High Speed Optical Networks--Experiments

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Collaborators

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Goals—Past year(s)

- Carry out experiments on installed optical communication systems

- To identify and investigate issues of interest in helping establish high speed operation of optical networks

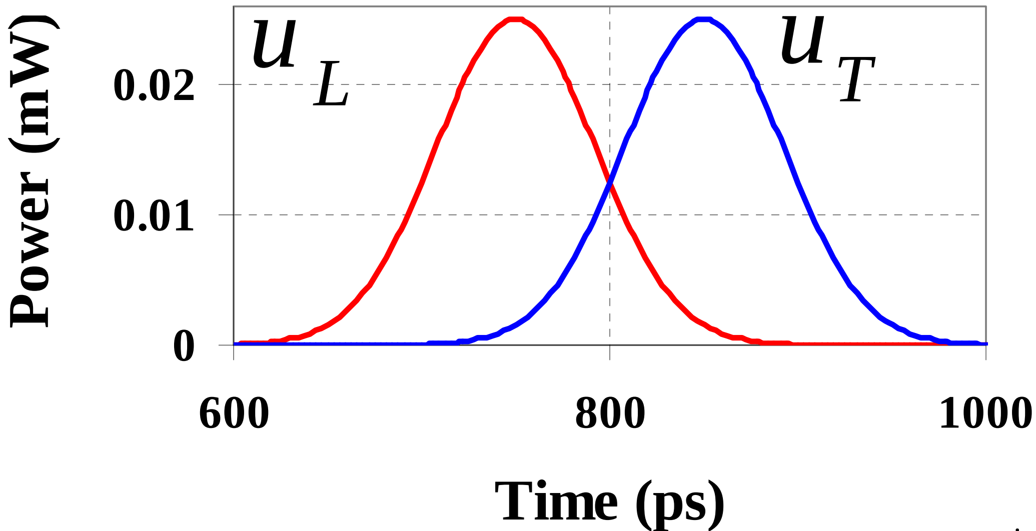
This year's effort

- We have shown in laboratory experiments that dispersion distribution is important for communications performance
- We moved these experiments from the lab to ATDNET/BossNet
- Implications for network management
- Investigated novel formats that can increase performance and relax constraints

Nonlinear Interaction

- Dispersion causes adjacent pulses to spread in time and overlap for part of the transmission distance
- The nonlinear interaction due to the optical fiber between adjacent pulses leads to timing jitter
- The dispersion distribution can alter the amount of timing jitter
- Large amounts of timing jitter causes errors

Nonlinear Interaction—Frequency Shift



FWHM = 100 ps

$$u = u_L + u_T$$

$$\frac{\mathrm{d} f_L}{\mathrm{d} z} = -\gamma \frac{\mathrm{d} |u_T|^2}{\mathrm{d} t}$$

Intensity variation of u_T shifts frequency of u_L

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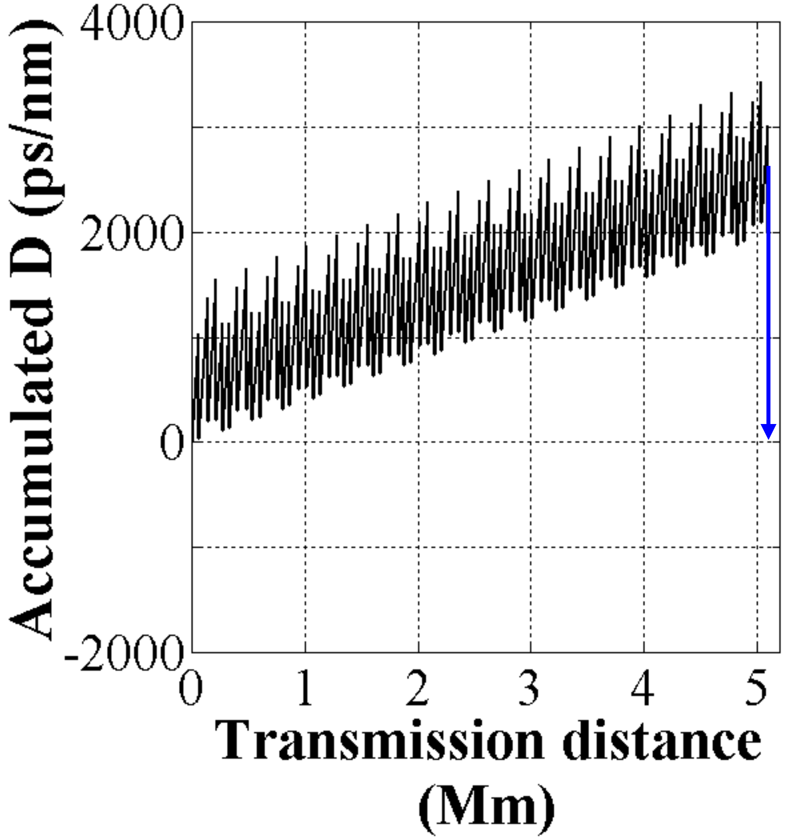
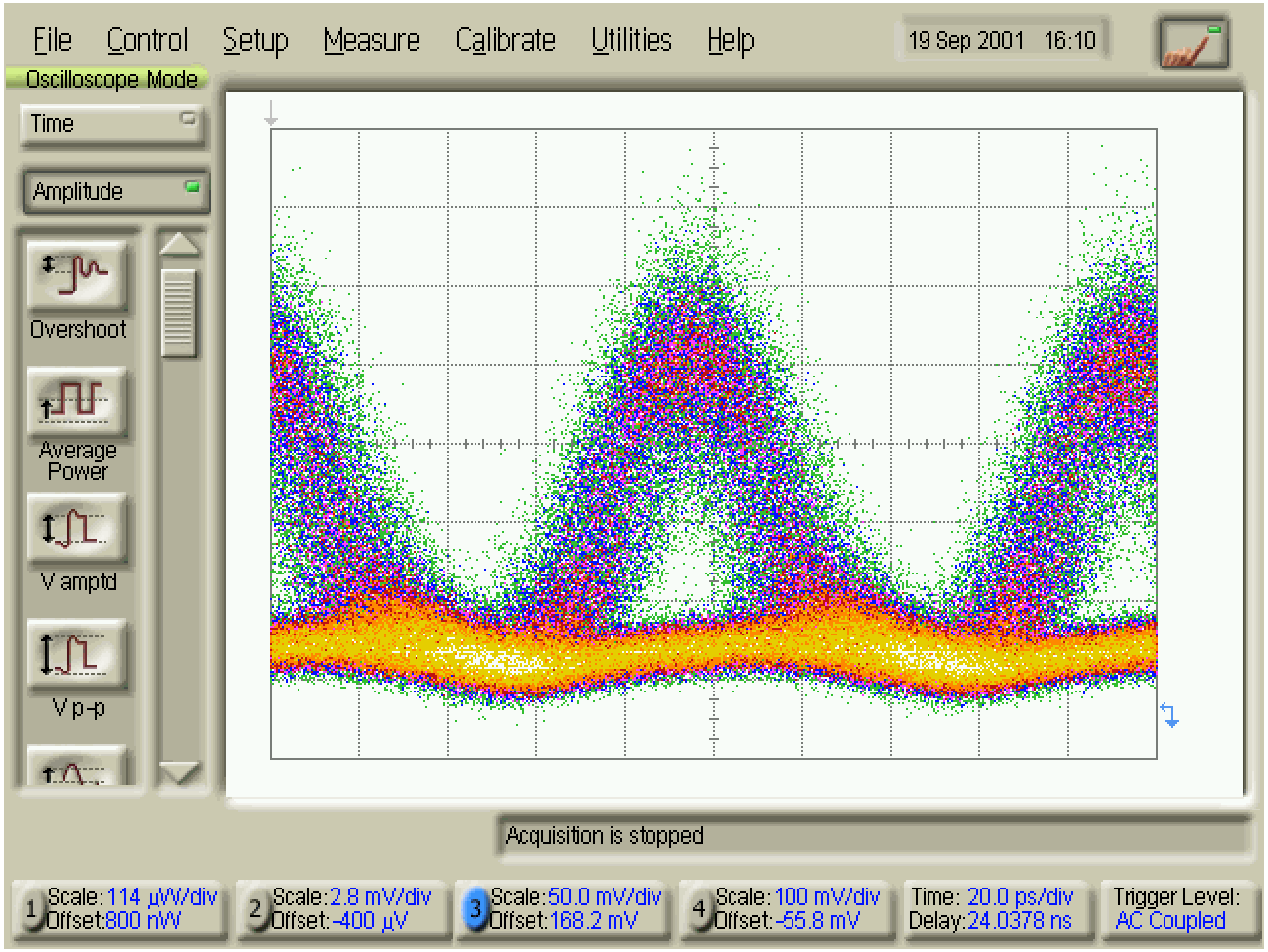
Residual compensation all at the end



Nearly closed eye and large error rate due to timing jitter



10 Gb/s

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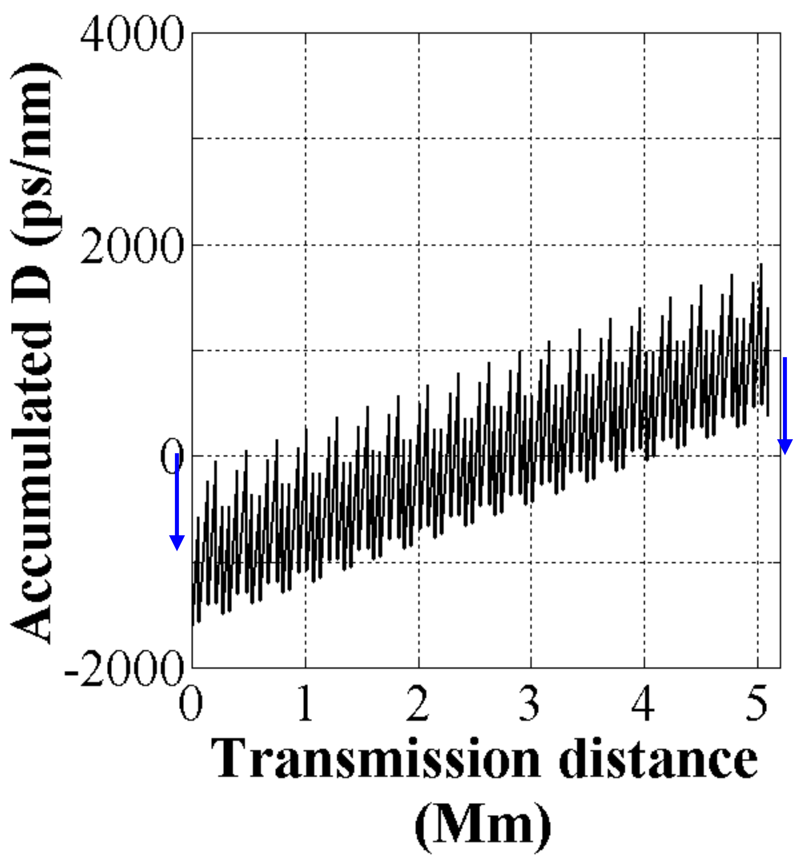
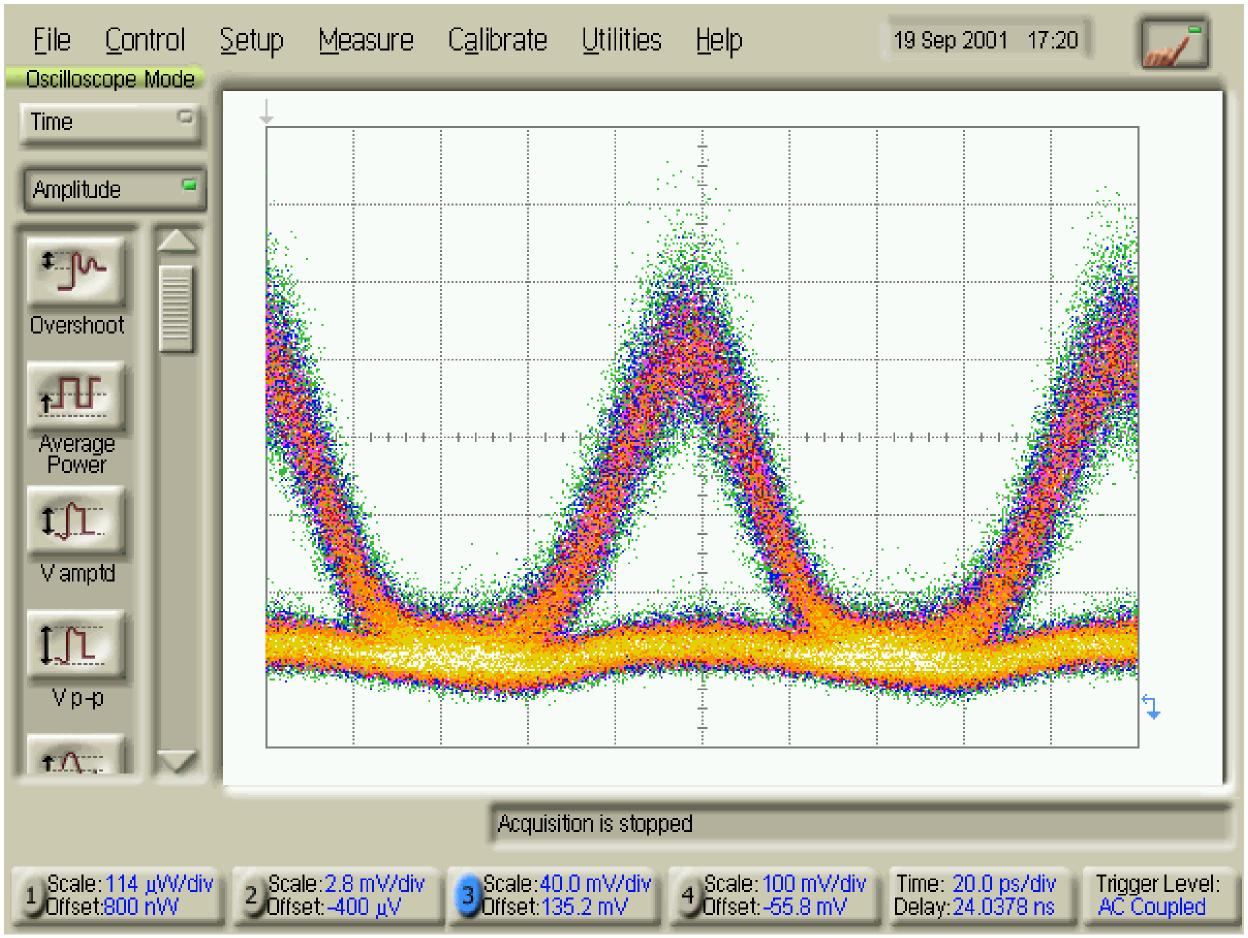
Split compensation between beginning and end



Open eye end low bit-error rate



10 Gb/s

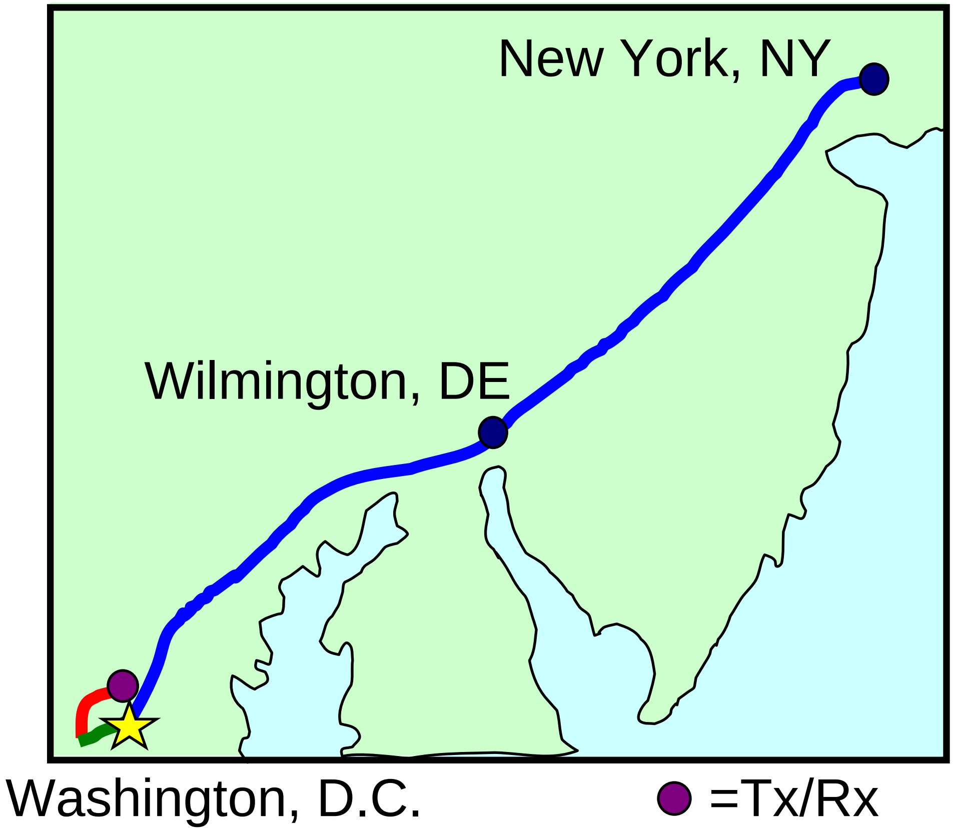
Laboratory Results

- Intra-channel cross-phase modulation $\longrightarrow$ timing jitter
- Dependent on dispersion map configuration
  - Most work to date on undersea transmission systems
  - Mitigated by symmetric pre- and post-compensation
- Laboratory investigation of terrestrial system
  - Xu, *et al*., IEEE Phot. Tech. Lett. **16**, 314 (2004)

Experiments on ATDNET/BossNet

- Measure timing jitter at 10 Gb/s on an installed terrestrial fiber path
- Obtain excellent qualitative agreement between measured values and numerical simulations
- Arrangement of dispersion compensation important for obtaining best transmission

Installed fiber path



One way distances:

Segment 1 (ATDNet):

- TrueWave RS (+4.5 ps/nm-km), 41 km
- Uncompensated

Segment 2

- AllWave (+17 ps/nm-km), 16 km
- Uncompensated

Segment 3 (BOSSNet):

- TrueWave Classic (+2.8 ps/nm-km)
  - To Wilmington: 186 km
  - To New York City: 389 km
- Compensated at 1550 nm
- Uneven EDFA spacing

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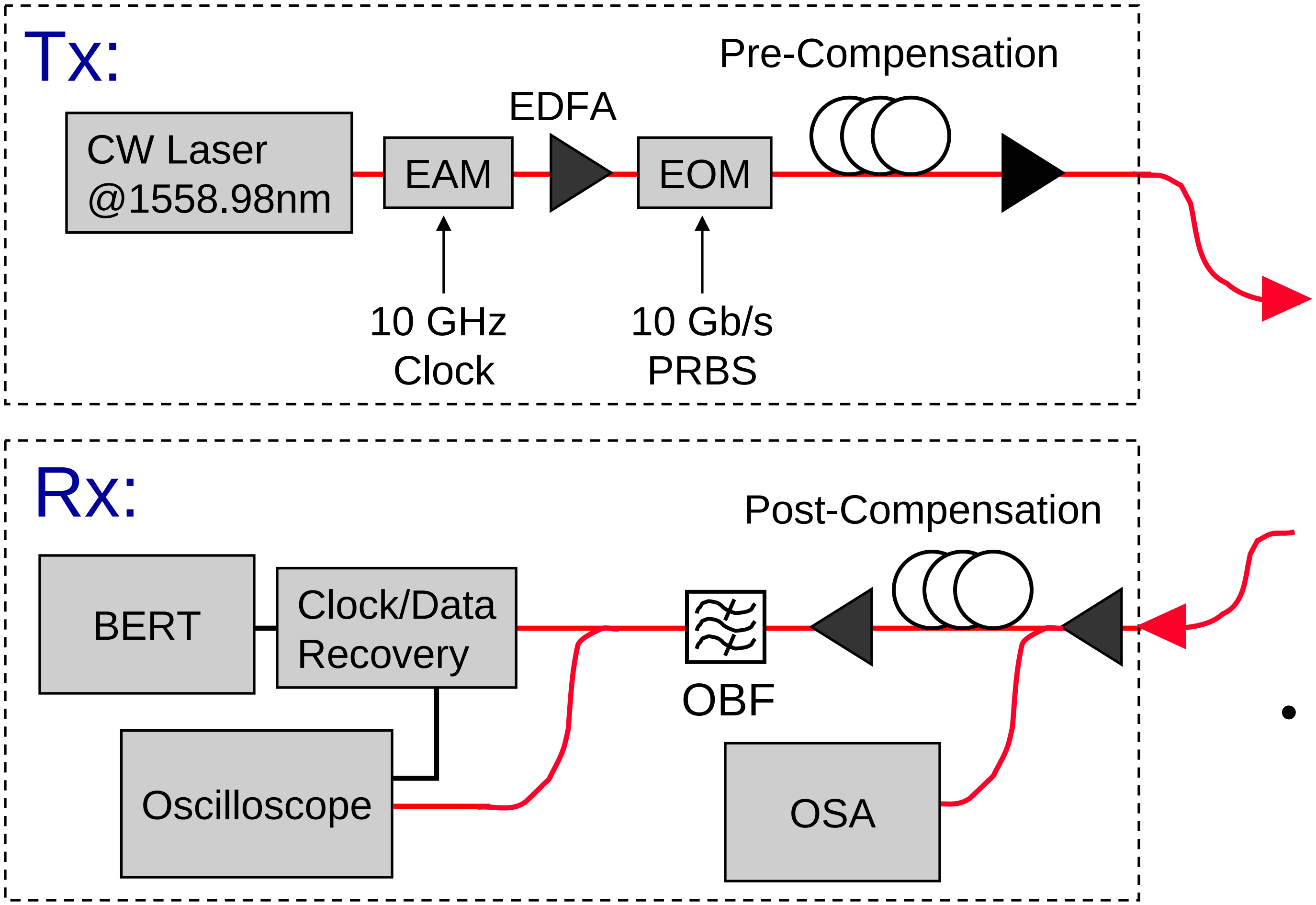
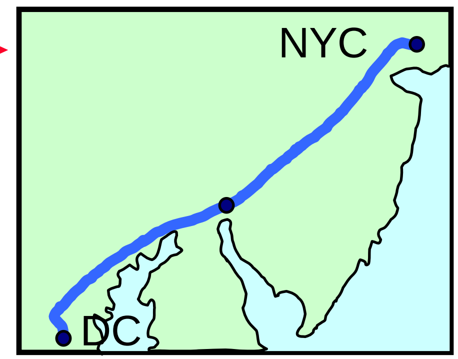
Experimental setup

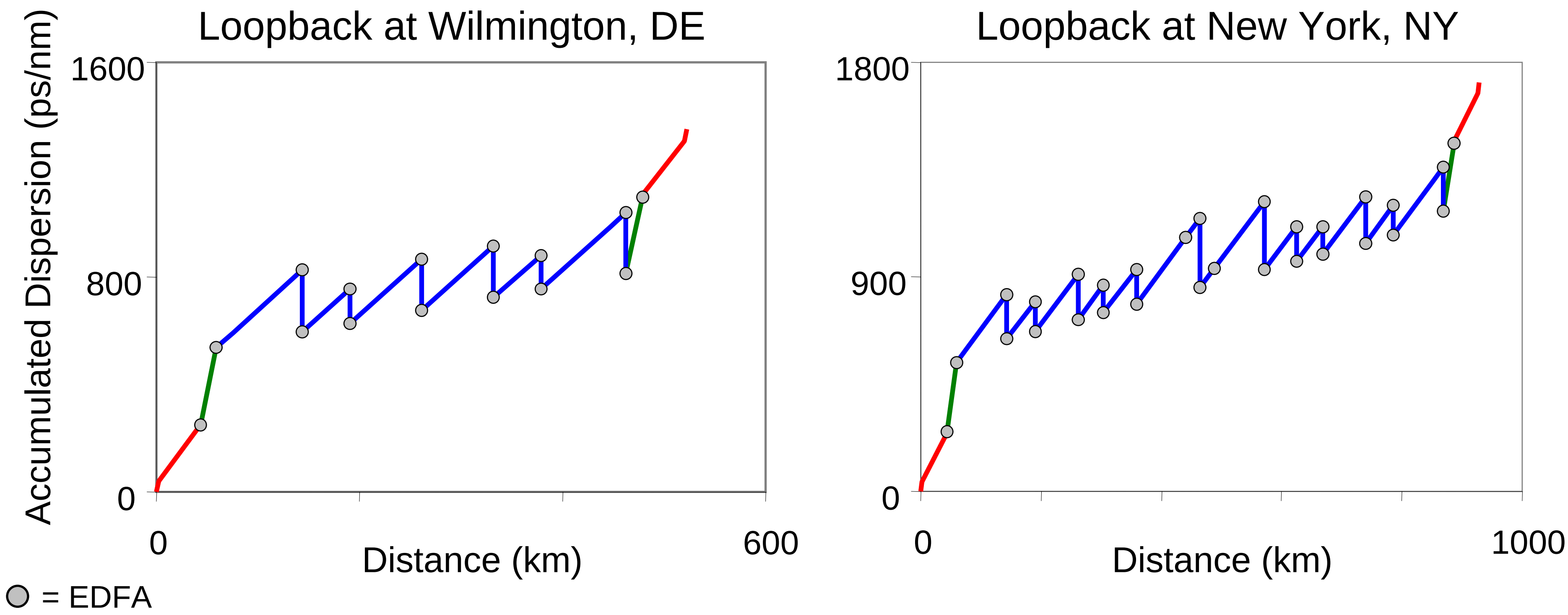


Installed network



- Tx/Rx co-located in D.C.

Dispersion maps



- Not including pre- and post-compensation
- Total accumulated dispersion for round trip at 1558.98 nm

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Numerical model

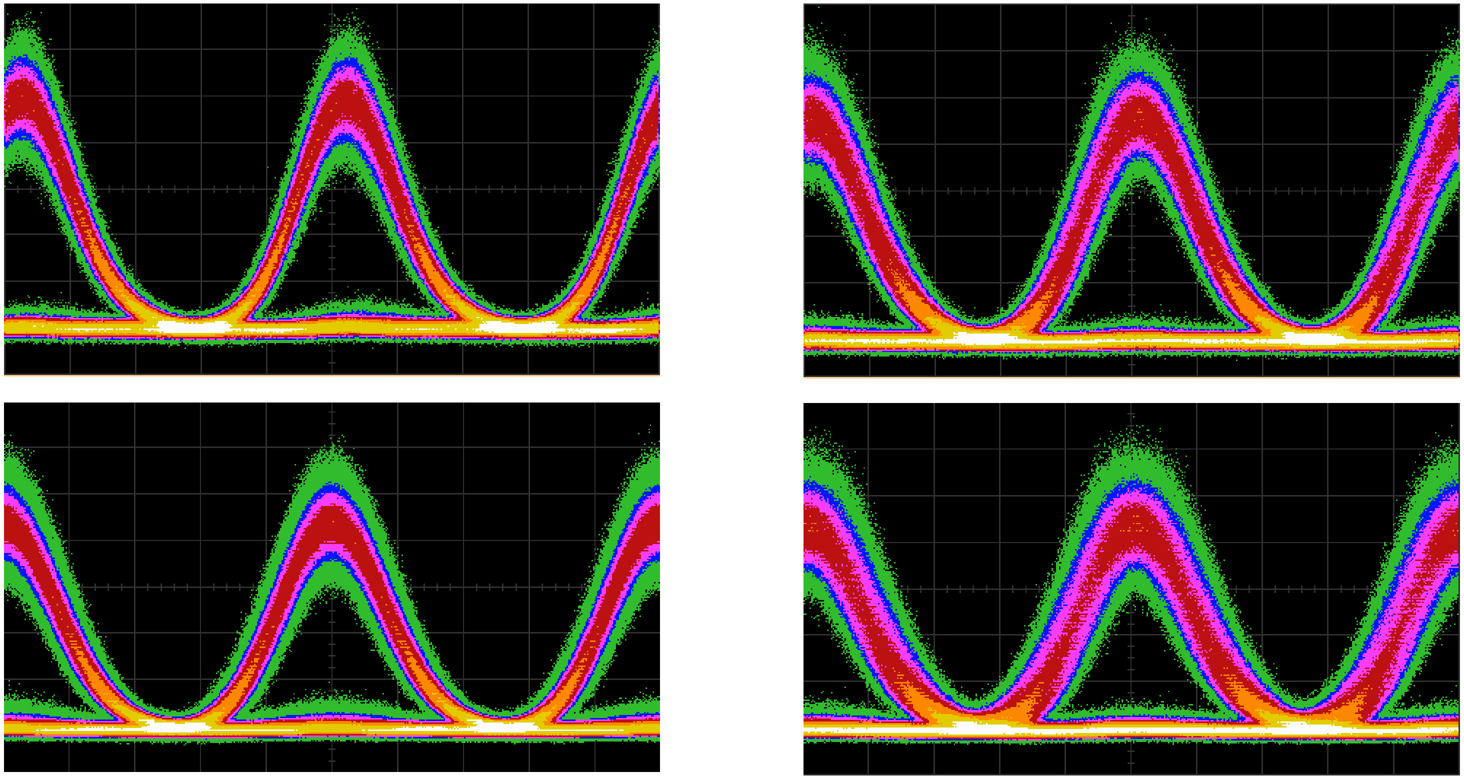
Timing jitter results compared with numerical simulation:

- Full nonlinear Schrödinger equation
- 200 Monte Carlo simulations
- Utilizing best estimate of system parameters:
  - Dispersion map
  - Amplifier noise figures
  - Power map

Eye diagrams

Wilmington, DE

New York, NY



50 % Pre-compensation

90 % Pre-compensation

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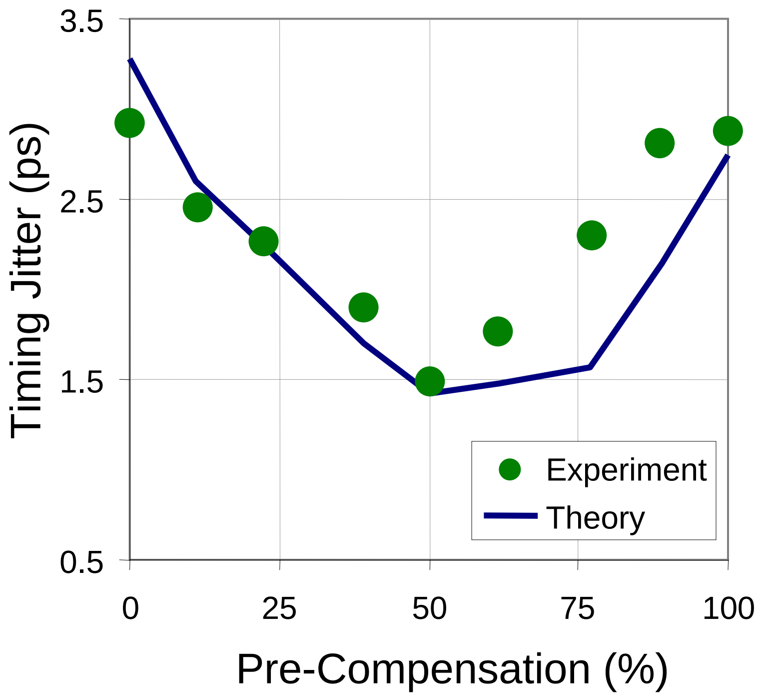
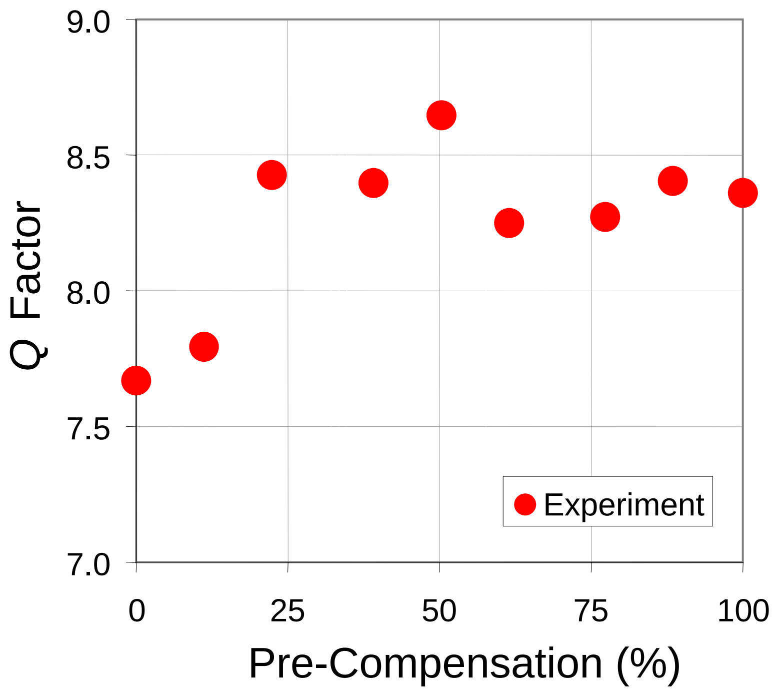
Wilmington loopback results





- Total transmission distance ~520 km
- Symmetric dispersion compensation minimizes timing jitter
- Excellent qualitative agreement with theory

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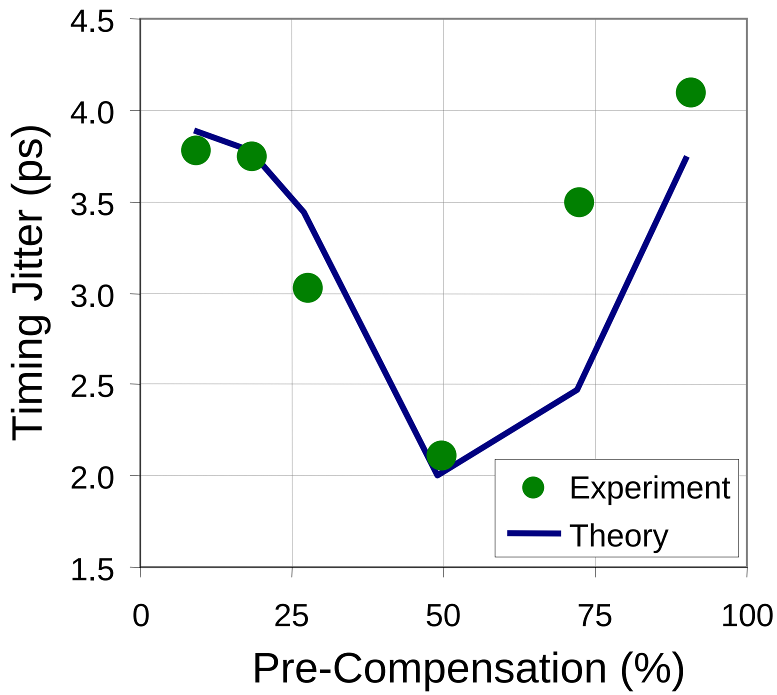
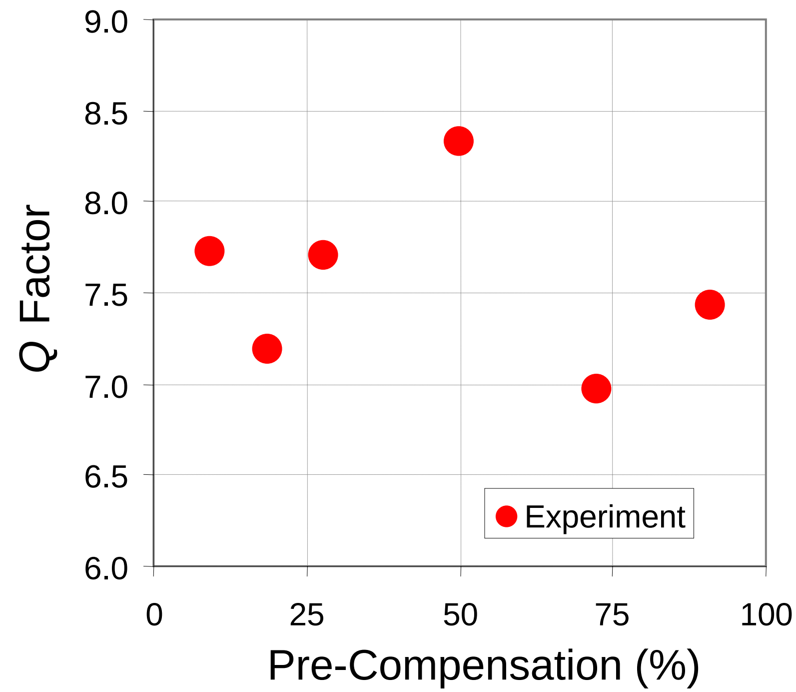
New York loopback results





- Total transmission distance ~930 km
- Jitter increased, but similar trend

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Summary

- Timing jitter measured on installed terrestrial link
- Qualitative agreement with simulations
- Ability to control dispersion compensation layout will be important in typical terrestrial systems may influence network management when paths change

Novel Formats

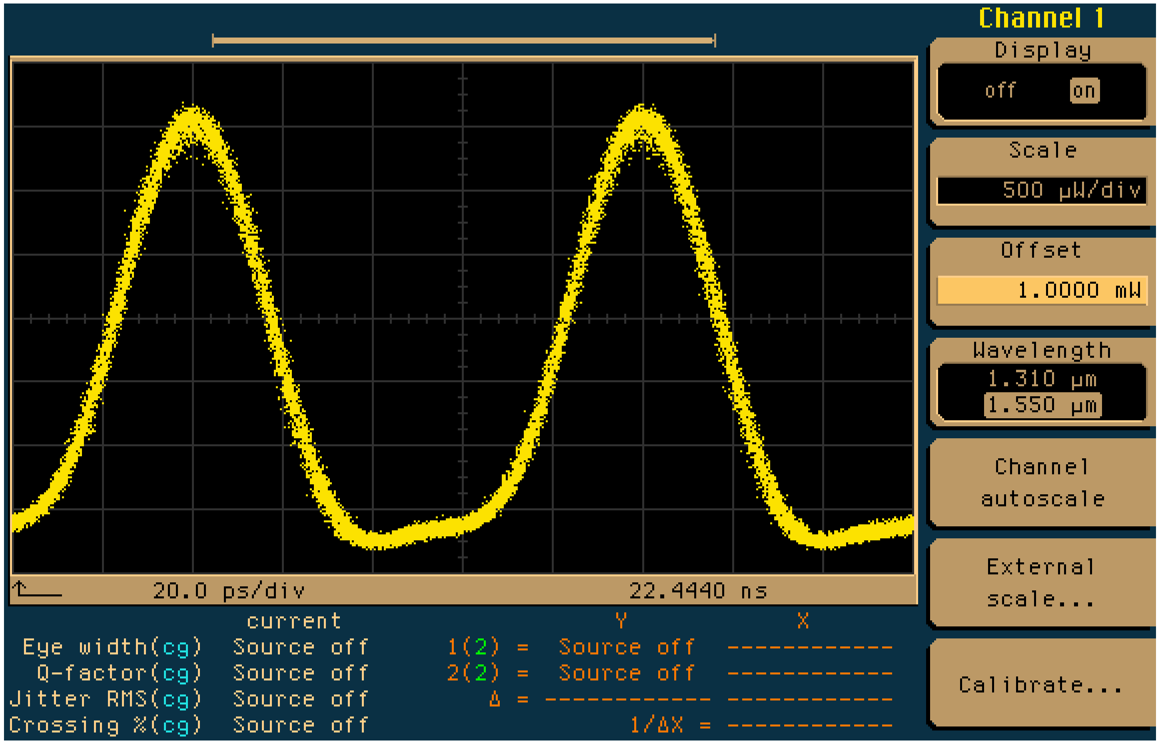
- Explore Novel formats
- DPSK
- QPSK
- QPSK and PolMux
- Others

DPSK

- Phase modulated signal
- 3 dB advantage over ASK
- Constant amplitude pulses
- Less “patterning”
- Security implications

DPSK Transmitted Intensity Pattern

10 Gb/s



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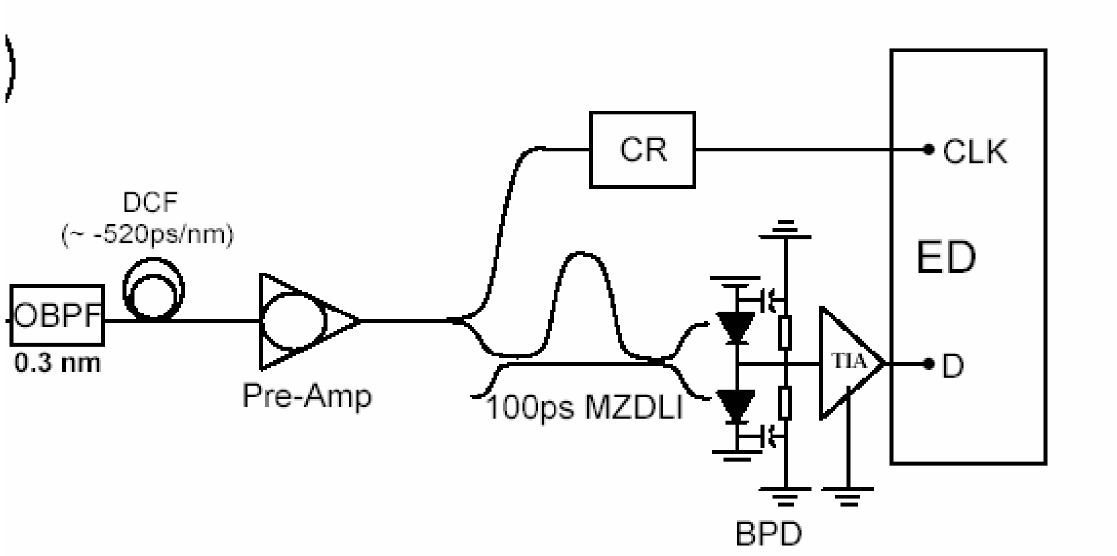
Receiver



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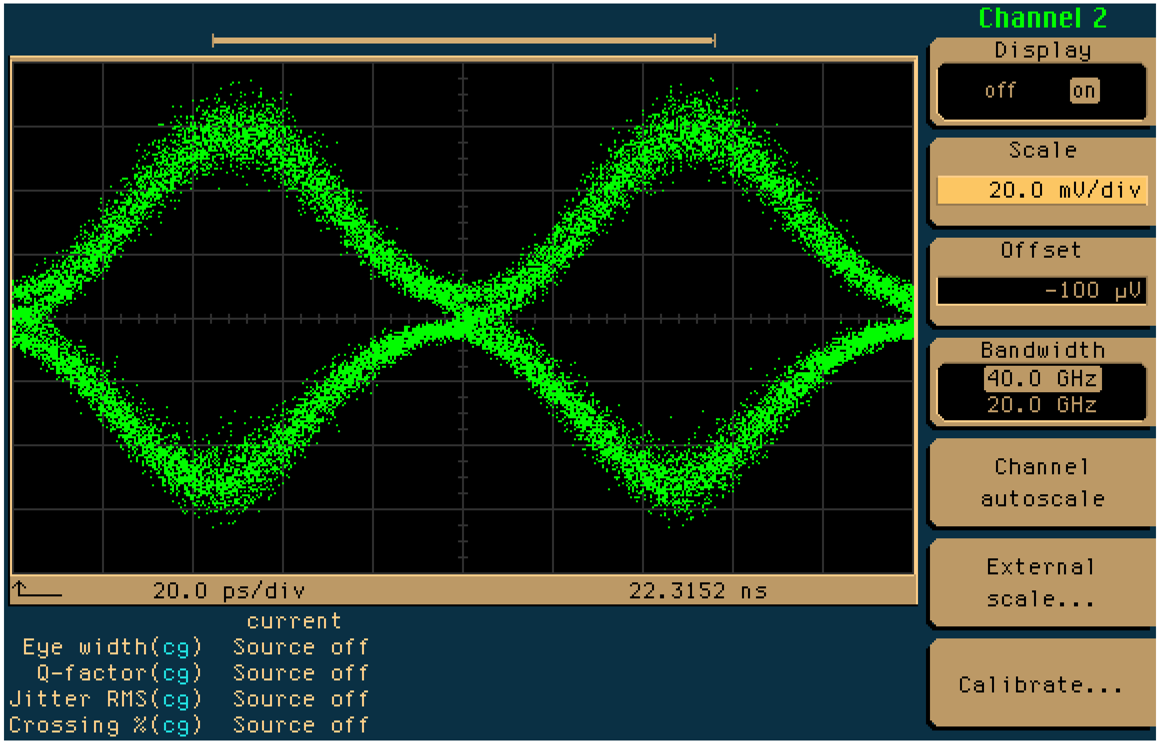
Demodulated Eye Pattern—10Gb/s



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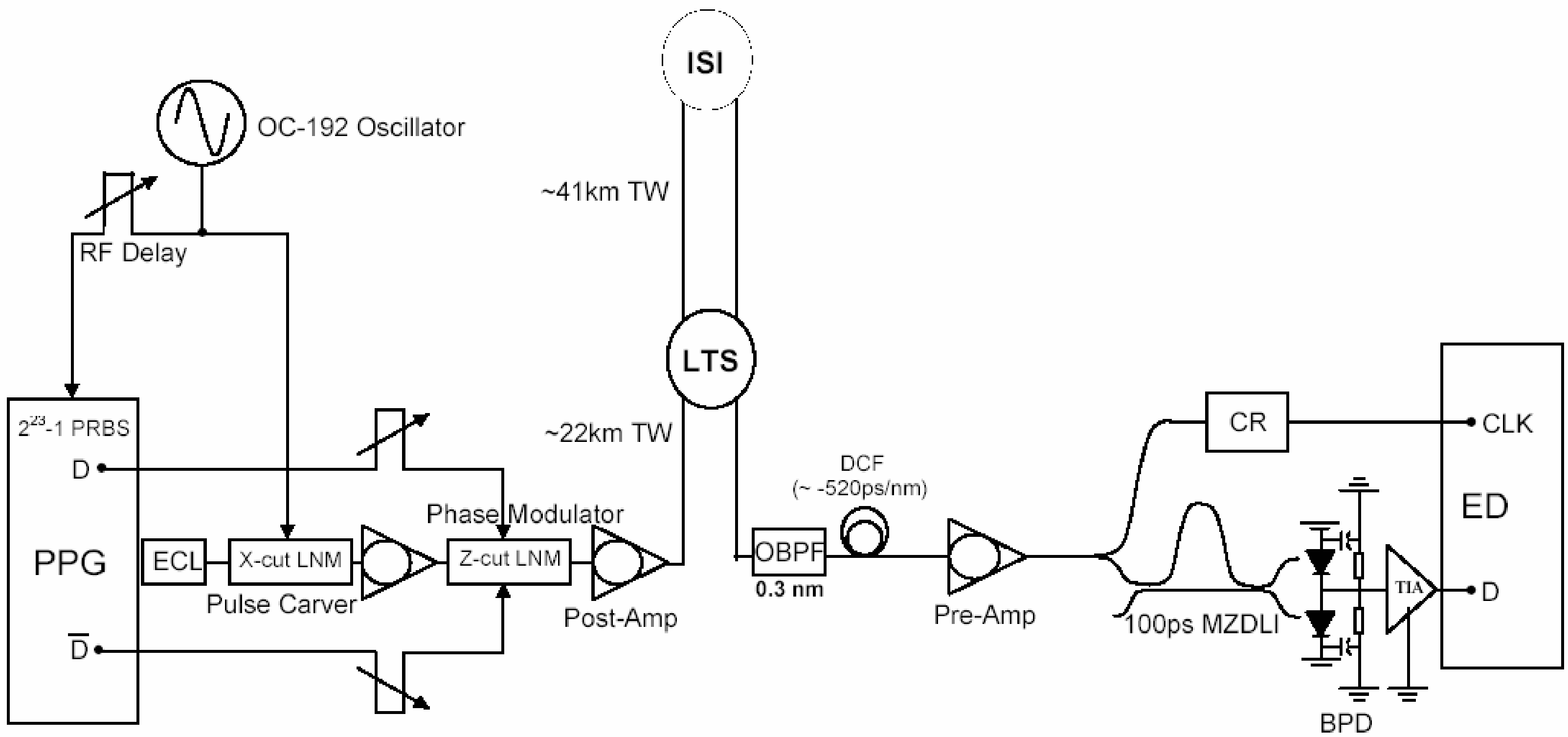
DPSK Loop Back from LPS to ISI

Error Rate < 1 ⑨ 10^{-13}



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DPSK

- 3 dB performance advantage over ASK
- Less Pattern Dependence in Transmission—maybe smaller timing jitter
- More difficult to detect—need specialized receiver
- Provides different information to network management

New Directions for Upcoming Year

- We are working with LTS to adapt measurements and theory to interactions with system and optical control plane

- LTS Personnel: Mark Ciccarello , Dave Hardesty, and Walter Kaechele