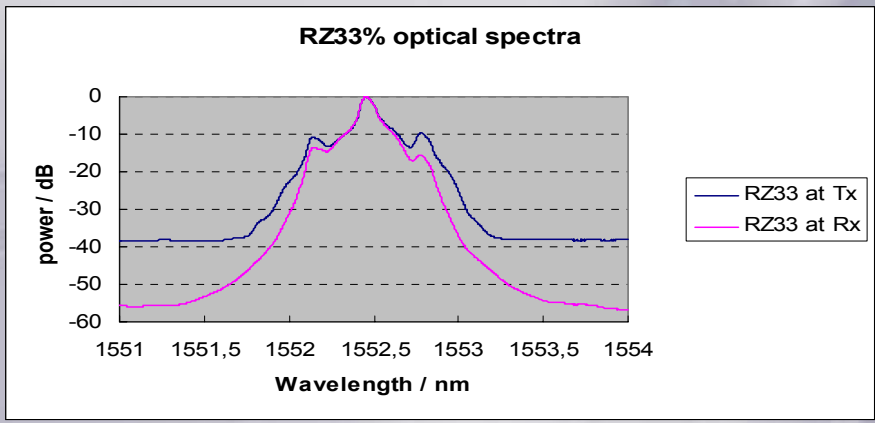
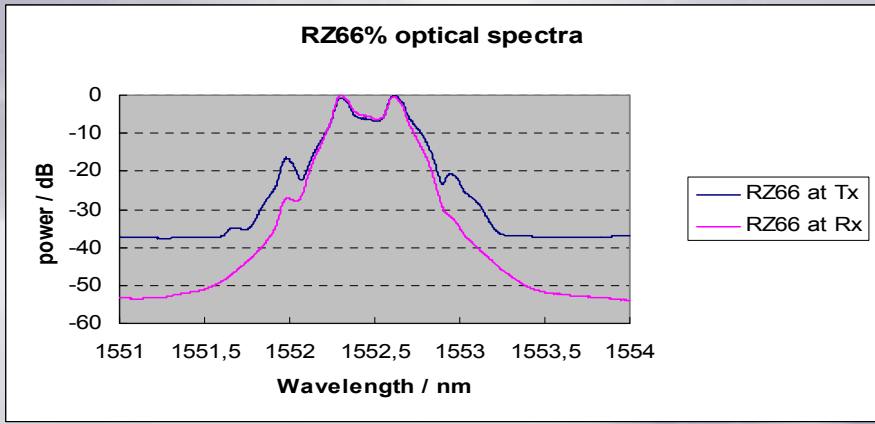


RZ (33)

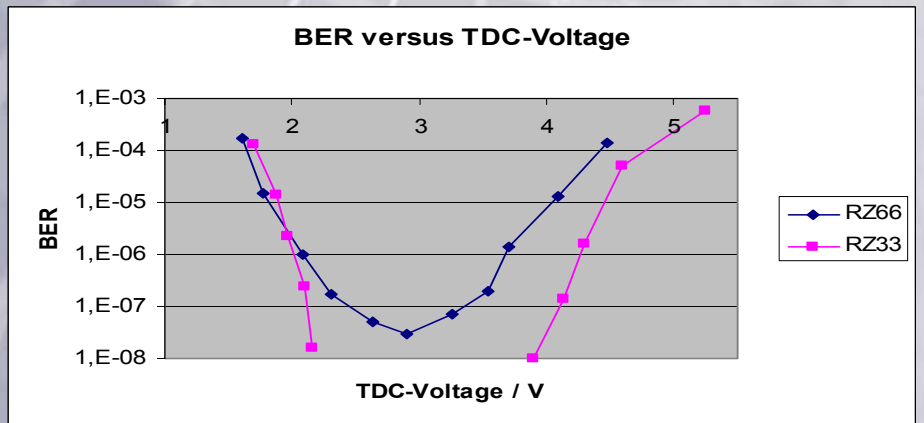


RZ / NRZ

Spectra (Rx / Tx) and BER for RZ (33 and 66)

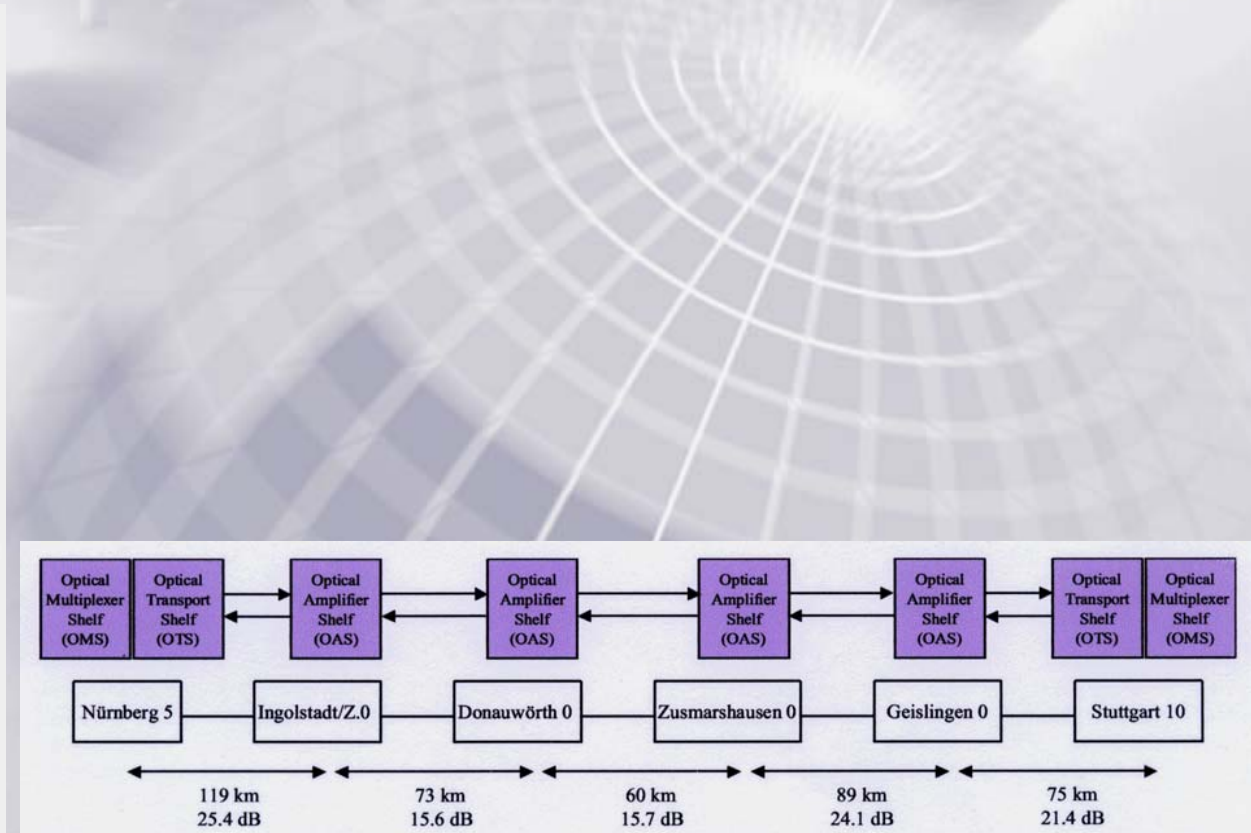
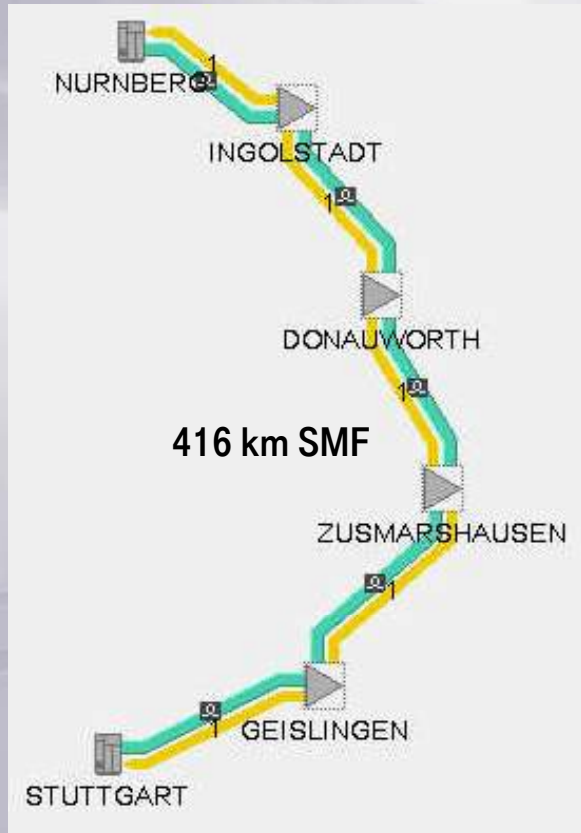


with reduced launch power (-10 dBm) and dispersion compensation mismatch (TDC: tunable dispersion compensator)



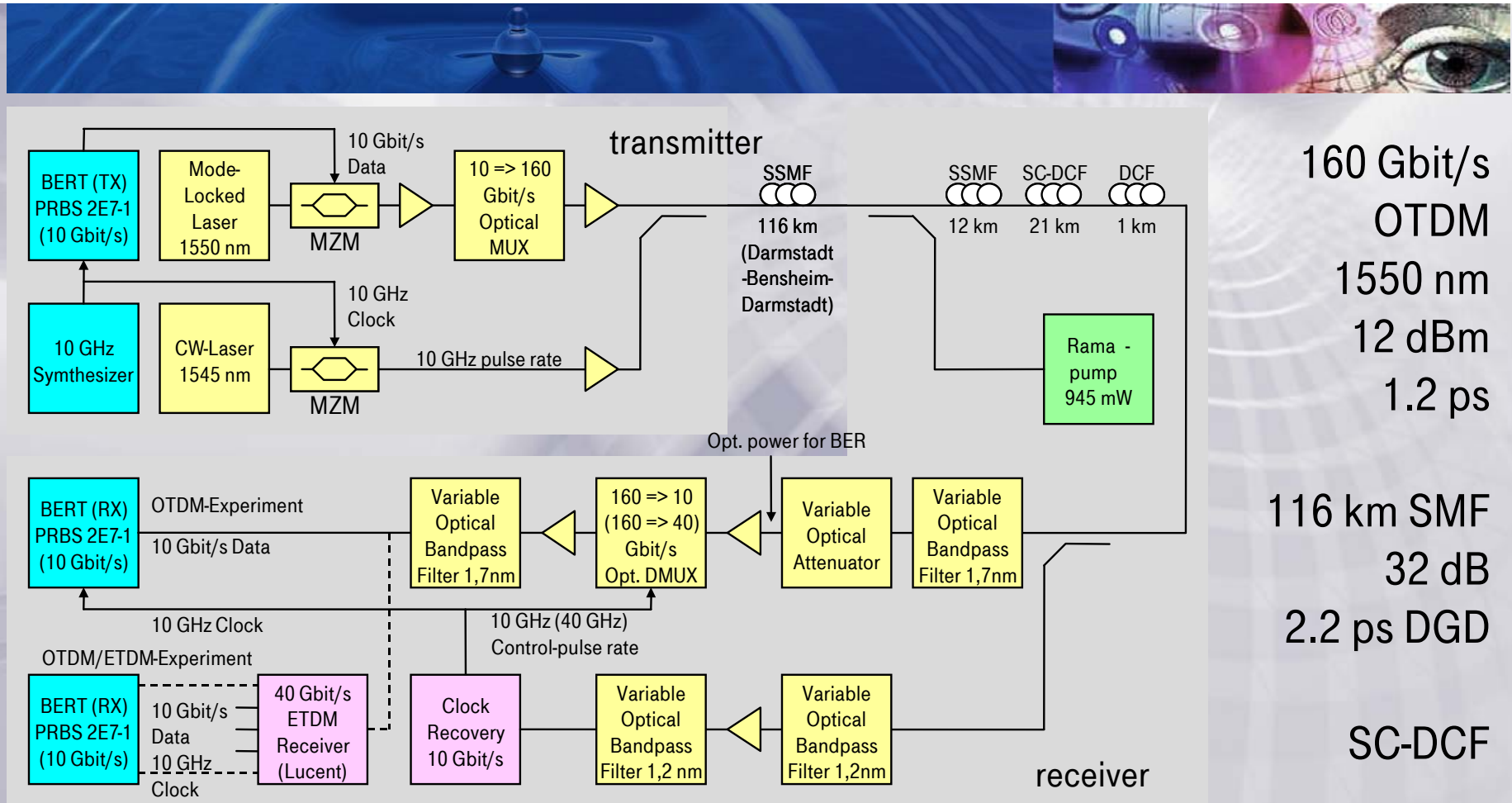
40 Gbit/s/ λ WDM Pilot Trial

Two Commercial Systems Tested



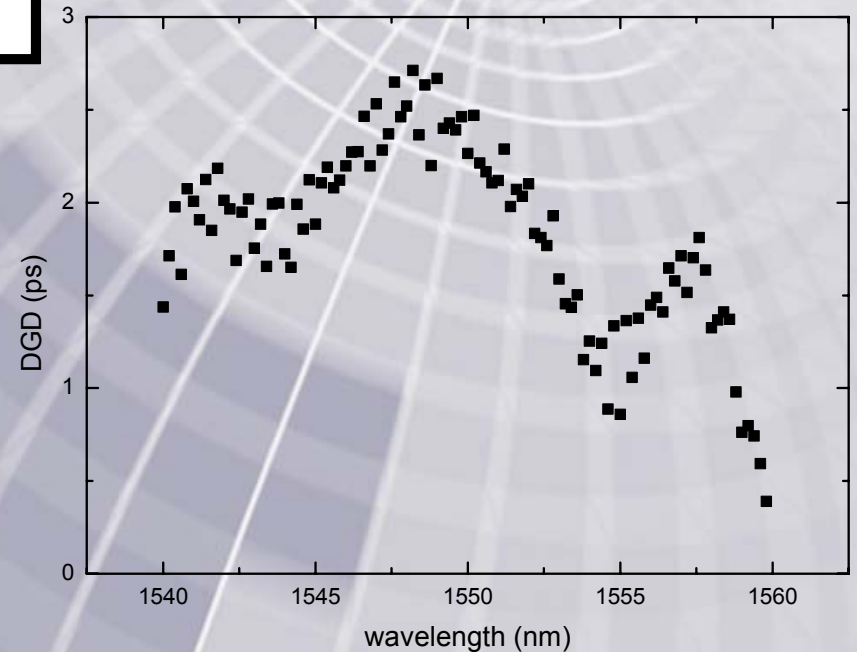
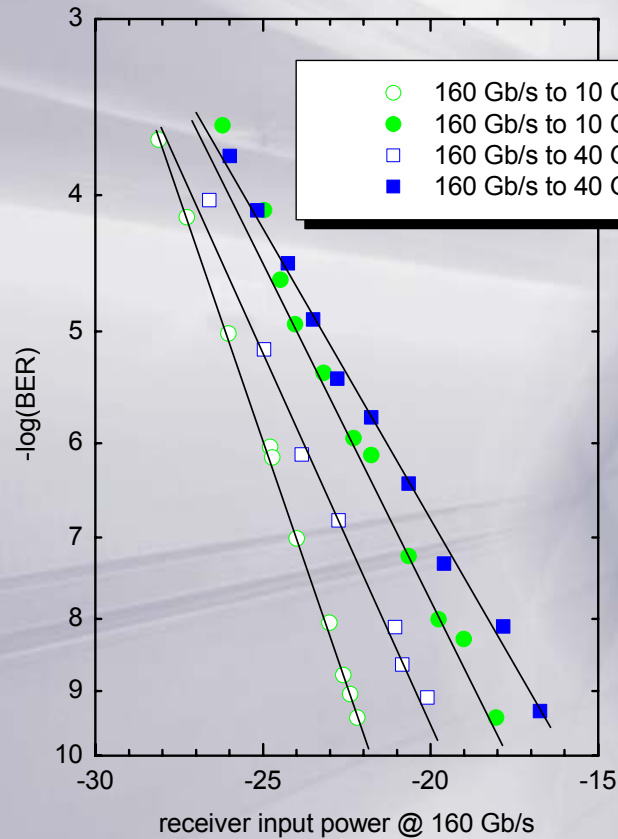
160 Gbit/s/ λ Field Experiment

Set-up (Unrepeated over 116 km SMF)



160 Gbit/s/ λ Field Experiment

BER and DGD



Pilot Trials / Field Experiments at 40/160G

Conclusion – What's next?



Contributions made

- **G.650**
- **G.652**
- **G.655**
- **G.664**
- **G.671**
- **G.691**
- **G.692**
- **G.959**
- **G.693**
- **G.cwdm**

Future Topics

- **Raman Amplification**
- **Signal Format (NRZ / RZ / CS-RZ / etc.)**
- **(O)TDM (mux / demux)**
- **Compensation Techniques**
 - Chromatic Dispersion
 - Polarization Mode Dispersion
 - adaptive
- **Polarization Multiplex**


ITU Workshop IP/Optical

Chitose, Japan, July 10, 2002



Thank You!

References

- 
- page3: **40 Gb/s Field Test on an Installed Fiber Link with High PMD and Investigation of Differential Group Delay Impact on the Transmission Performance**
W. Weiershausen, H. Schöll, F. Küppers, R. Leppla, B. Hein, H. Burkhard, E. Lach, G. Veith
OFC 1999, San Diego, California, USA, Technical Digest, ThI5, 125-127
- page8, 9: **40 Gb/s RZ unrepeated Transmission over 252 km SMF using Raman Amplification**
M. Gunkel, F. Küppers, J. Berger, U. Feiste, R. Ludwig, C. Schubert, C. Schmidt, H.G. Weber
OFC 2001, Anaheim, California, USA, Technical Digest, TuU3
Unrepeated 40 Gb/s RZ Transmission over 252 km SMF using Raman Amplification
M. Gunkel, F. Küppers, J. Berger, U. Feiste, R. Ludwig, C. Schubert, C. Schmidt, H.G. Weber
Electronics Letters, Vol. 37, No. 10, 646-648, May 10, 2001
- page10, 11: **Automated polarization control demonstrated in a 1,28 Tbit/s (16x2x40 Gbit/s) polarization multiplexed DWDM field trial**
N.E. Hecker, E. Gottwald, K. Kotten, C.J. Weiske, A. Schöpflin, P.M. Krummrich, C. Glingener
ECOC 2001, Amsterdam, MO.L.3.1
- page15, 16: **160Gbit/s transmission over 116km field-installed fibre using 160Gbit/s OTDM and 40Gbit/s ETDM**
U. Feiste, R. Ludwig, C. Schubert, J. Berger, C. Schmidt, H.G. Weber, B. Schmauss, A. Munk, B. Buchold, F. Küppers, F. Rumpf
Electronics Letters, Vol. 37, No. 7, 443-445
160 Gbit/s Transmission over 116 km Field-Installed Fiber Using 160 Gbit/s OTDM and 40 Gbit/s ETDM
U. Feiste, R. Ludwig, C. Schubert, J. Berger, C. Schmidt, H.G. Weber, B. Schmauss, A. Munk, B. Buchold, D. Briggmann, F. Küppers, F. Rumpf
OFC 2001, Anaheim, California, USA, Technical Digest, ThF3
- page4-14: Reasearch Program KOMNET under Contract by the German Ministry of Education and Research BMBF
Partners: Alcatel, Lucent Technologies, Siemens, T-Systems (among others), www.hhi.de/komnet/