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High Speed Transmission Experiments and Modeling

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Introduction

- Goals are to identify impairments limiting communication performance
- Where possible overcome limitations
- Use closely coupled Experiment and Theory

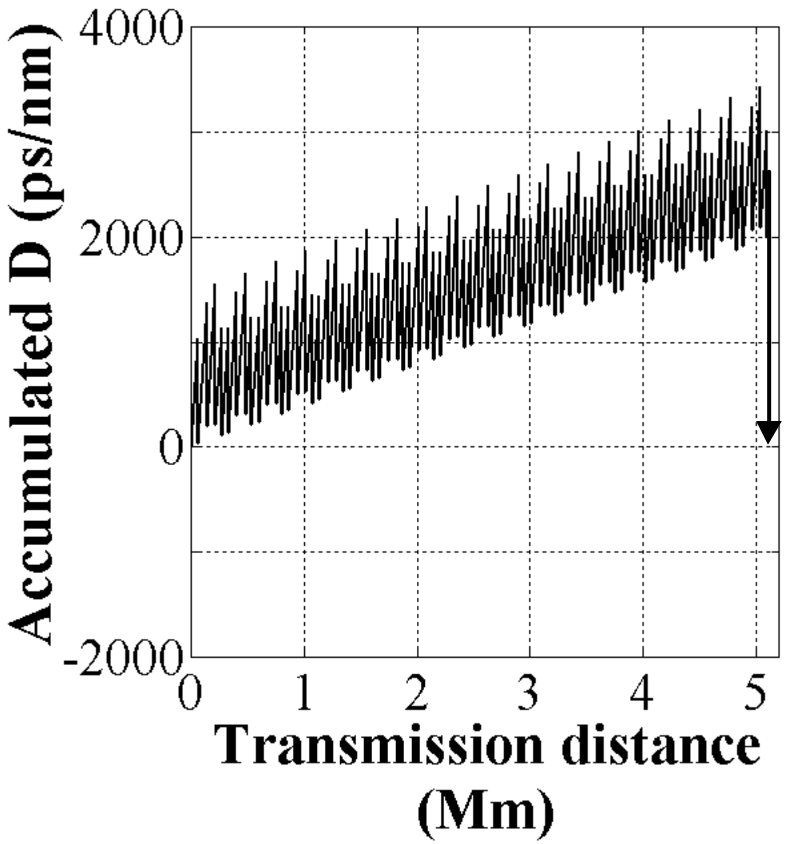
Areas of significant impact of research

- •Reduction of pulse jitter due to nonlinear and effects in the fiber
- •Accurate receiver models
- •Realistic laboratory experiments
- •Network experiments
- •Polarization Statistics

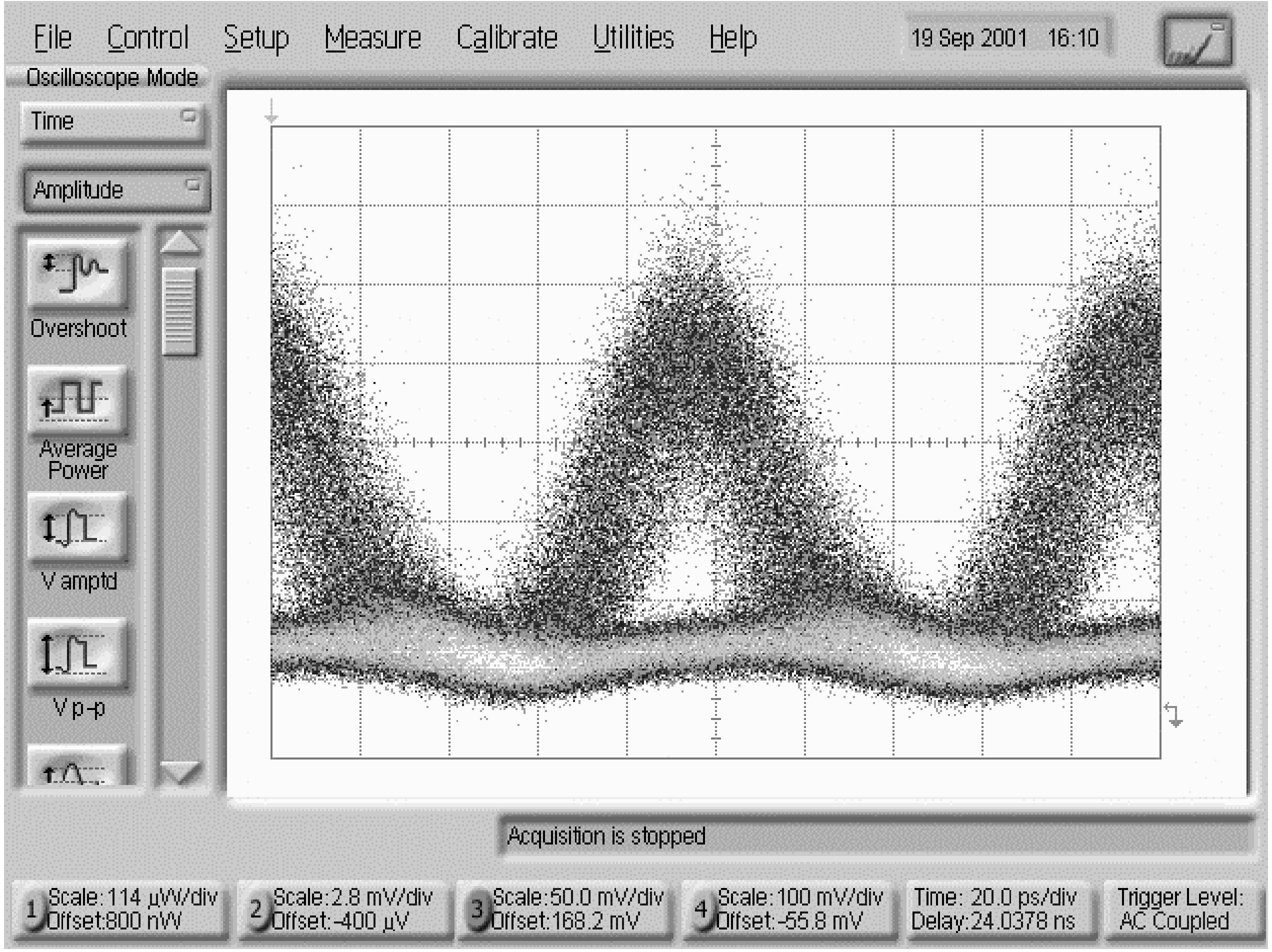
Dispersion and nonlinear penalty

- Pulse spreading due to fiber dispersion causes pulses to interact via nonlinear effects in the fiber
- Accumulated dispersion during transmission affects the size of the penalty
- Experimentally we show the optimum dispersion distribution

Dispersion compensation at the receiver—All post

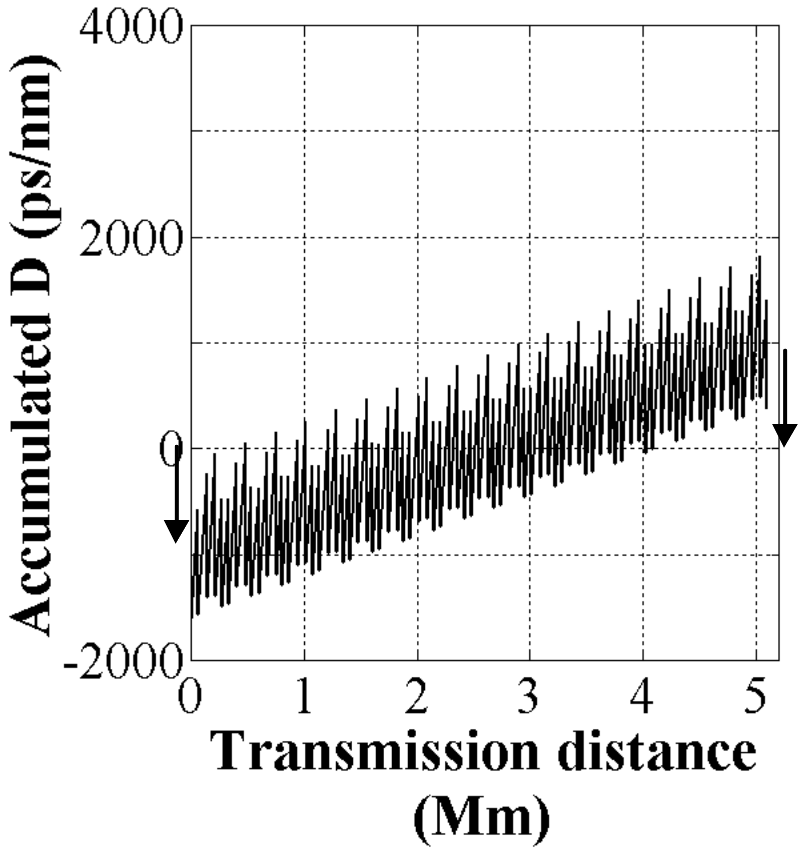


Nearly closed eye and large bit-error rate

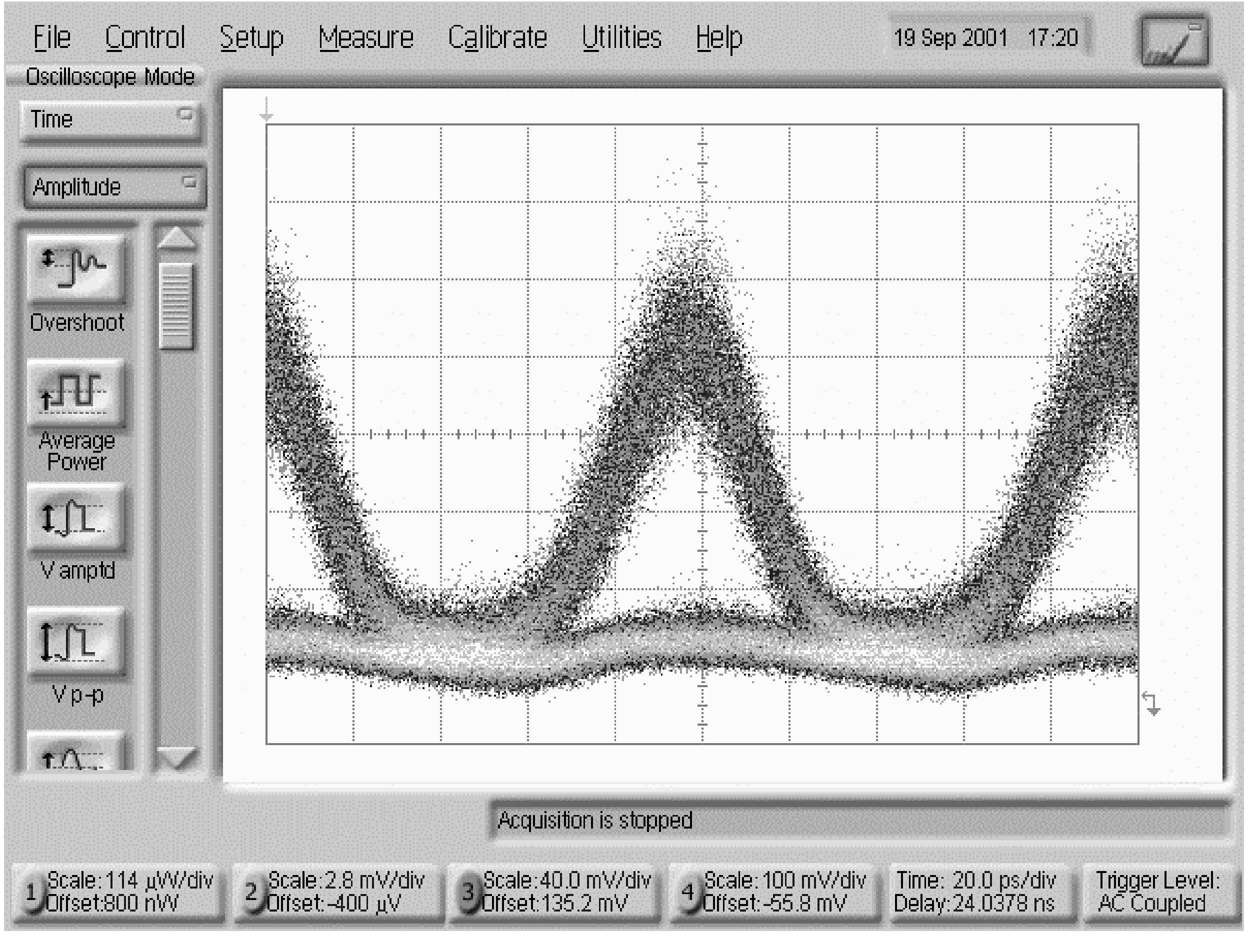


10 Gb/s

Compensation at the beginning and end

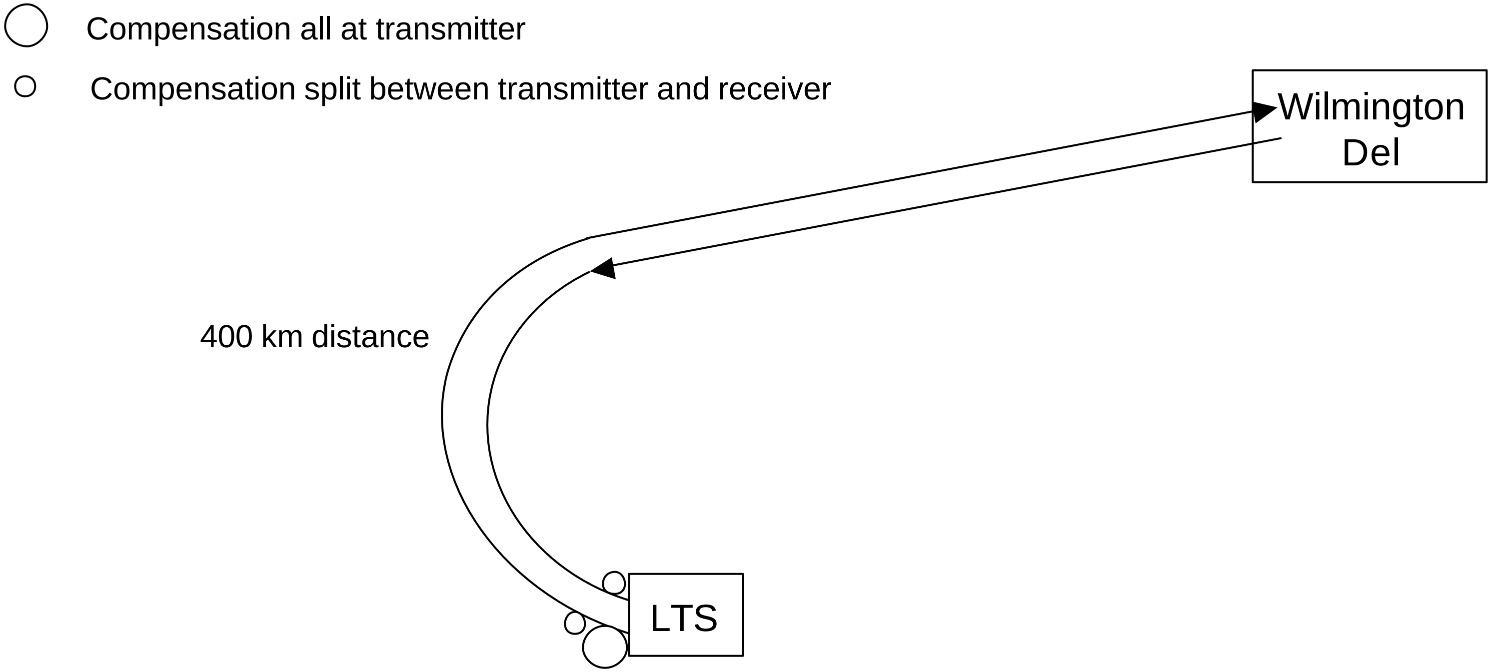


Open eye end low bit-error rate



10 Gb/s

Network demonstration of dispersion distribution



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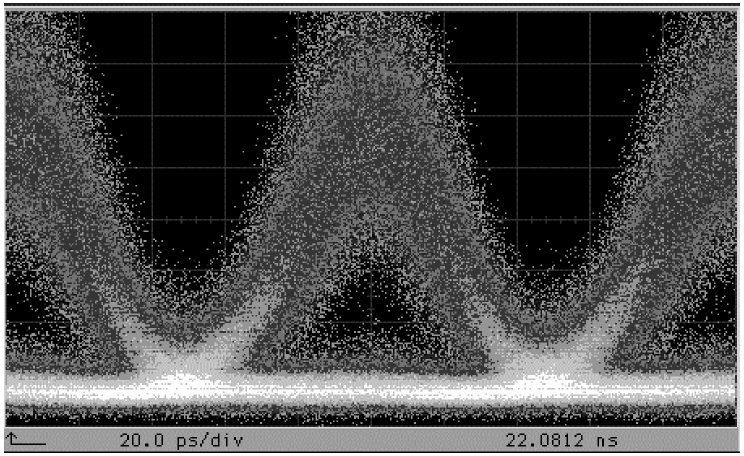
Effect of dispersion compensation-Preliminary

LTS – Wilmington

All at the transmitter

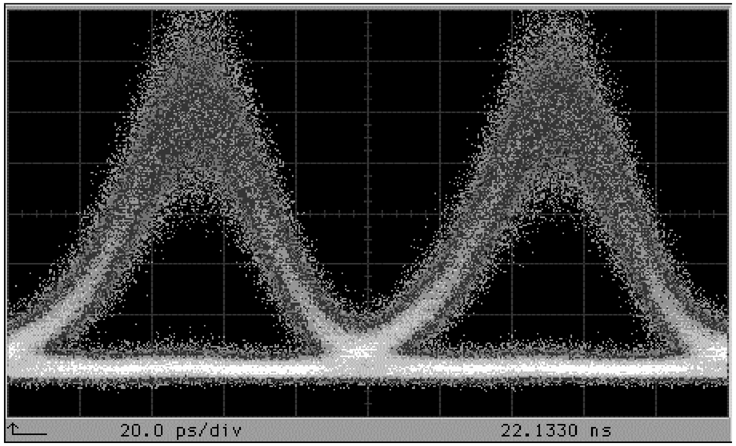


BER = 1×10^{-7}

10 Gb/s

LTS – Wilmington

Split between the transmitter and receiver



BER = 1×10^{-10}

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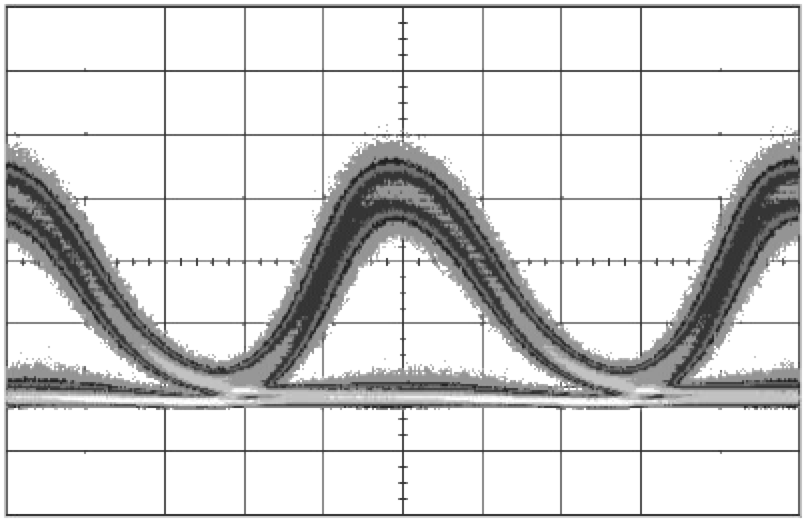
New BOSSNet Experiments

- 10 Gb/s RZ transmission over ATDNet and BOSSNet
- Loop-back occurs at Wilmington, DE, ~250 km one-way path length
- Investigating impact of dispersion compensation on the transmitted signal

BOSSNet Results

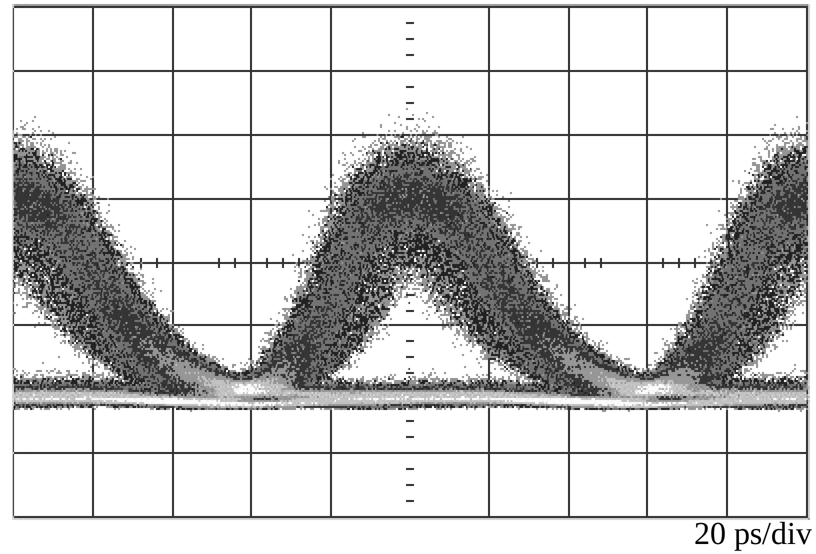
LTS to Wilmington, DE at 10 Gb/s:



Pre- and Post-Compensation

Timing Jitter: 2.54 ps

BER: ~10^{-11}



All Post-Compensation

Timing Jitter: 6.18 ps

BER: ~10^{-8}

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Implications for Optically Switched Networks

- In optically switched systems dispersion distribution may vary depending on the route
- Network management may need to be aware of the dispersion distribution and compensate for it even over short distances
- This was previously thought to be important only in very long haul systems
- Planning 40 Gb/s Network experiments

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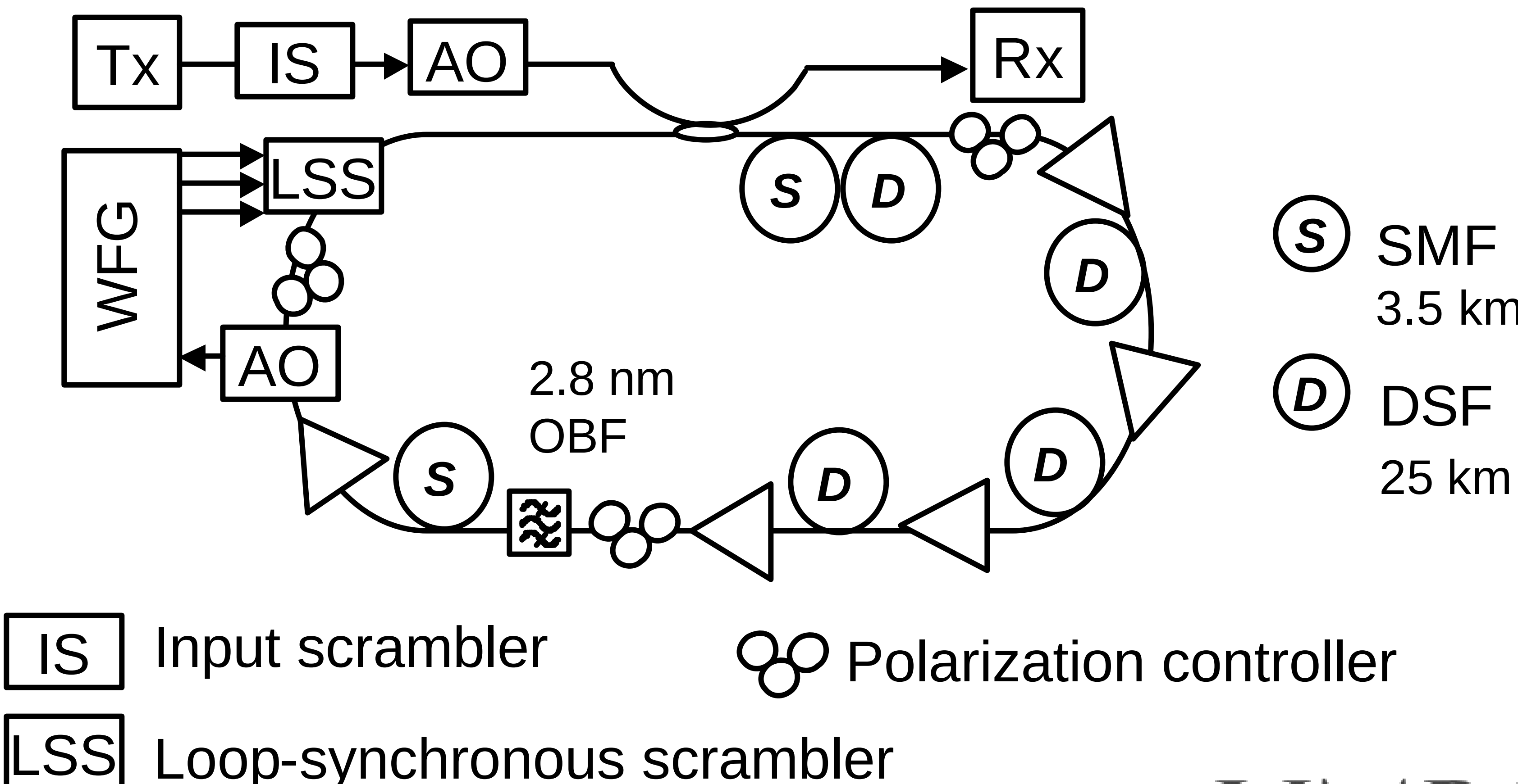
Laboratory Experiments and Receiver Model

- Recirculating loops are a cost effective way to study long distance transmission and prototype systems

- We have shown for the first time that most loop experiments are artificial due to periodic polarization effects

- Our method of correcting this is now becoming an industry standard

Experimental Lab setup

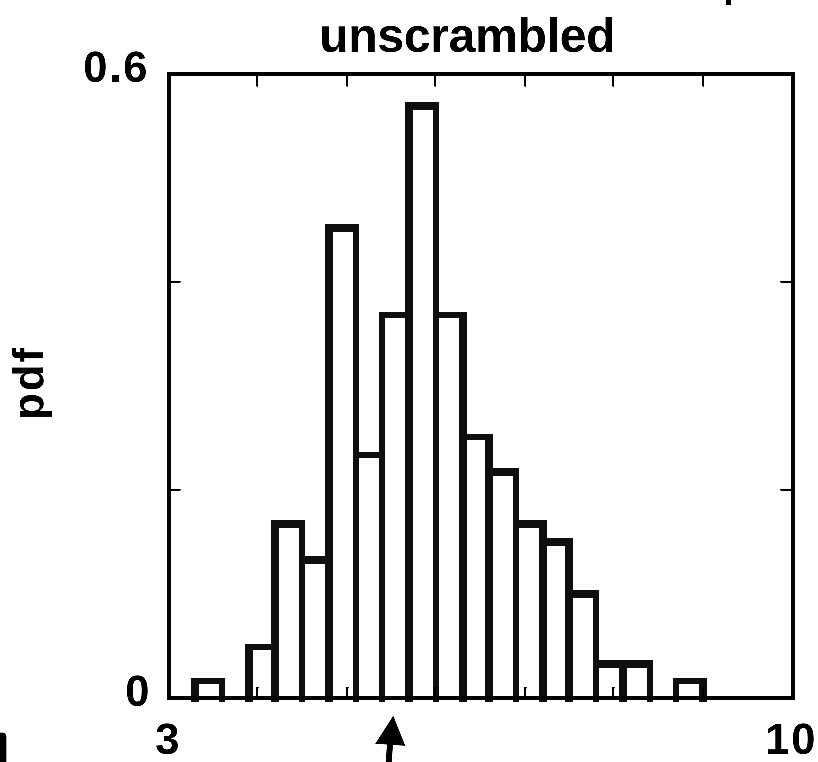


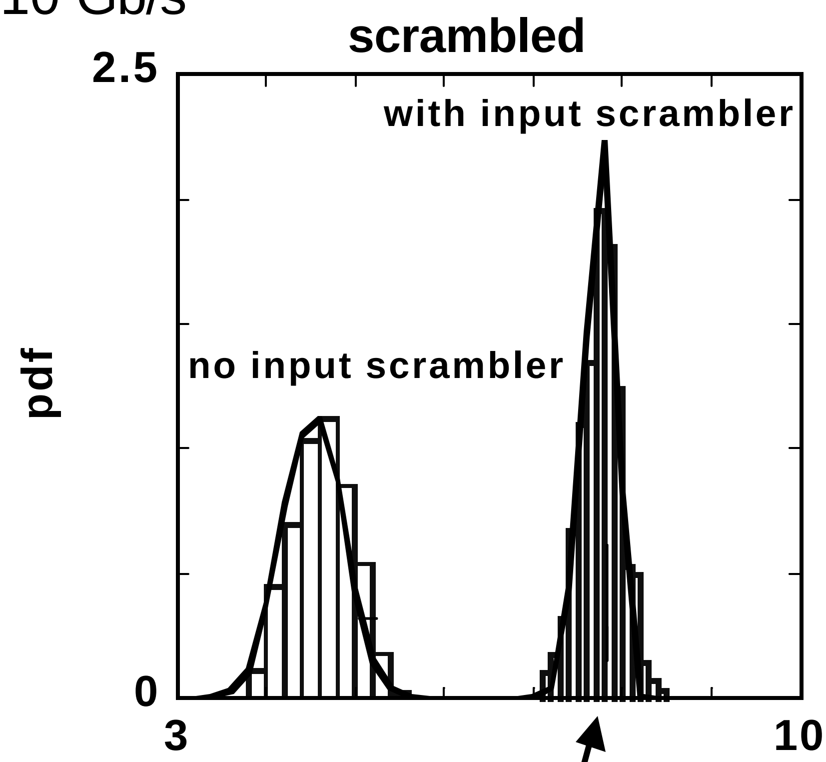
The *Q*-factor distribution @ 10,000 km

PDL = 0.2 dB/round trip

10 Gb/s

— simulation





experimental data

Unrealistic distribution due to periodicity

Realistic distribution that would be seen in installed systems

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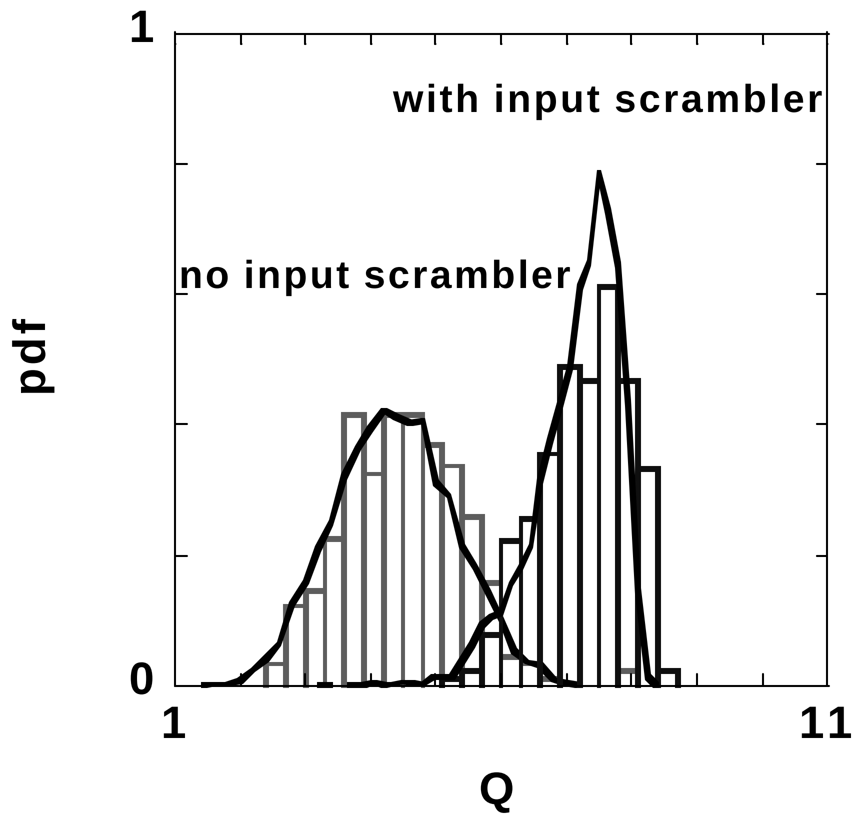
The *Q*-factor distribution @ 10,000 km

PDL = 0.6 dB/round trip

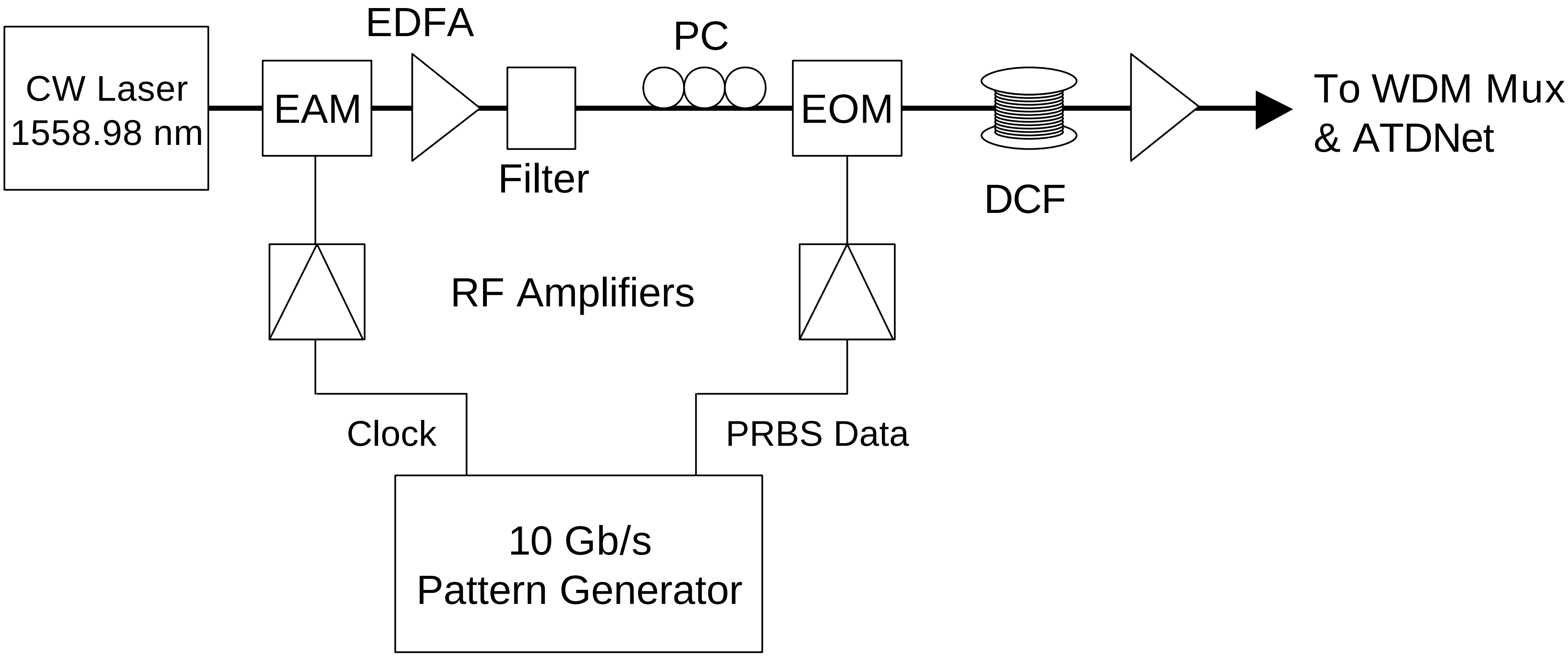


Simulation using accurate receiver model matches experimental data

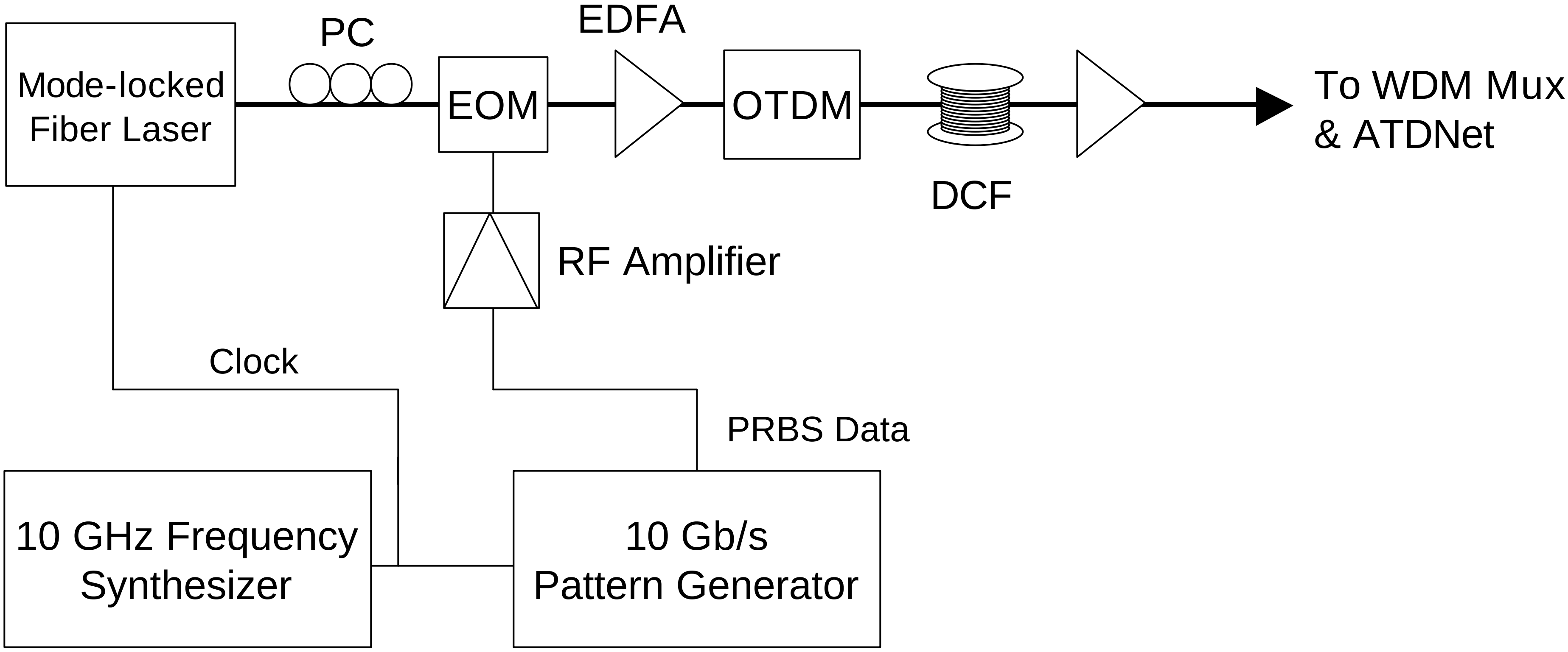
Network Experiments

- High speed components enable up to 40 Gb/s experiments
- Detailed measurements on the new ATDNET fiber ensure high data rate transmission
- Data will help in the design of future all-optical high speed networks

10 Gb/s RZ Transmitter Design at LTS



40 Gb/s RZ Transmitter



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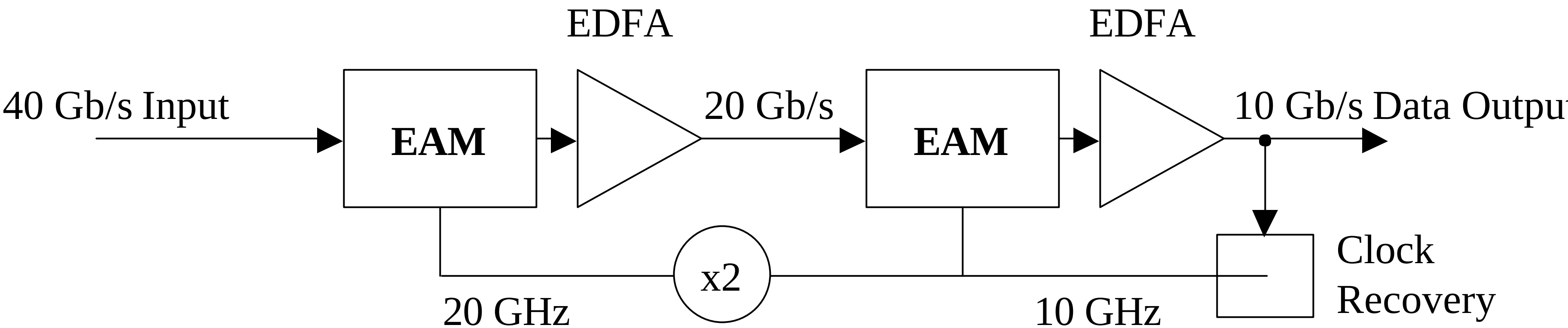
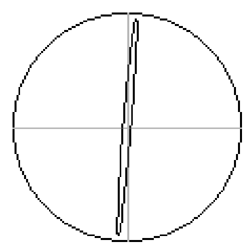
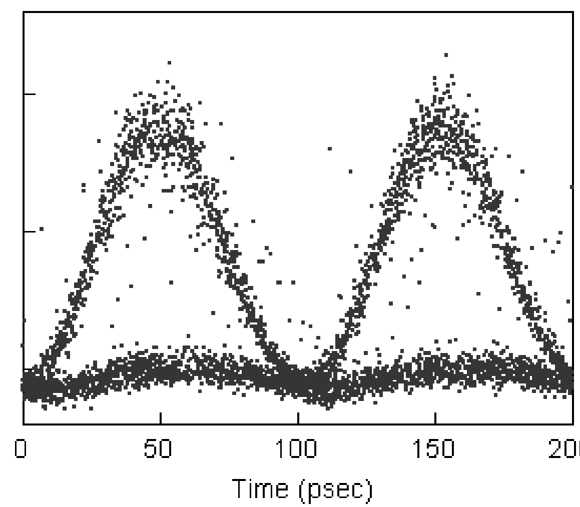
40 Gb/s polarization independent receiver



Demuxed Eye Diagrams at 4000 km

BER < 10^{-8}



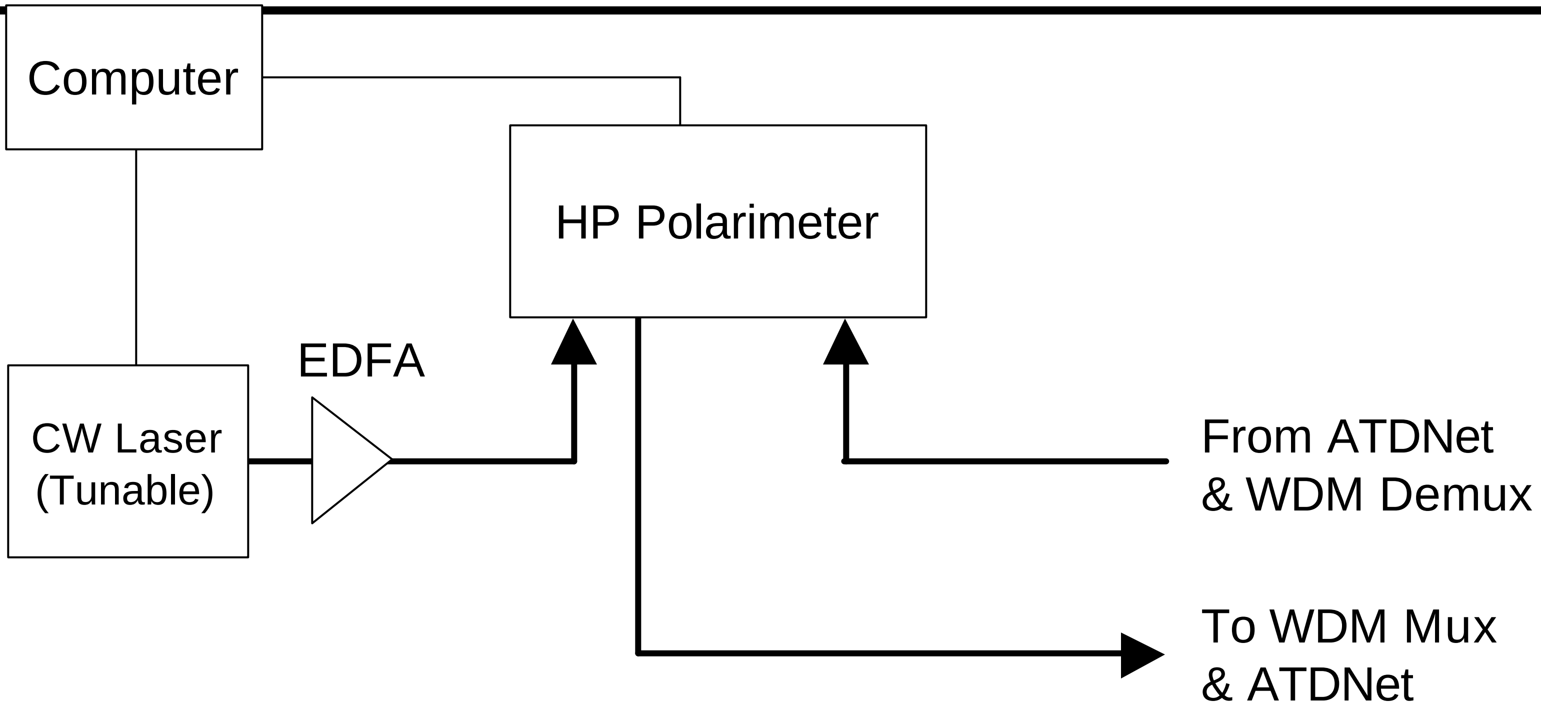


No added jitter and works in Network environment

Polarization Mode Dispersion (PMD)

- PMD in the old ATDNET fibers prevented 40 Gb/s transmission
- New fibers will permit 40 Gb/s transmission
- There will be some PMD and polarization dependent loss (PDL) penalty for longer sections, especially coupling to BossNet
- Statistics are not simple

Polarization Measurement



-Polarimeter includes automated polarization controller
-Jones Matrices measured as a function of wavelength and time

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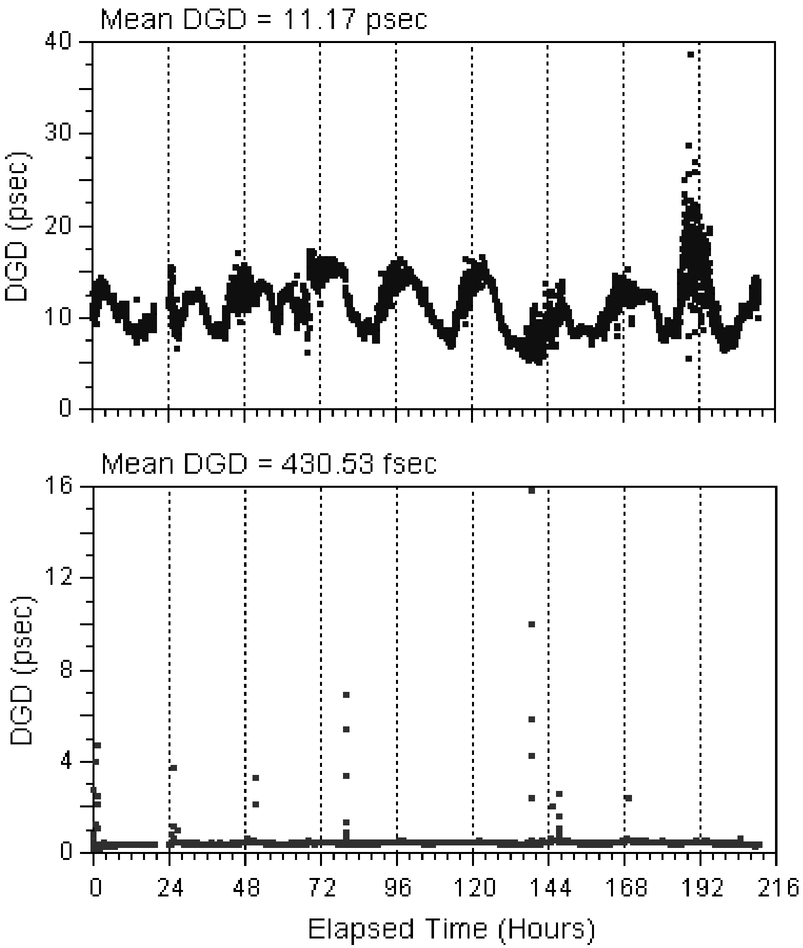
Low DGD in New fiber

- Simultaneous comparison of the DGD in the old and new fiber links to DARPA/ISI

- Lower DGD → 40 Gb/s now possible



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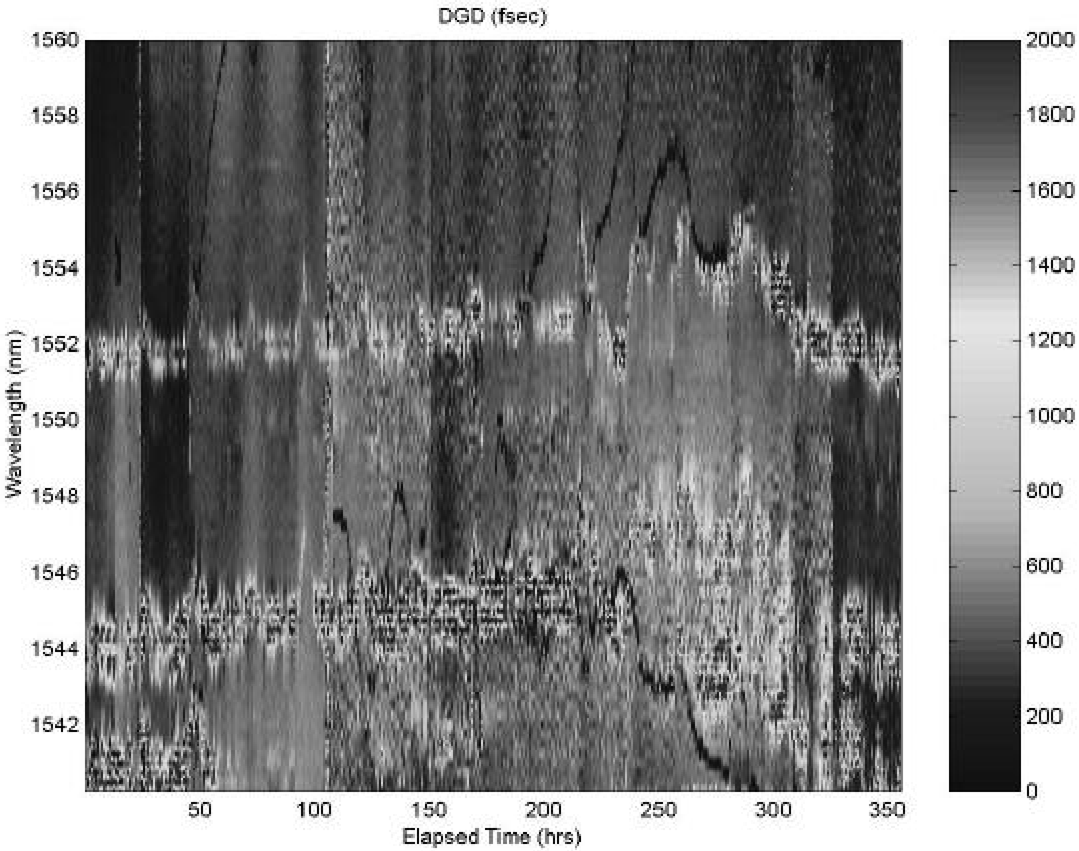
DGD of TrueWave-RS Link to DARPA/ISI measured over 300 hrs in Oct 2002: Wide Spectral Sweep



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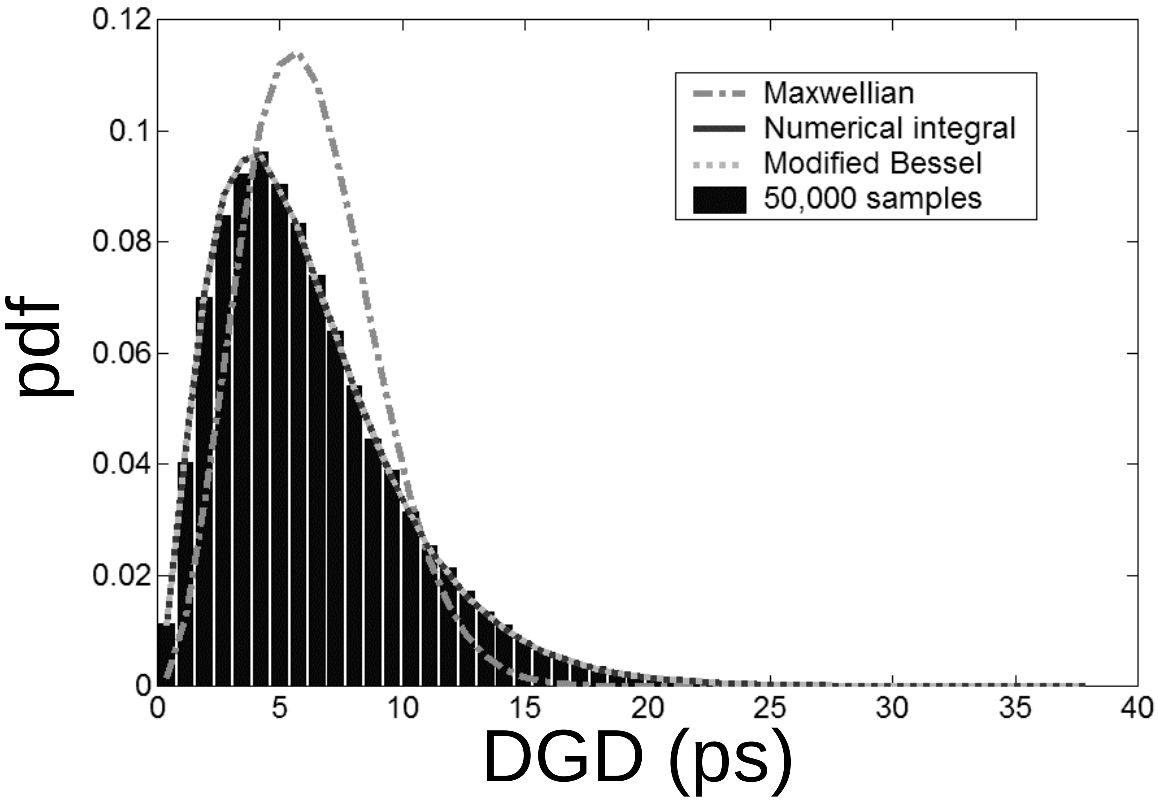
Laboratory Experiments for DGD

- We have recently conducted laboratory experiments which challenge the accepted notion of the statistical distribution in optical networks
- Simulations show that the variation of fiber orientation causes non-Maxwellian statistics
- Most outage probability caculations are based on the Maxwellian statistics

Non-Maxwellian DGD distributions



The pdf of DGD in a recirculating loop with slow drift is NOT Maxwellian

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Non-Maxwellian DGD distributions

- If long sections of a link do not drift quickly, but the connections between them do, it is easy to obtain non-Maxwellian statistics for the DGD
- This is observed in models of a recirculating loop with loop-synchronous scrambling
- Such a model plausibly explains non-Maxwellian statistics observed in ATDNet and BossNet

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Conclusions

Dispersion distribution rules developed for terrestrial systems with network demonstration of the importance of these rules even at relatively short distances. This has future implications for network design and management.

Realistic laboratory long distance experiments now possible with innovative scrambling techniques. Technique is being adopted by major industrial laboratories. Receiver models show the importance of including polarized noise to obtain accurate results.

Determined that new fiber in ATDNET is capable of transmitting 40 Gb/s without PMD impairment. Experimental techniques for transmitting and receiving 40 Gb/s on ATDNET have been developed. The non-Maxwellian statistics will require new models for prediction of outage probabilities in optical networks.

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Future Directions

- Interrelated phase shift keying experiments, theoretical modeling, and coding (Professors Carter, Morris, Menyuk)
- Combine polarization multiplexing with QPSK to achieve 4 symbols per bit slot
- Develop Dispersion monitoring and dynamic compenstation devices for this work (Professor Chen)