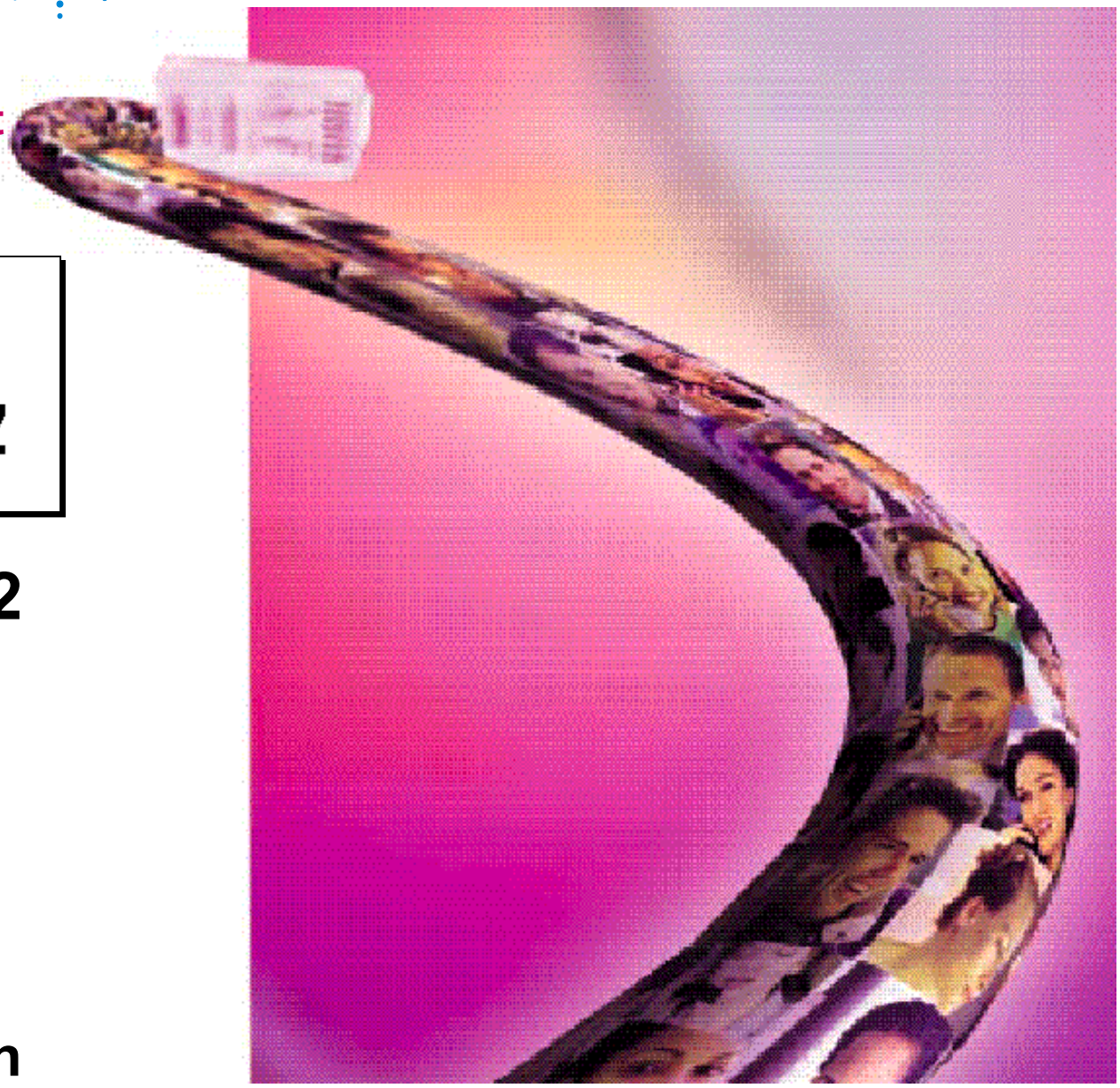
- Slides 1-10: Industry Buzz
- Slides 11-59: Dispersion Measurement Challenges eSeminar

Agilent Technologies



THE 40G INDUSTRY BUZZ

March 5, 2002

presented by:

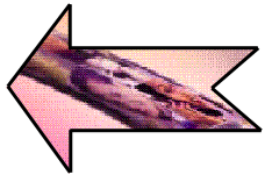
Larry DesJardin

THE 40G Industry Buzz

- Industry Update & Commentary
- “Late Breaking News” from Agilent
- Viewer Poll & Feedback

THE 40G Industry Buzz

- *Industry Update & Commentary*



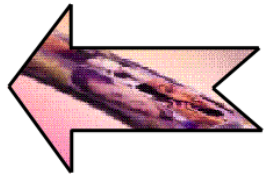
- **“Late Breaking News” from Agilent**
- **Viewer Poll & Feedback**

SPI-5 Specification Approved

- OIF Specification
- Physical layer and Link layer interactions
- Allows packet and cell transfers in OC-768
- Enables OC-768 ATM and POS

THE 40G Industry Buzz

- **Industry Update & Commentary**
- ***"Late Breaking News" from Agilent***
- **Viewer Poll & Feedback**



Late Breaking Agilent News

New Dispersion Measurement Products:

- **Agilent 86038A Optical Dispersion Analyzer**
  - **Simultaneous PMD, CD, GD, PDL and IL measurements**
  - **High speed measurements**
  - **High accuracy for CD and PMD measurements: < 0.05ps**
  - **High dynamic range > 50 dB**
  - **CD measurements corrected for PMD**
  - **Wavelength accuracy: ±0.3pm with integrated wavelength meter**
  - **S, C and L band wavelength coverage (1370 - 1640nm)**

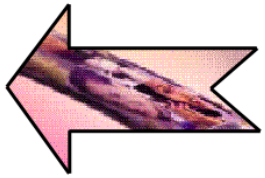
Late Breaking Agilent News

New VCOs for 40Gb/s applications:

- **1st Surface-Mount VCOs for 40Gb/s**
  - **19.9 GHz and 39.81 GHz**
  - **Low Phase Noise**
  - **Differential Outputs**
  - **Available at FEC rates**

THE 40G Industry Buzz

- Industry Update & Commentary
- "Late Breaking News" from Agilent
- *Viewer Poll & Feedback*



Viewer Poll and Feedback

Will 40Gb/s first be used for

a) **Short Reach Interfaces**

b) Long Haul transport

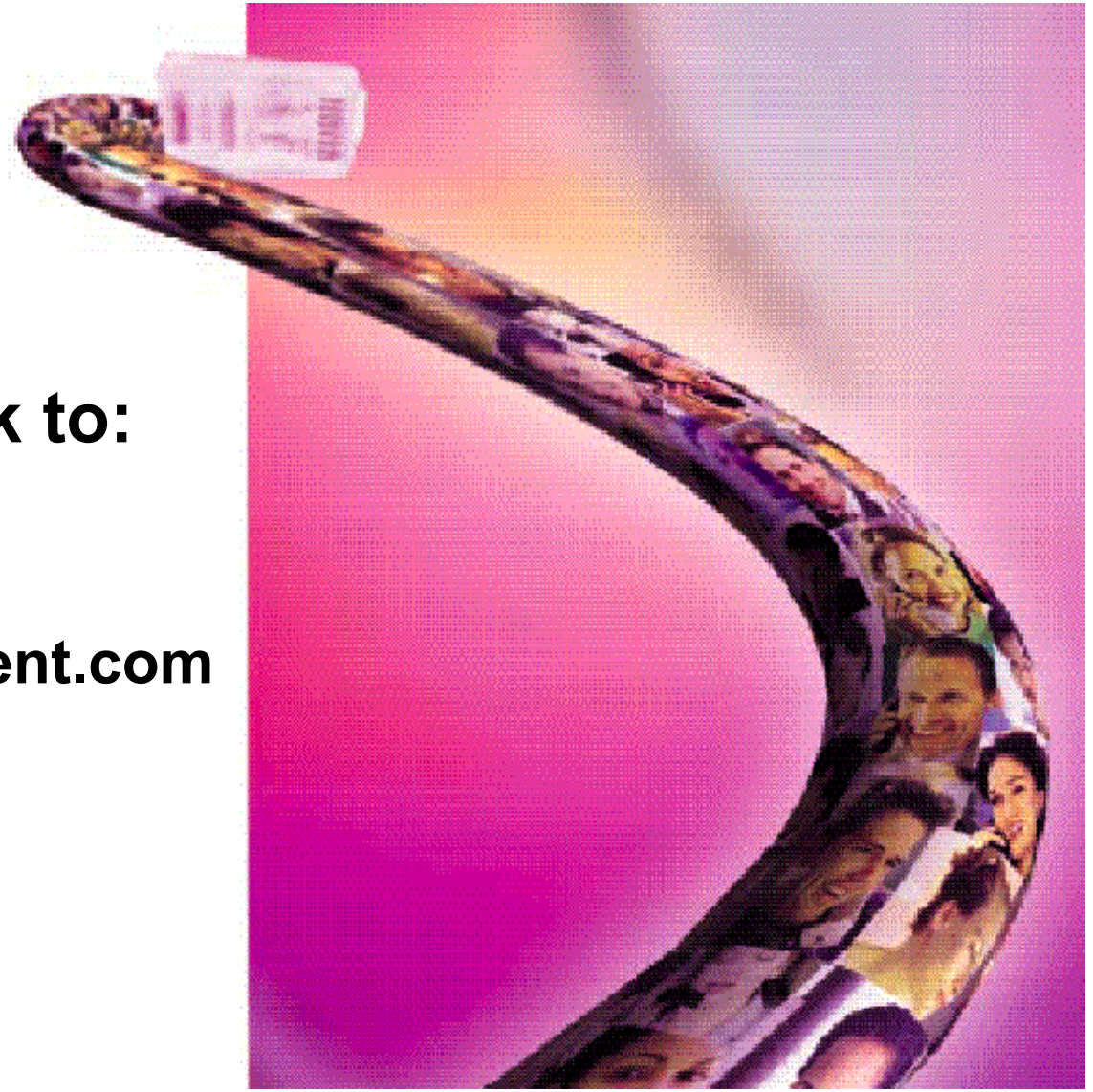
c) Too close to call.....

Poll Results:

a) **Short Reach Interfaces** 

Agilent Technologies

THE 40G INDUSTRY BUZZ



Send any feedback to:

larry_desjardin@agilent.com

Agilent Technologies

Dispersion Measurement Challenges for the Next Generation 40 Gb/s Optical Networks

March 5 2002

presented by:

Johann Fernando

Topics

Conceptual review of chromatic and polarization-mode dispersion

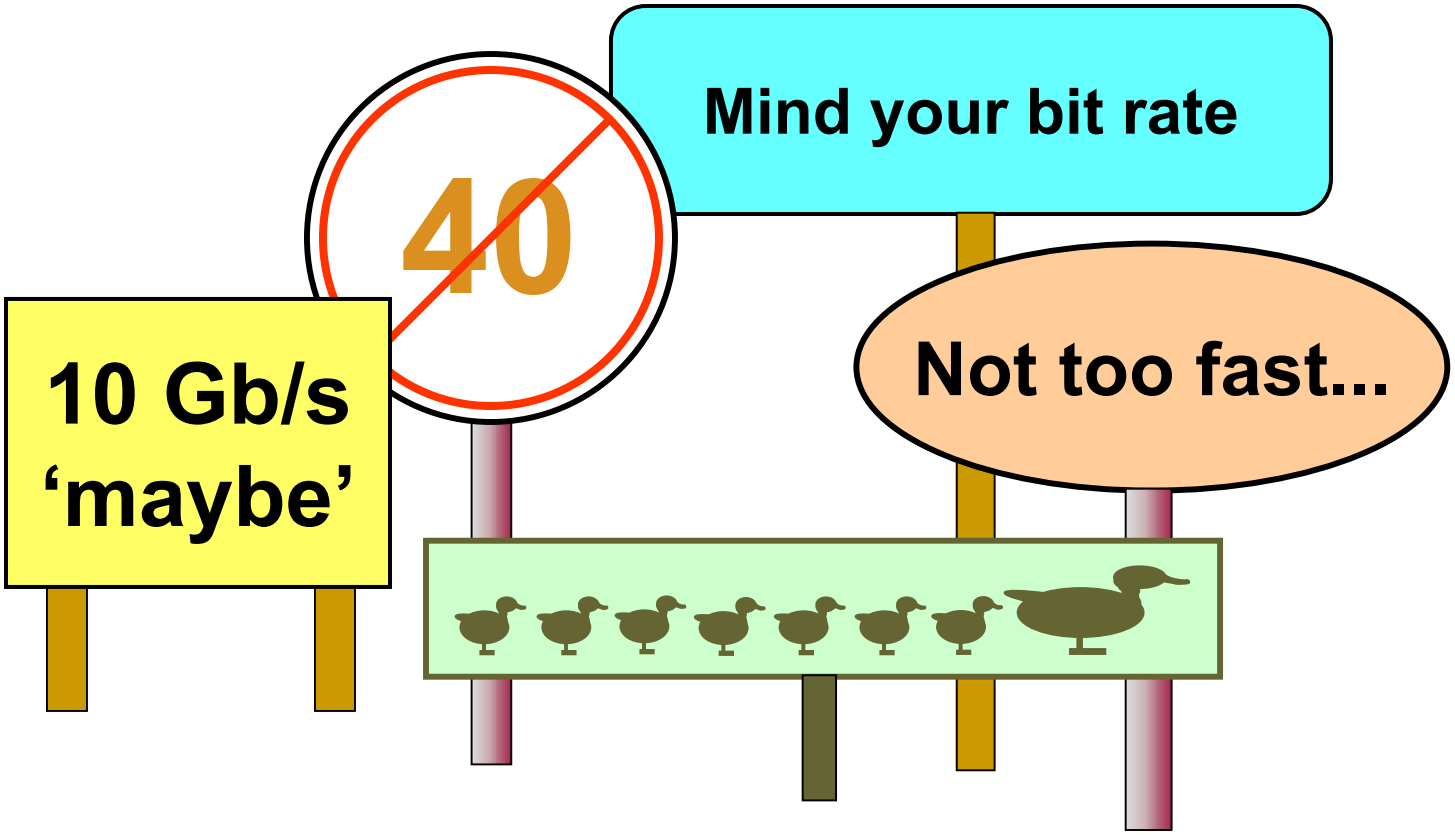
Impact of CD and PMD on high-speed digital lightwave systems

Common CD and PMD measurement methods

New dispersion measurement solutions offered by Agilent

The Road to 40 Gbit/s

Chromatic Dispersion and PMD post speed limits for high-speed systems



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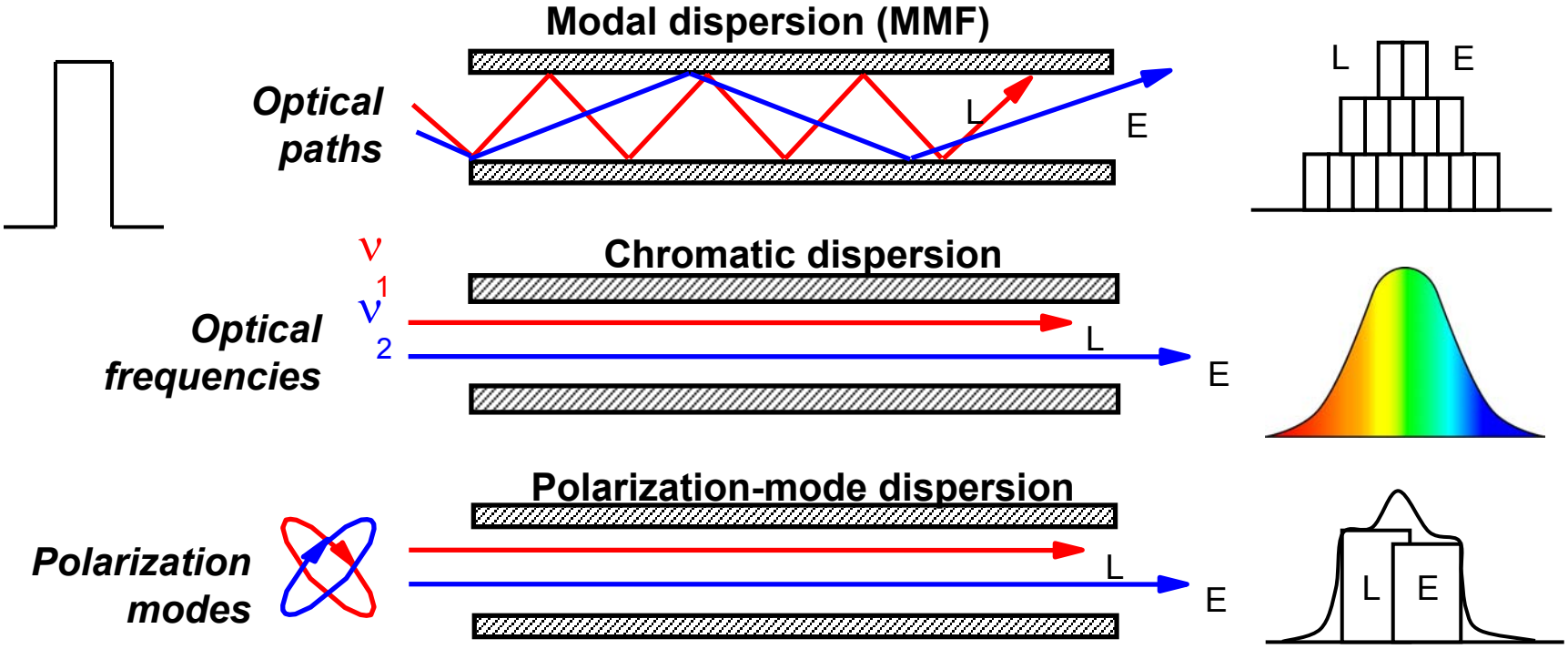
Review of CD and PMD

Types of dispersion in optical fiber

(first order only)



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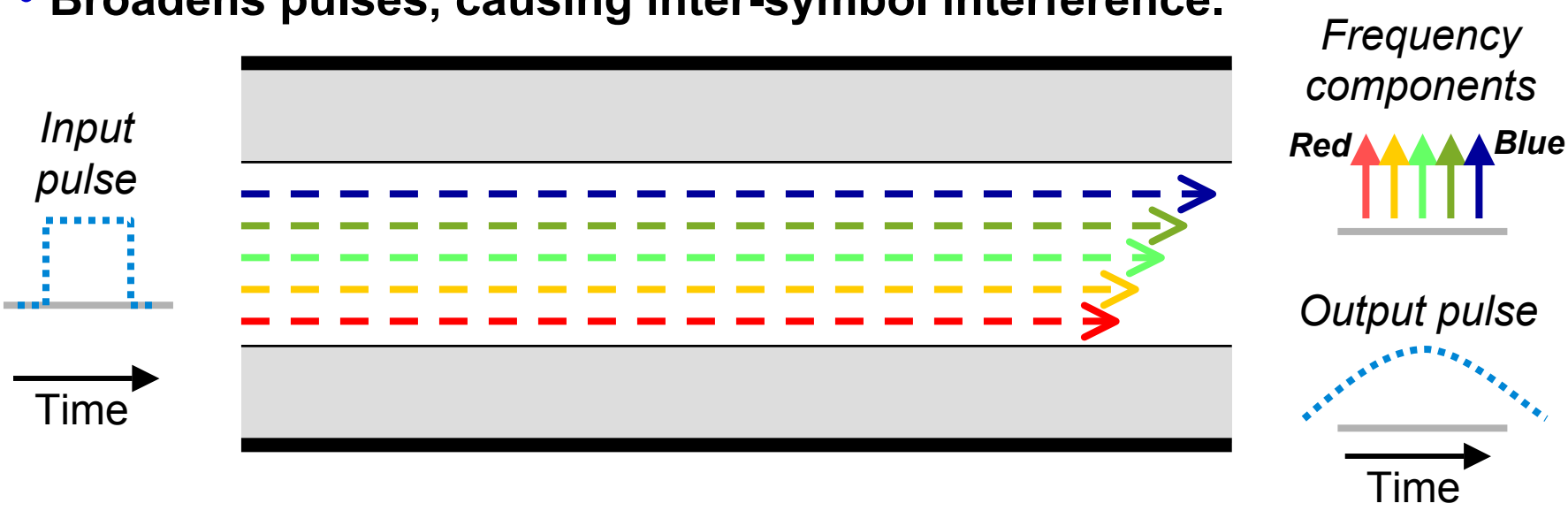
Review of CD

Chromatic dispersion in single-mode fiber

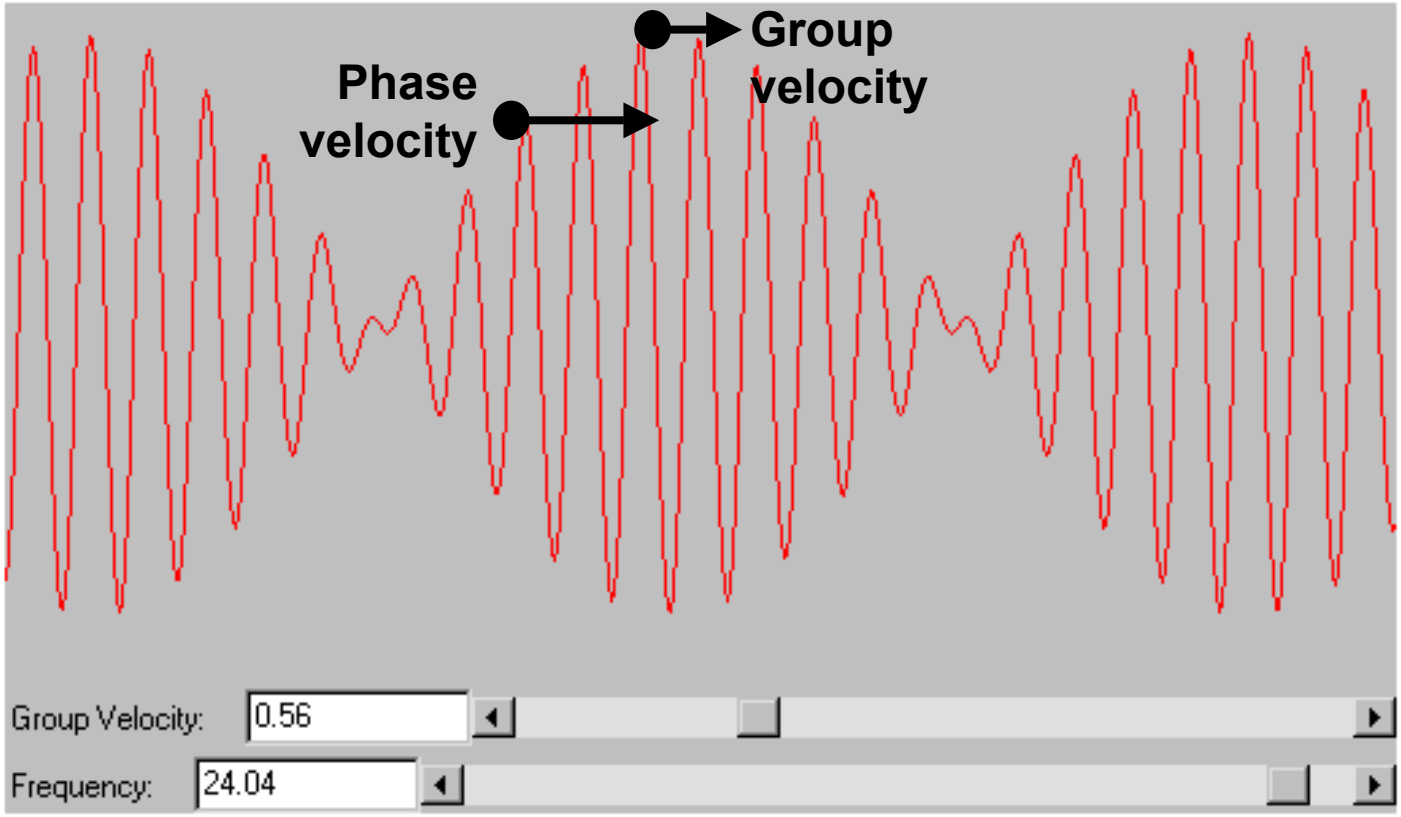
- **Arises from material properties and details of the waveguide design.**
- **Broadens pulses, causing inter-symbol interference.**



- **Static compensation to 10Gb/s, and to 40Gb/s at medium length.**
- **Temperature dependence requires adaptive compensation at 40Gb/s.**

Review of CD

Speed of *light* versus speed of the *signal*



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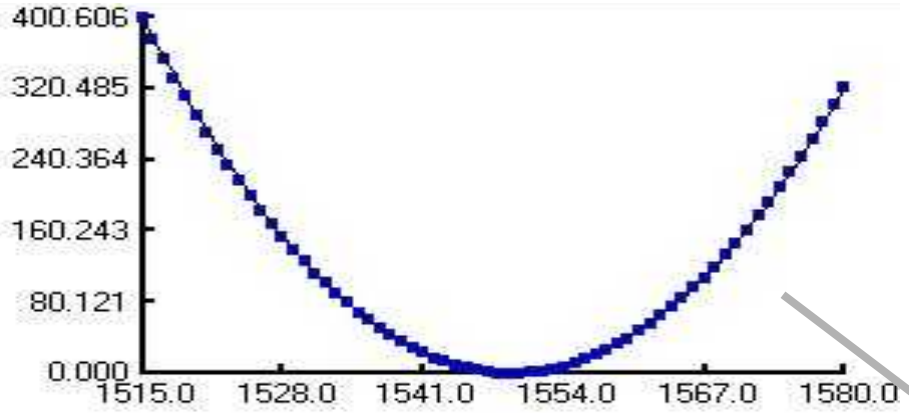
Review of CD

Chromatic dispersion definitions

Group delay
Propagation time for a *modulated* lightwave

Relative group delay
τ_g
(ps)

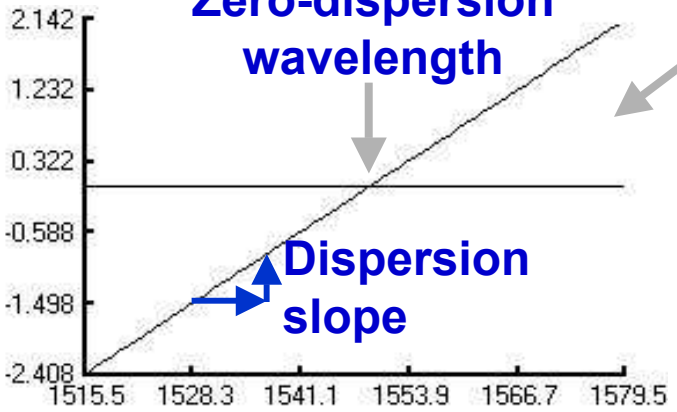


$$D = \frac{1}{L} \cdot \frac{\partial \tau_g}{\partial \lambda}$$

Zero-dispersion wavelength

CD Coeff.
Is the slope of the relative GD curve

Chromatic dispersion *coefficient*
D
(ps/nm-km)



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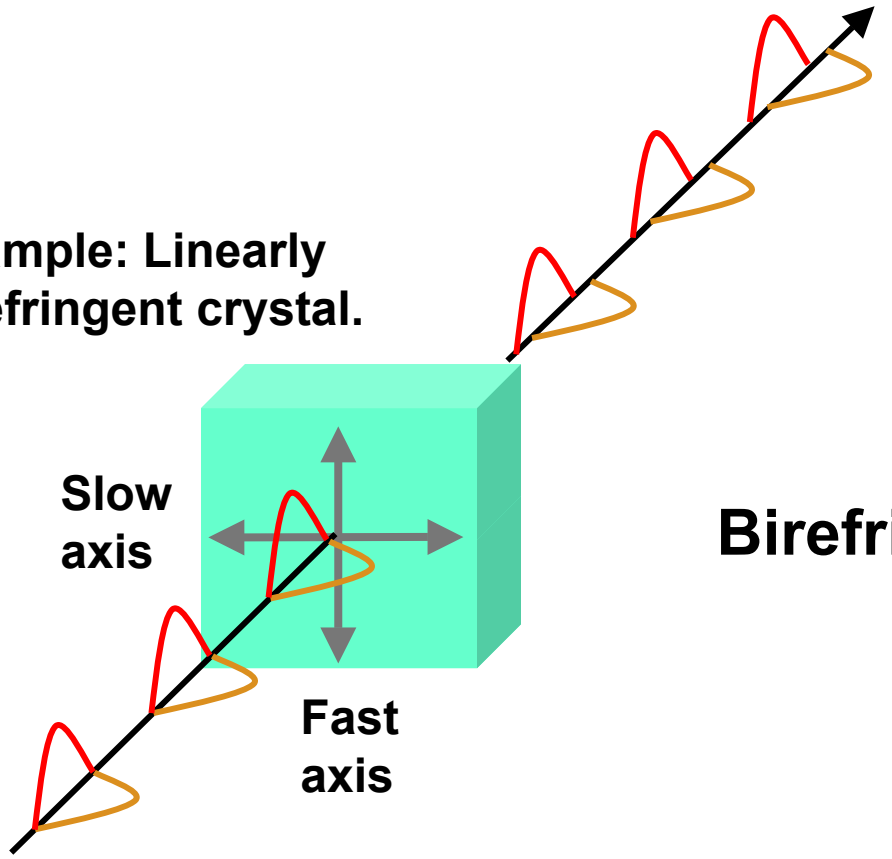
Birefringence: the *root* of polarization mode dispersion (PMD)

Example: Linearly birefringent crystal.

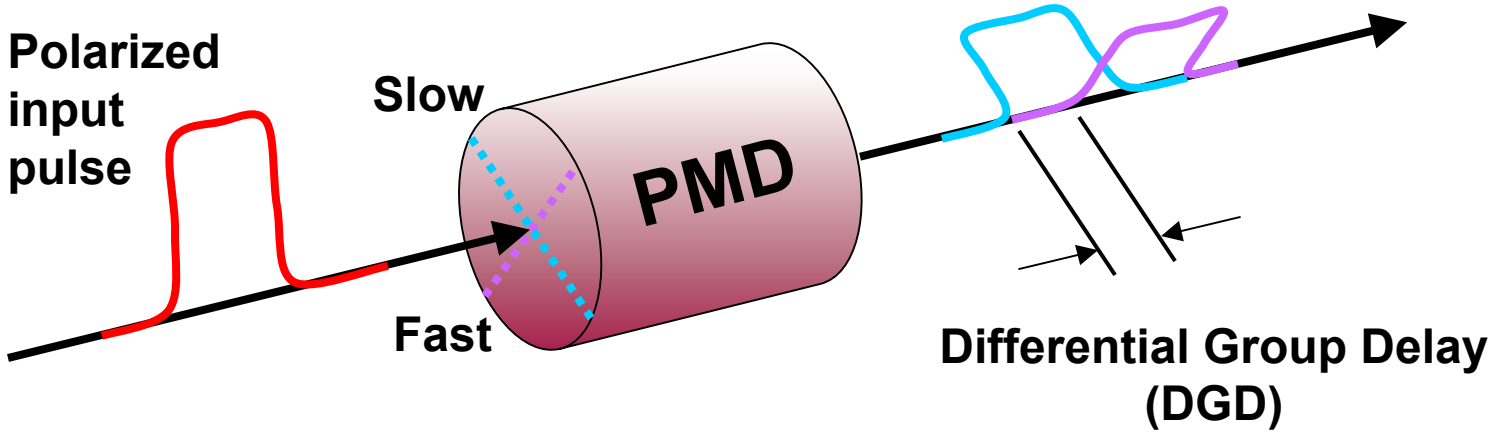


Birefringence is the difference in refractive index between orthogonal polarization states.

Birefringence = $n_{slow} - n_{fast}$

Review of PMD

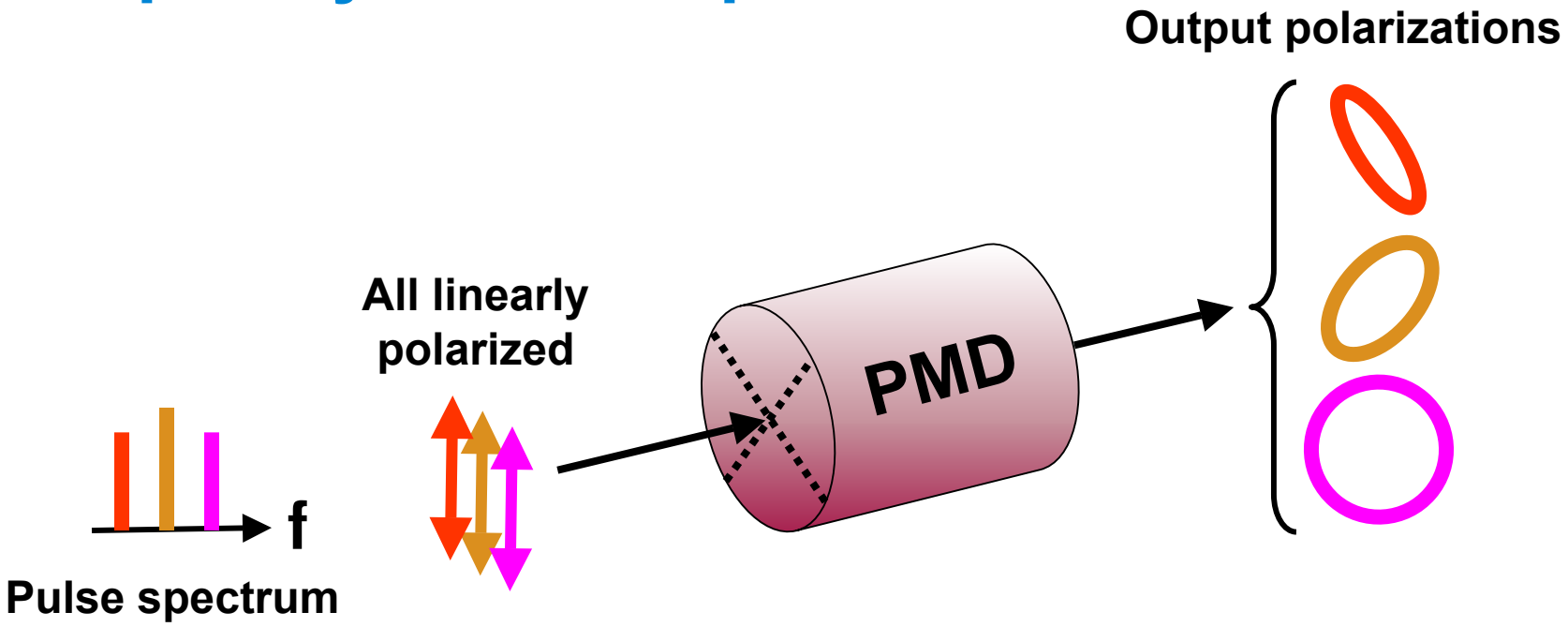
"Time domain" picture of PMD



- Output contains two differentially delayed images of the input pulse
- Output polarizations are orthogonal if there is no PDL
- Relative intensities depend upon the input state
- Causes inter-symbol interference and bit errors

Review of PMD

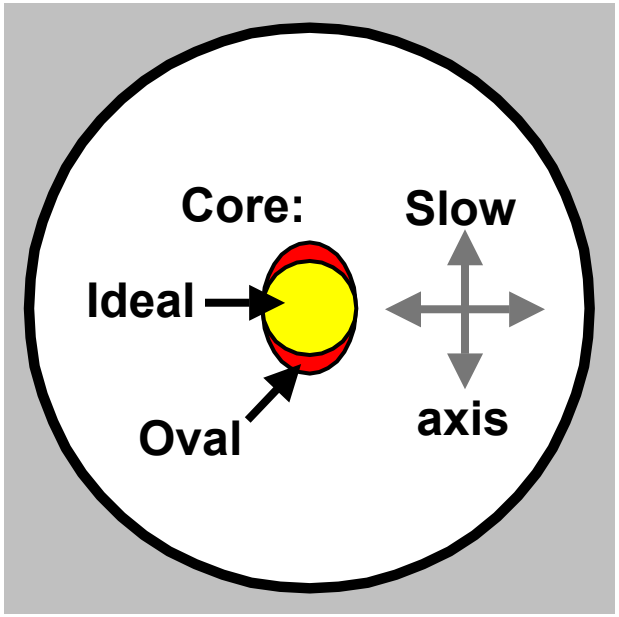
"Frequency domain" picture of PMD



- Each frequency component transforms differently
- Signals tend to depolarize
- Pulses overshoot, and distort into adjacent bit slots

Origins of birefringence in single-mode fibers

Single-mode fiber (SMF)



This has two *primary* origins:

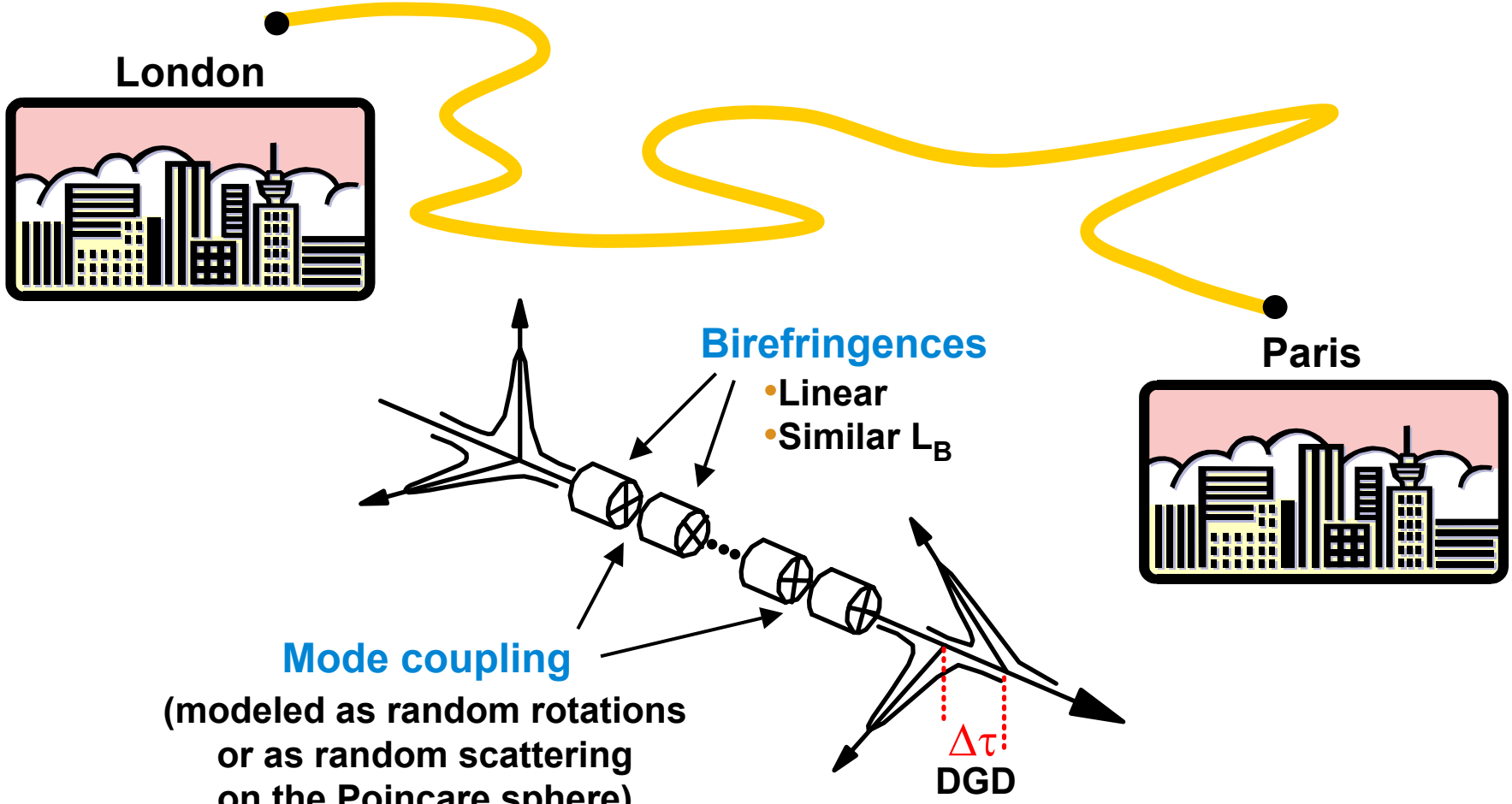
Form birefringence **characteristic of a non-circular waveguide.**

Stress birefringence **due to forces *set up by* a non-circular core.**

In unperturbed, short fibers (meters in length), fiber PMD is proportional to length.

Review of PMD

Fiber modeled as a chain of birefringences



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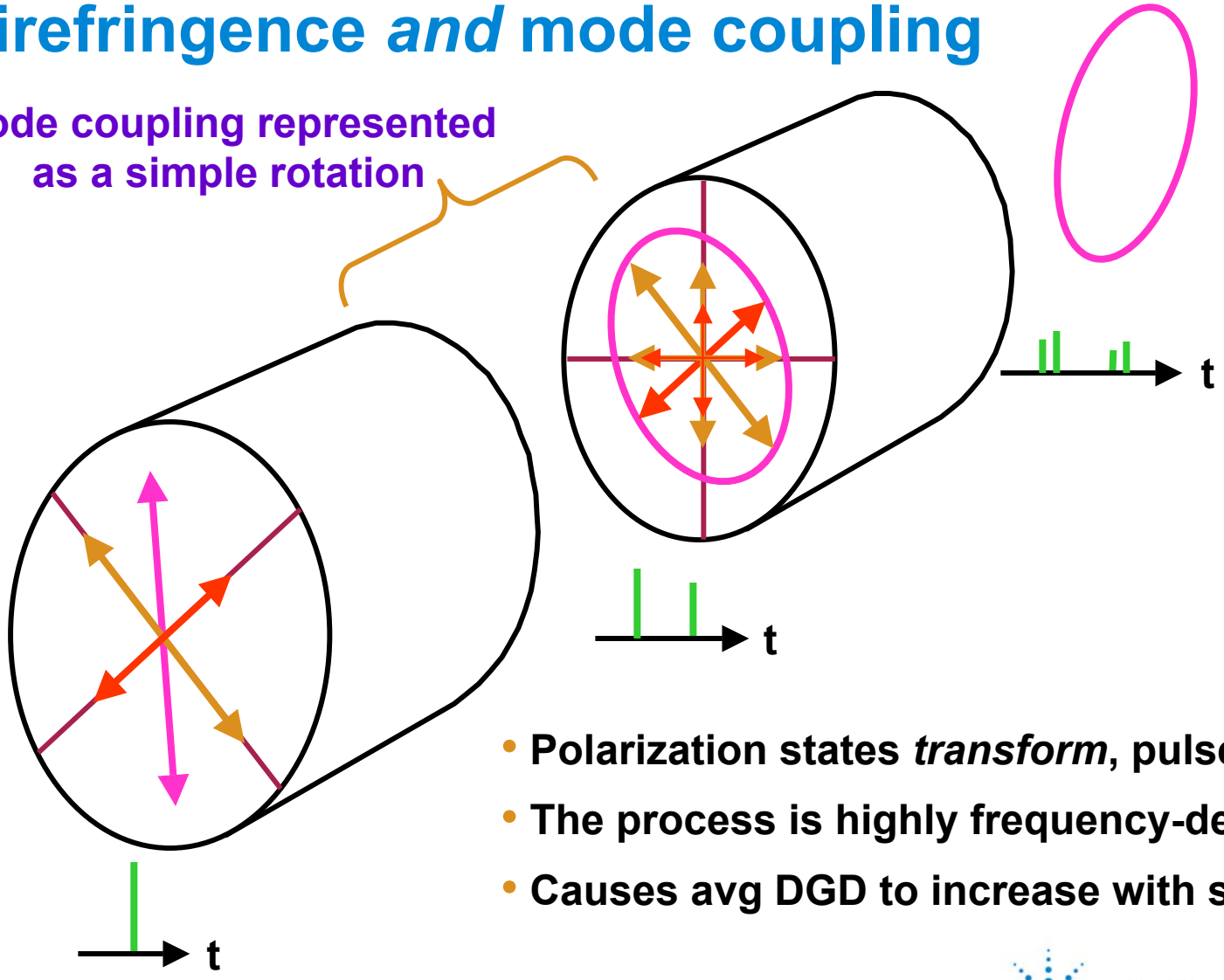
Review of PMD

Birefringence *and* mode coupling

Mode coupling represented as a simple rotation



- Polarization states *transform*, pulses *broaden*
- The process is highly frequency-dependent
- Causes avg DGD to increase with sqrt length

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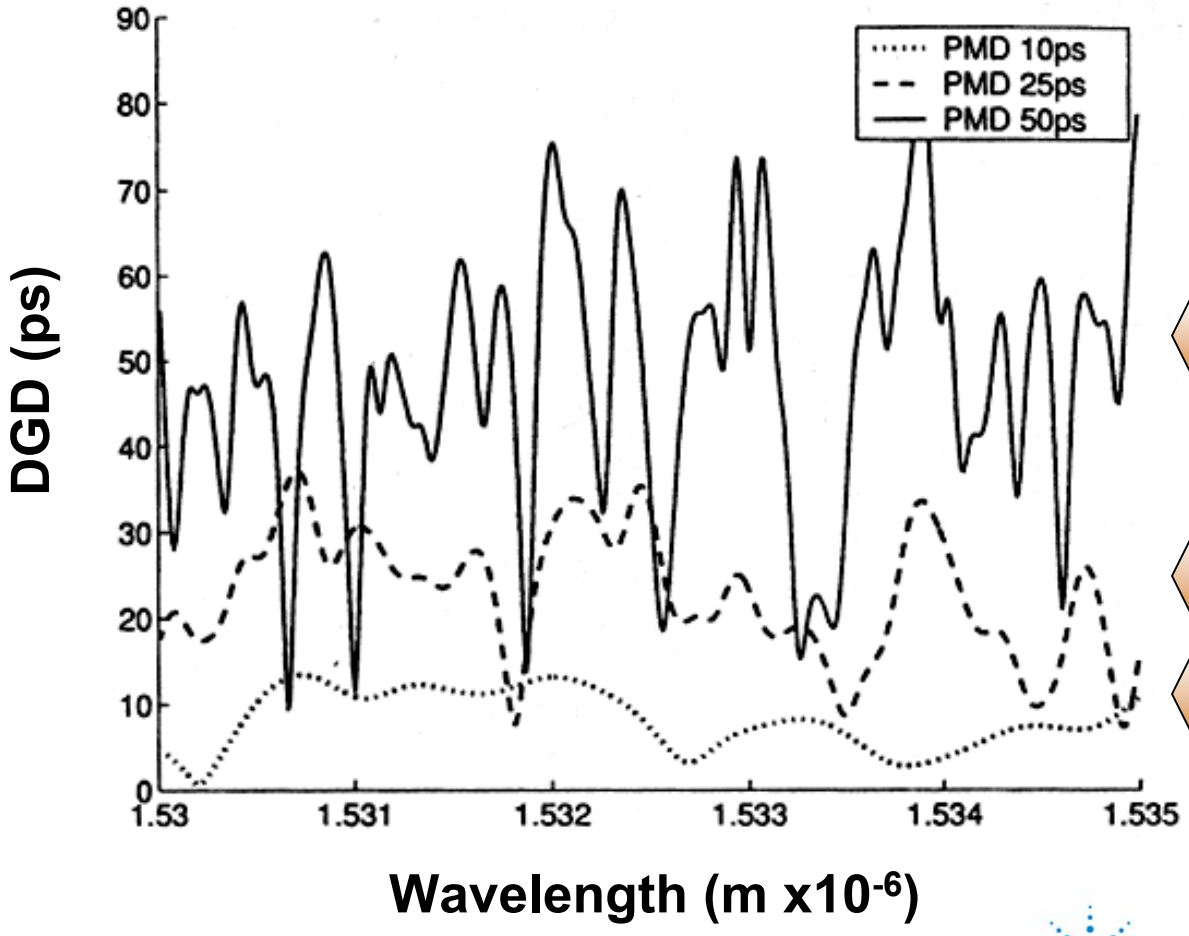
Review of PMD

DGD versus wavelength

S.Sarkimukka, et al., *IEEE J. Lightwave Techn.*, vol.18, 1374, October 2000



Average DGD:

50ps

25ps

10ps

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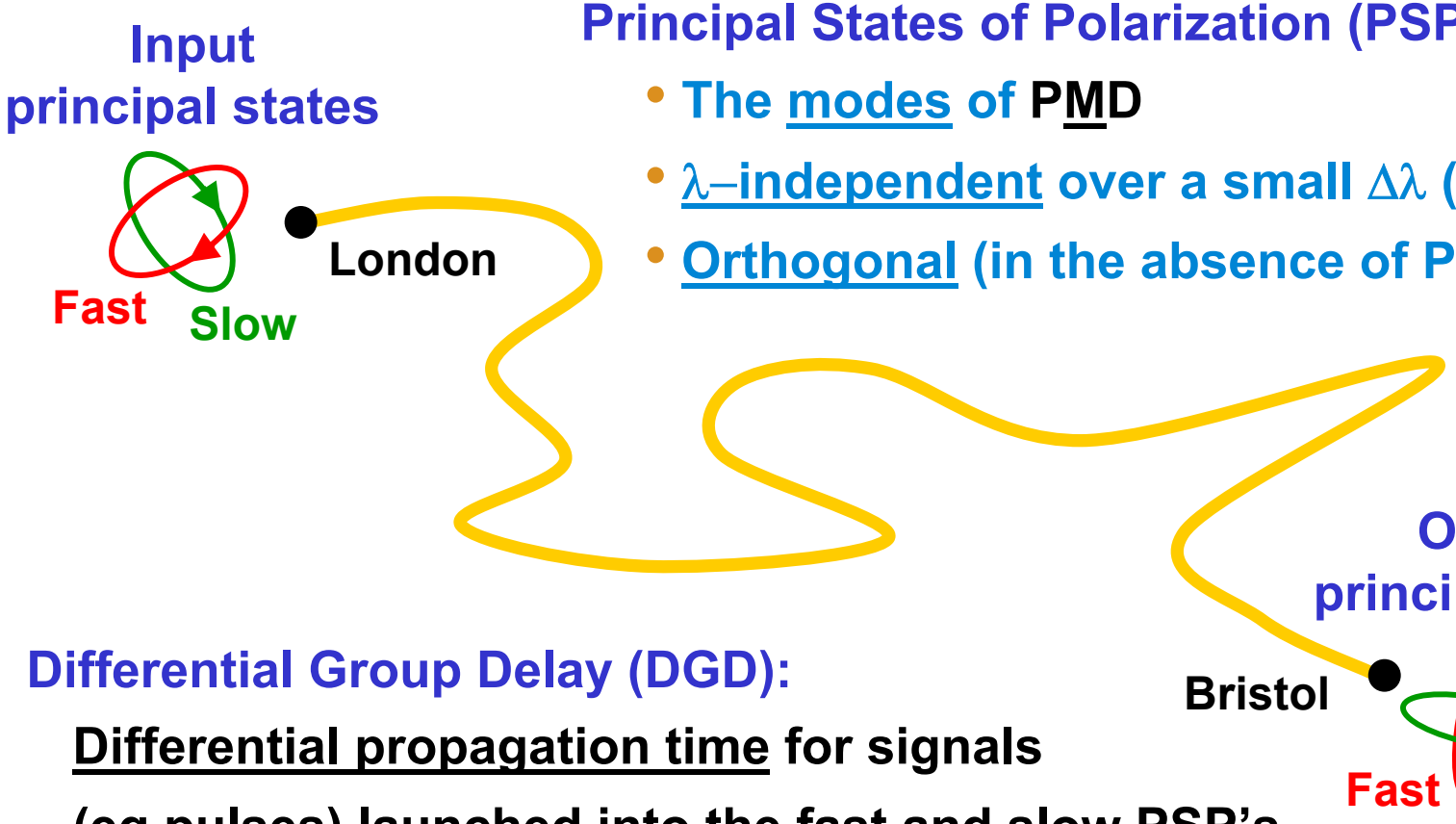
Review of PMD

The Principal States Model of PMD

C.Poole, R.Wagner, *Elect. Lett.*, 1029, Sept. 1986.



Principal States of Polarization (PSP's):

- The modes of PMD
- λ–independent over a small Δλ (by definition)
- Orthogonal (in the absence of PDL)

Differential Group Delay (DGD):

Differential propagation time for signals (eg pulses) launched into the fast and slow PSP's.

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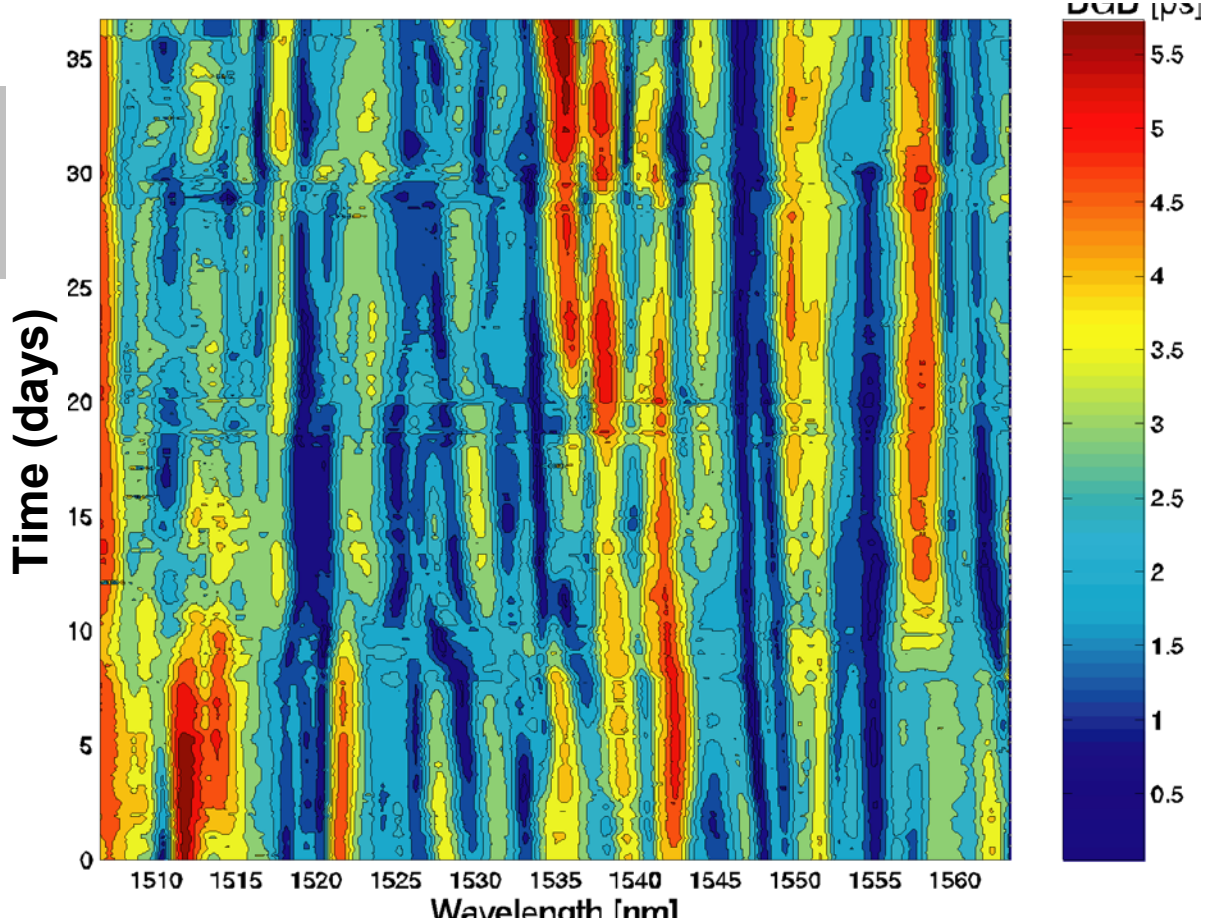
Review of PMD

Measurement of DGD over *wavelength* and *time*

M.Karlsson, et al., IEEE. J. Lightwave Techn., vol.18, 941, July 2000

127km buried DSF



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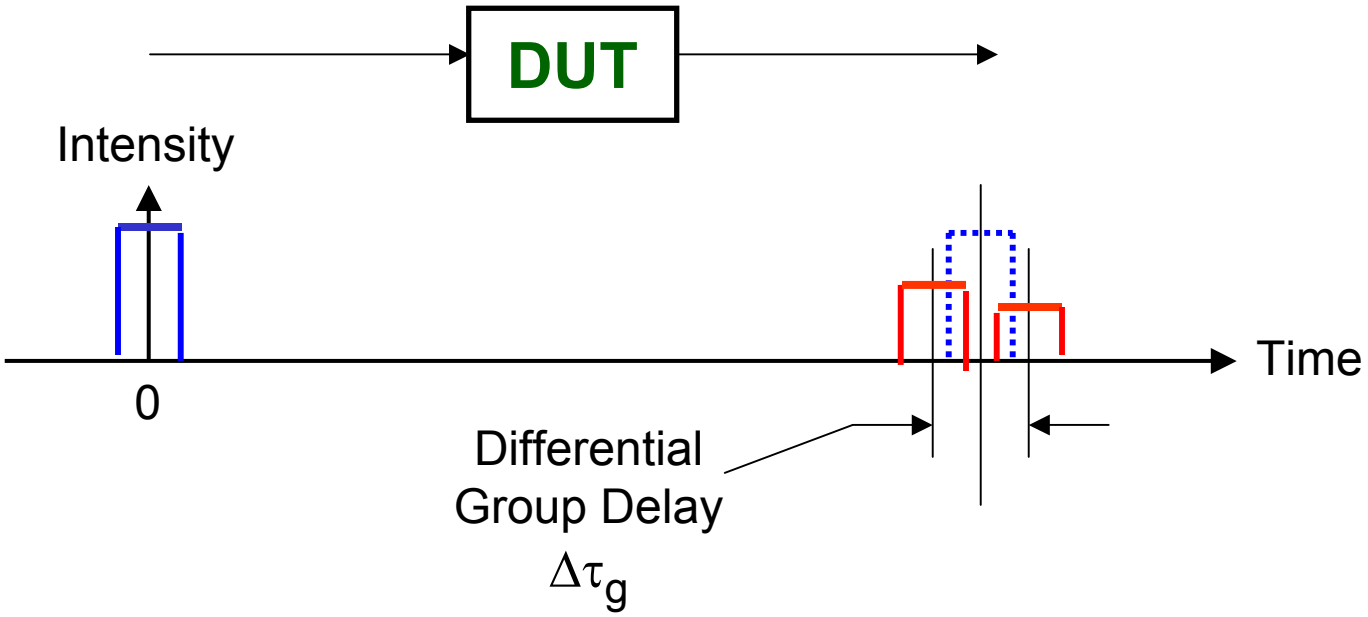
Review of CD and PMD

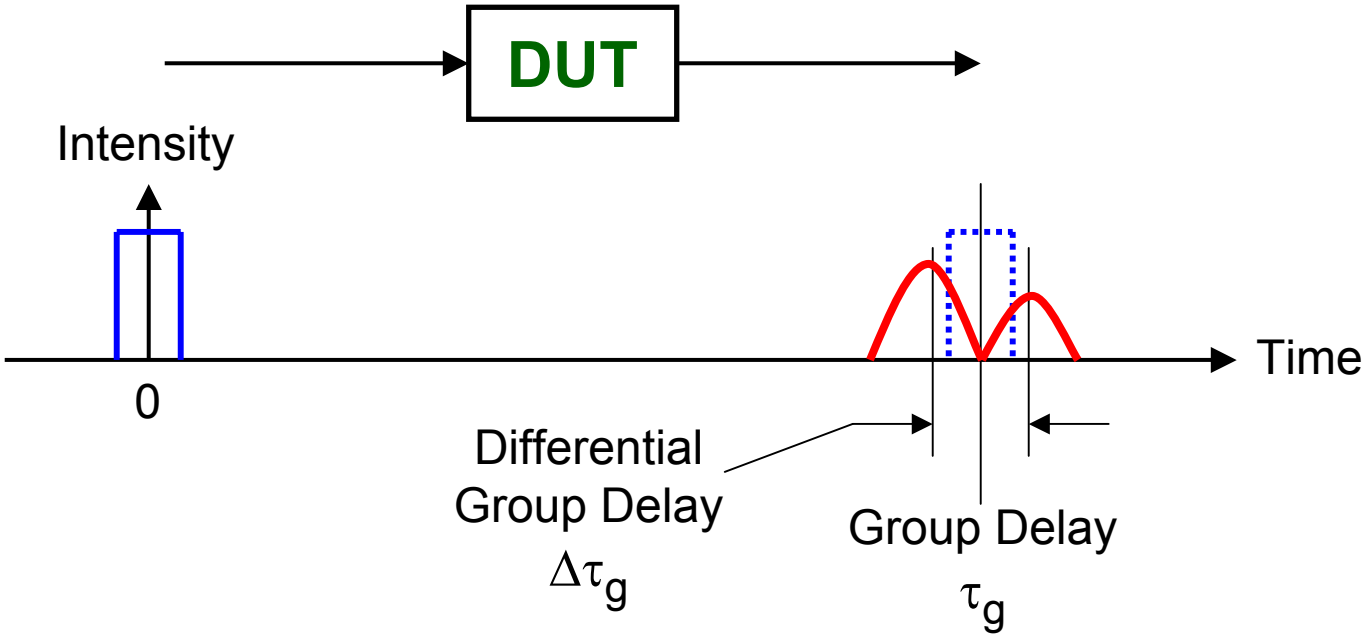
Group Delay (CD) and *Differential* Group Delay (PMD)



- PMD splits the pulse into images separated by ±DGD/2.
- Amplitudes of the pair of pulses depend upon input polarization.

Review of CD and PMD

Group Delay (CD) and *Differential* Group Delay (PMD)



- Both images are widened by chromatic dispersion.
- Widening of fast, slow pulses differ due to *second-order* PMD.

Topics

Conceptual review of chromatic and polarization-mode dispersion

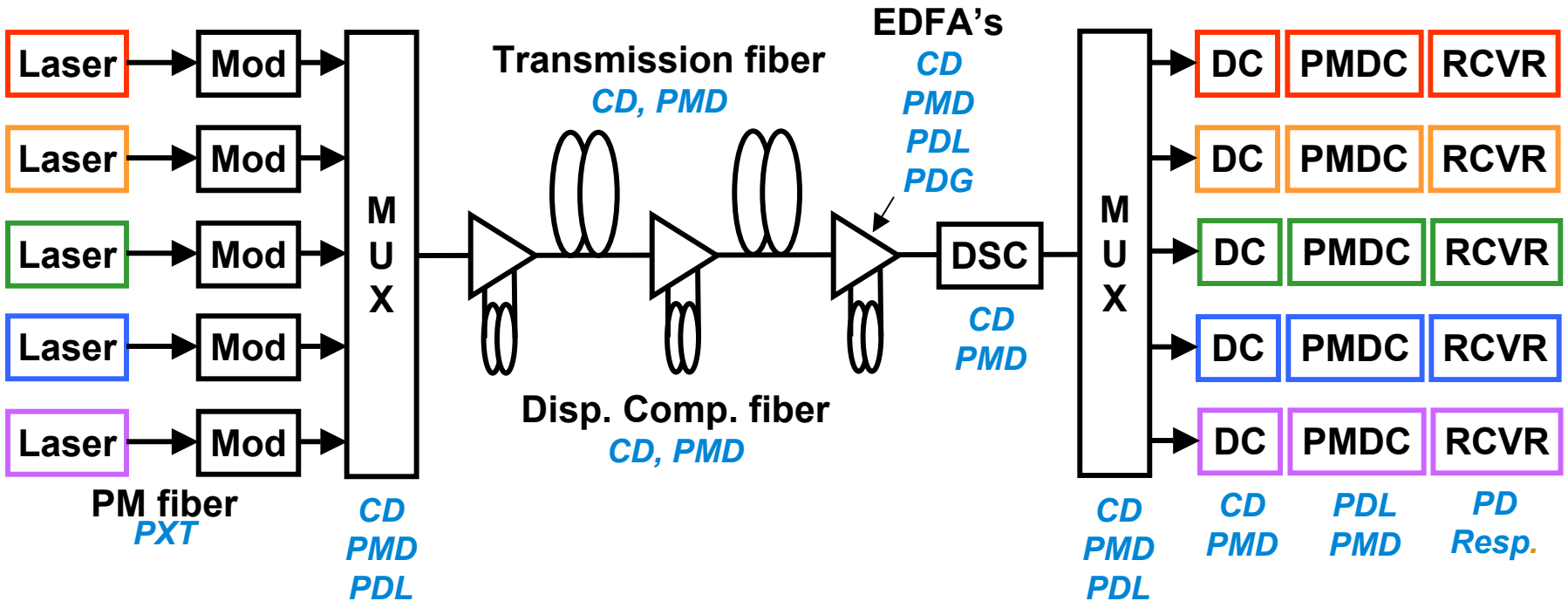
Impact of CD and PMD on high-speed digital lightwave systems

Common CD and PMD measurement methods

New dispersion measurement solutions offered by Agilent

Impact of CD and PMD

Dispersive and polarization impairments in a typical DWDM network



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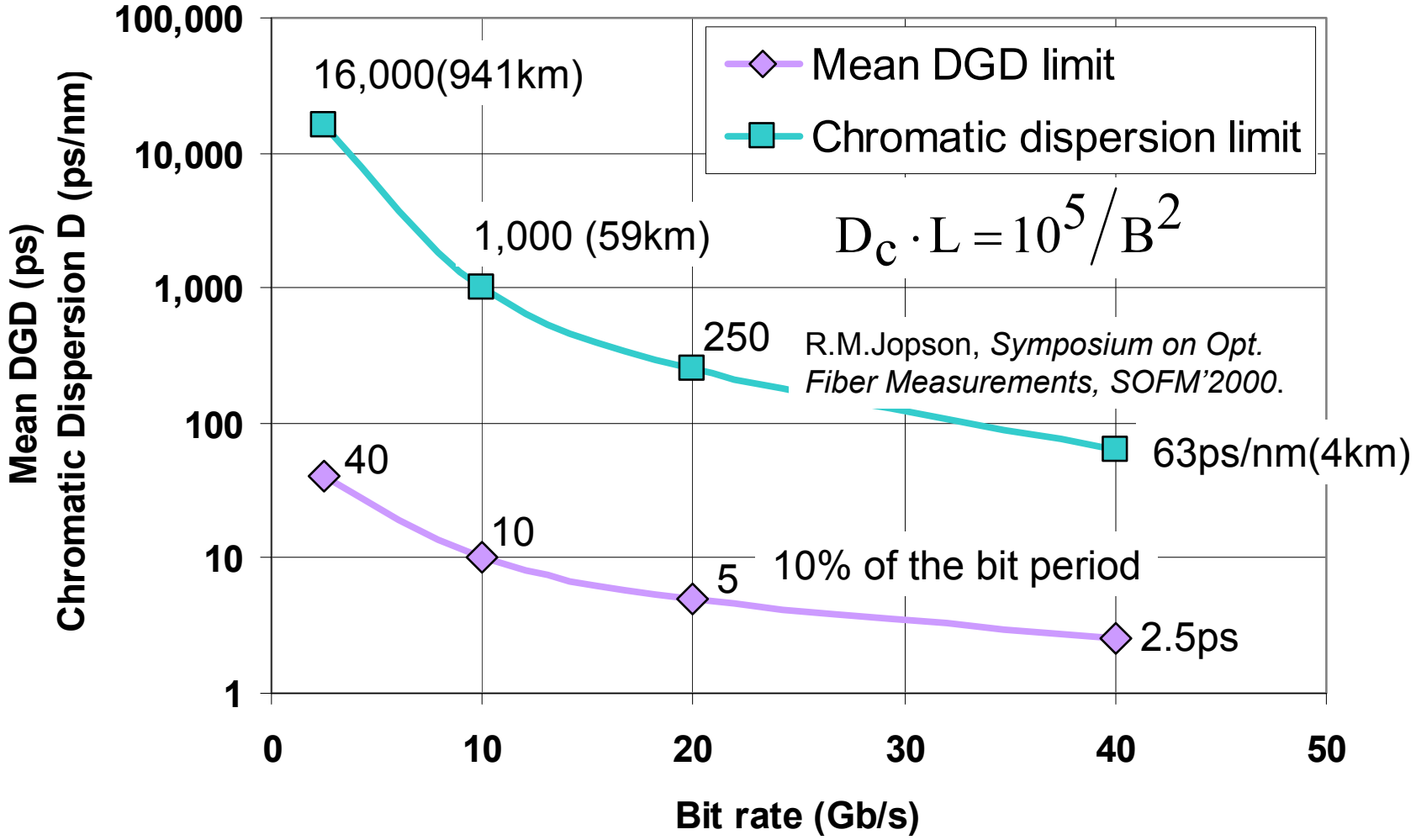
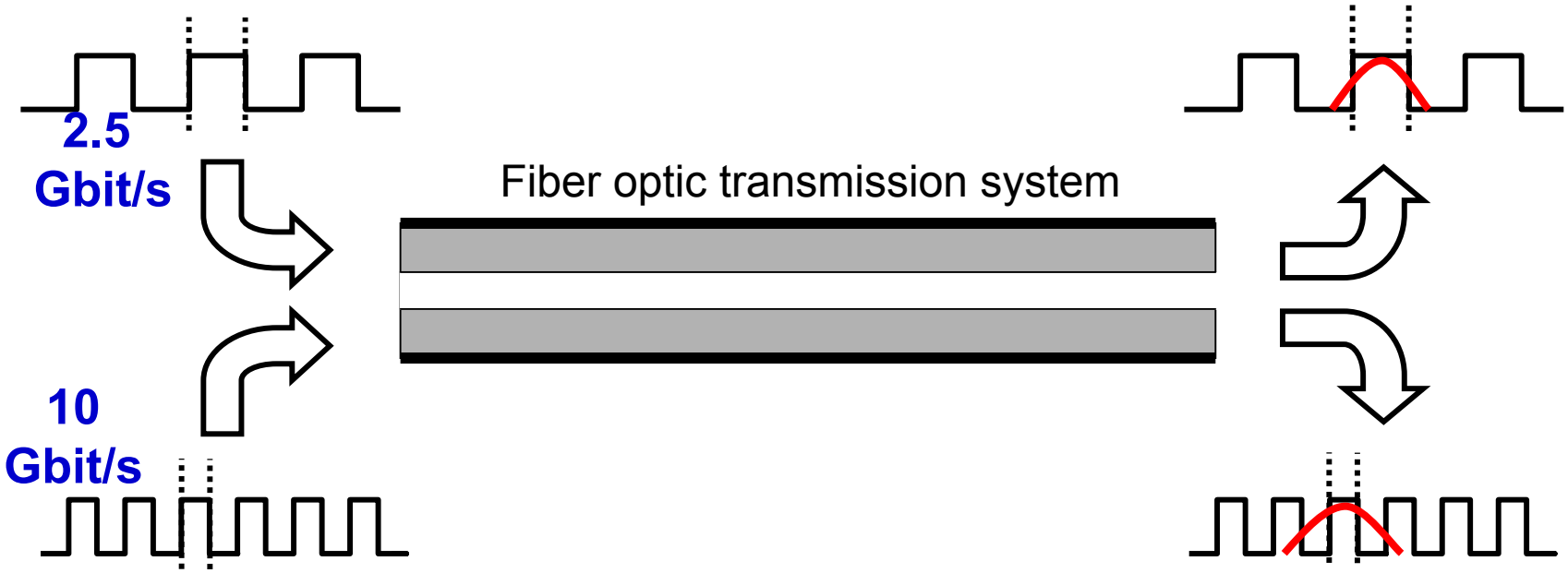
Review of CD and PMD

System tolerance of CD/PMD



Review of CD and PMD

Dispersion limit is highly bit rate dependent



Broader spectrum → More spreading

Narrower bit slot → *More sensitive* to spreading

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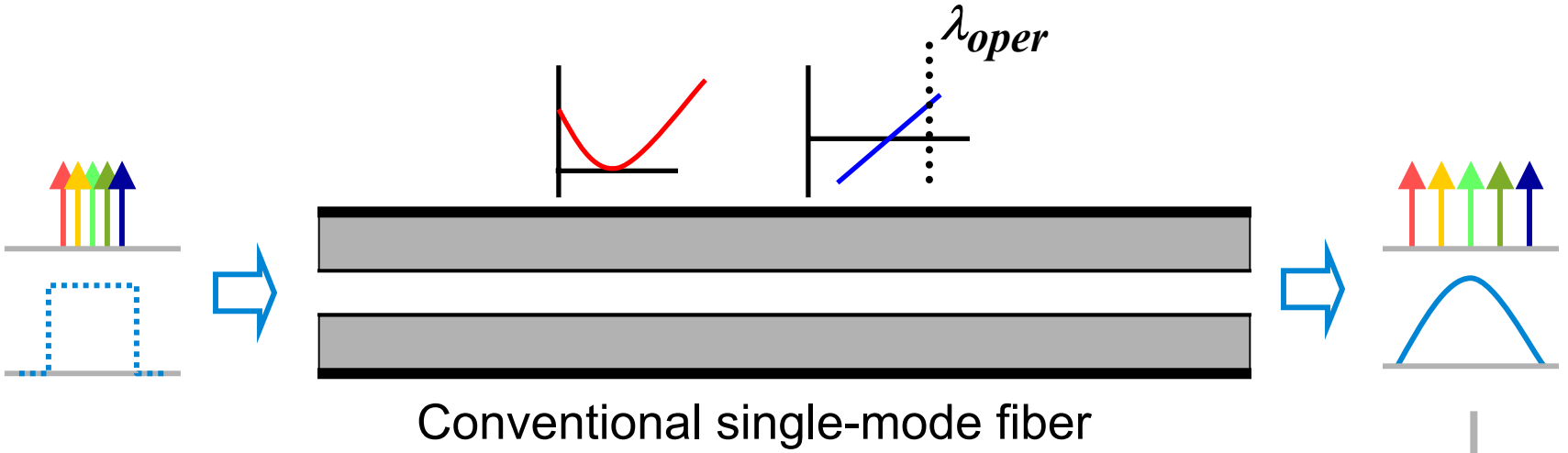
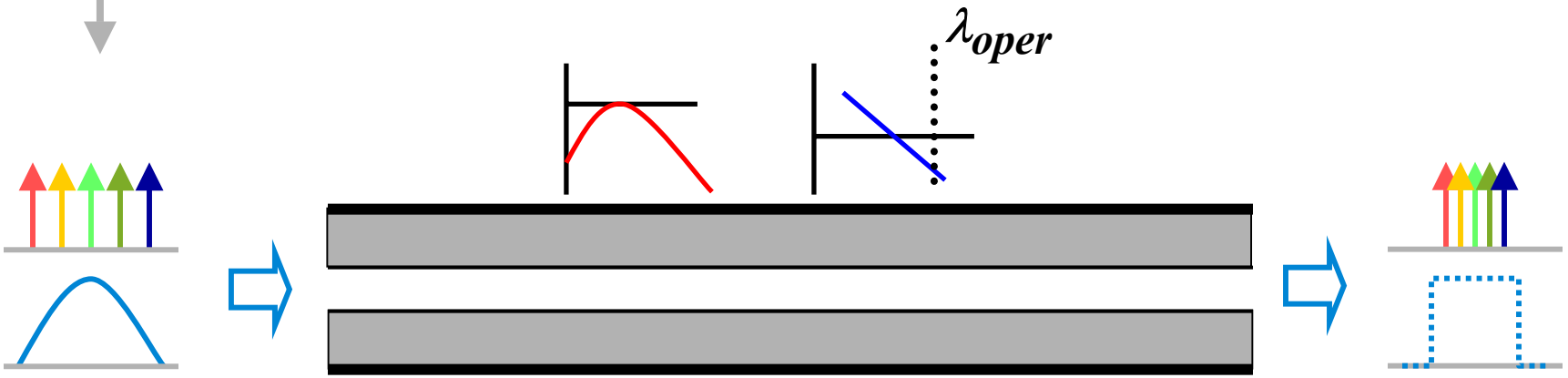
Dispersion Management

Dispersion Compensating Fiber (DCF)



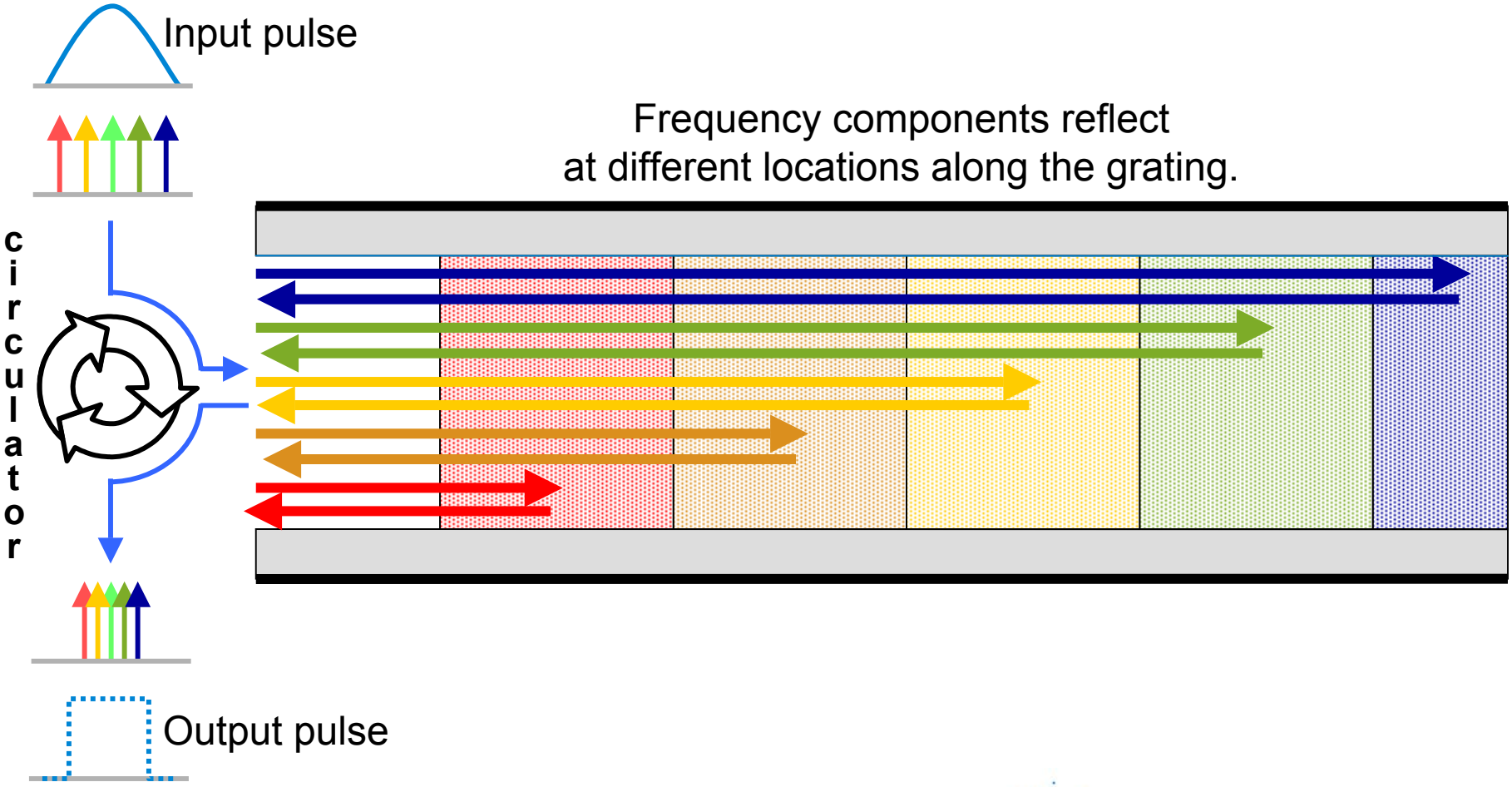
Conventional single-mode fiber



Dispersion compensating fiber

Dispersion Management

Chirped fiber Bragg gratings



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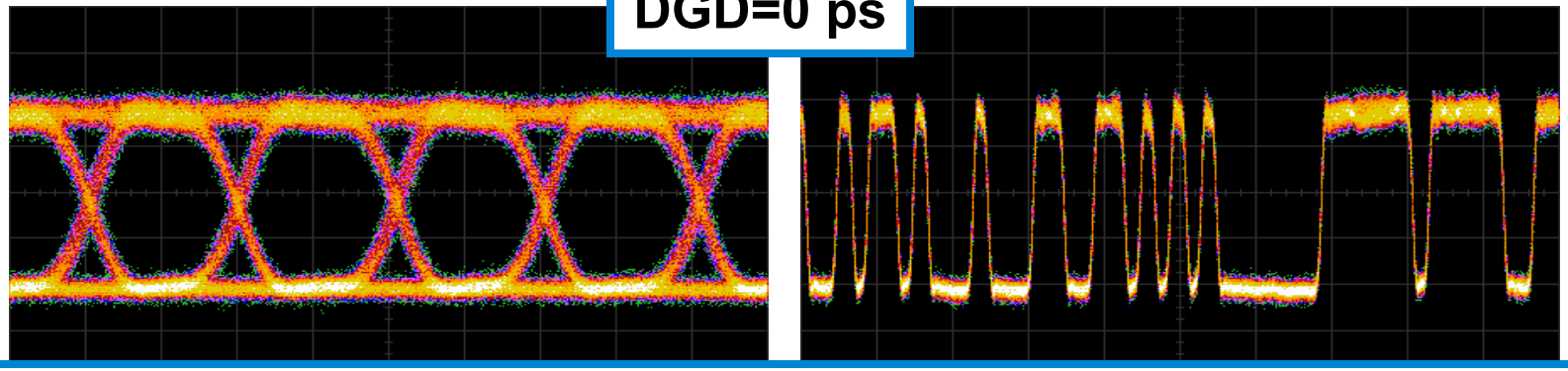
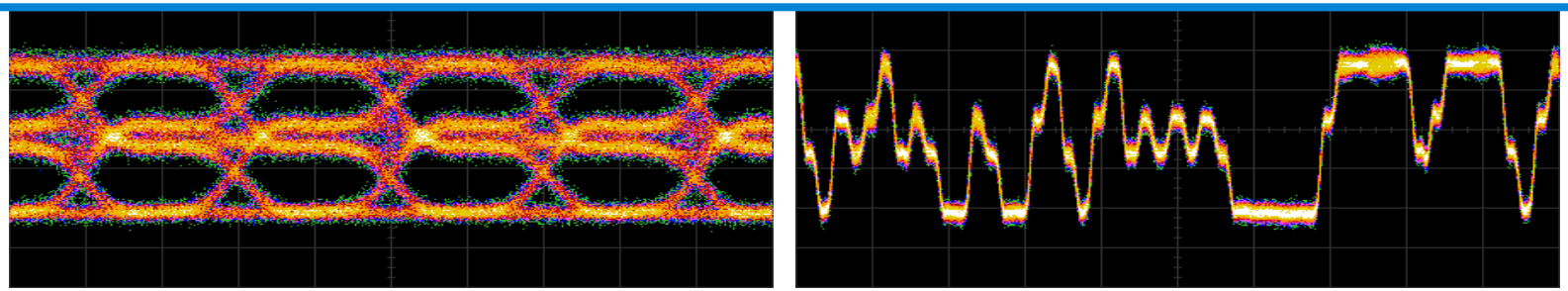
Dispersion Management

Impact of severe *1st-order* PMD in a 10 Gb/s system

DGD=0 ps



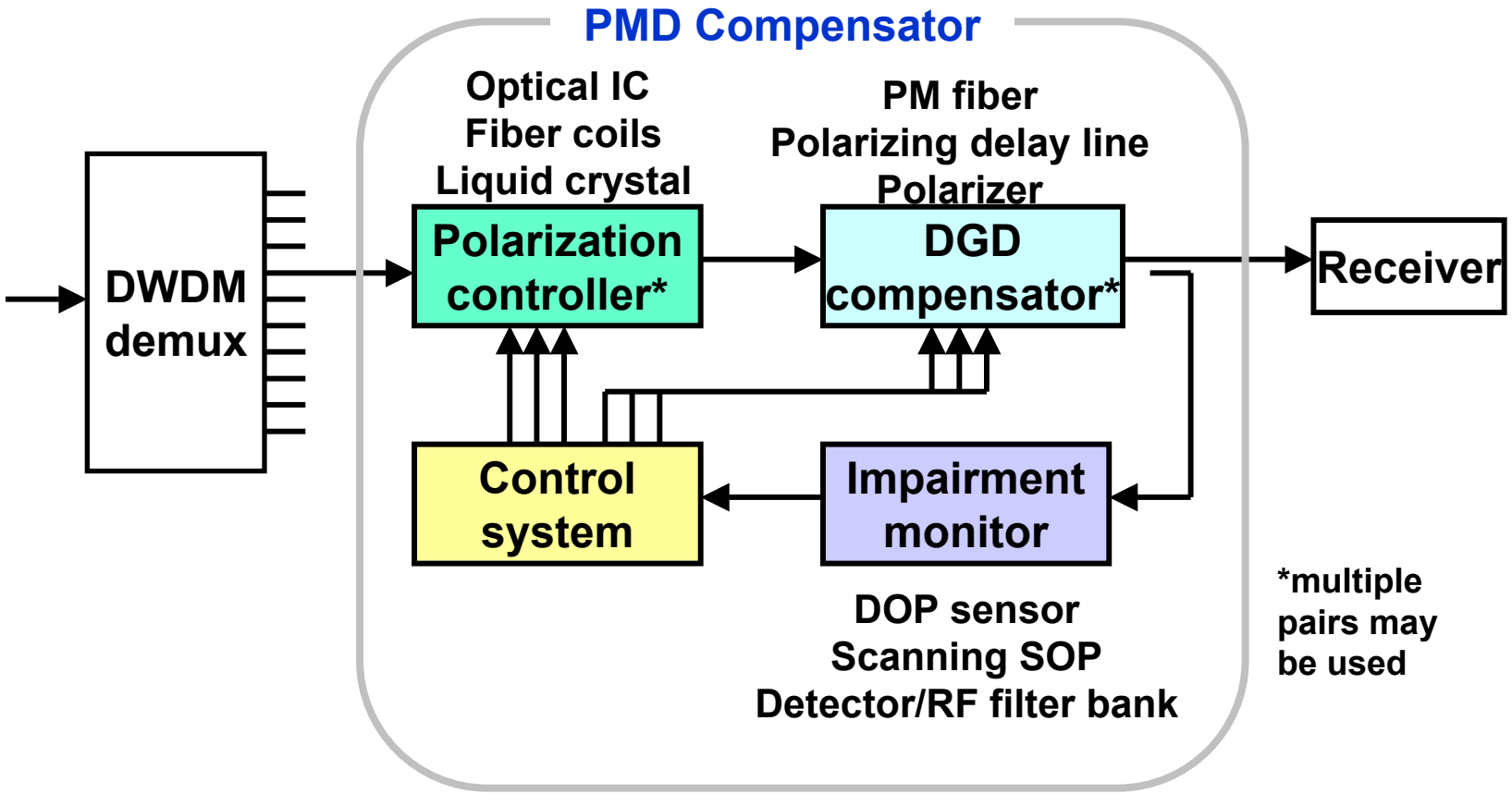
DGD~1 bit period, light roughly split between fast, slow modes)



In actual systems, the average DGD over time and wavelength must be < 0.15 bit period.

Dispersion Management

Optical PMD compensation at the receiver



Adjust to cancel DGD or to transmit on a single polarization mode.

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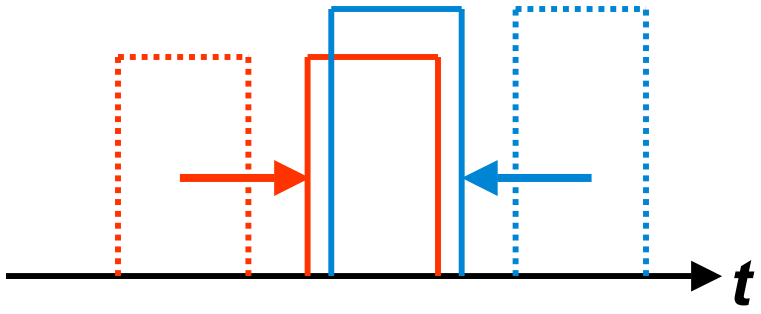
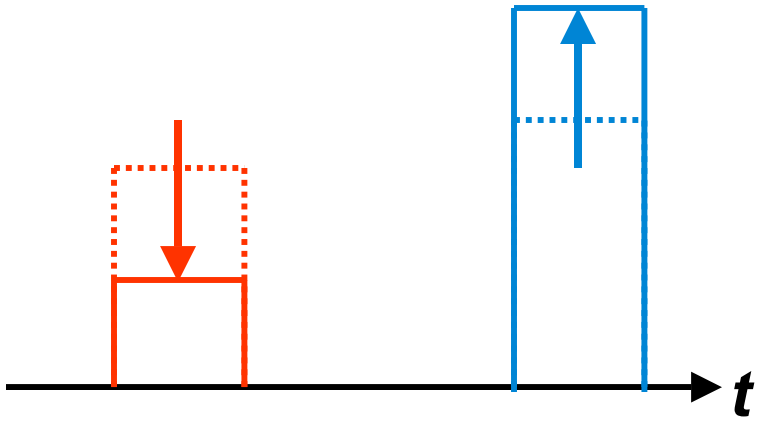
Dispersion Management

Strategies for 1st-order optical PMDC



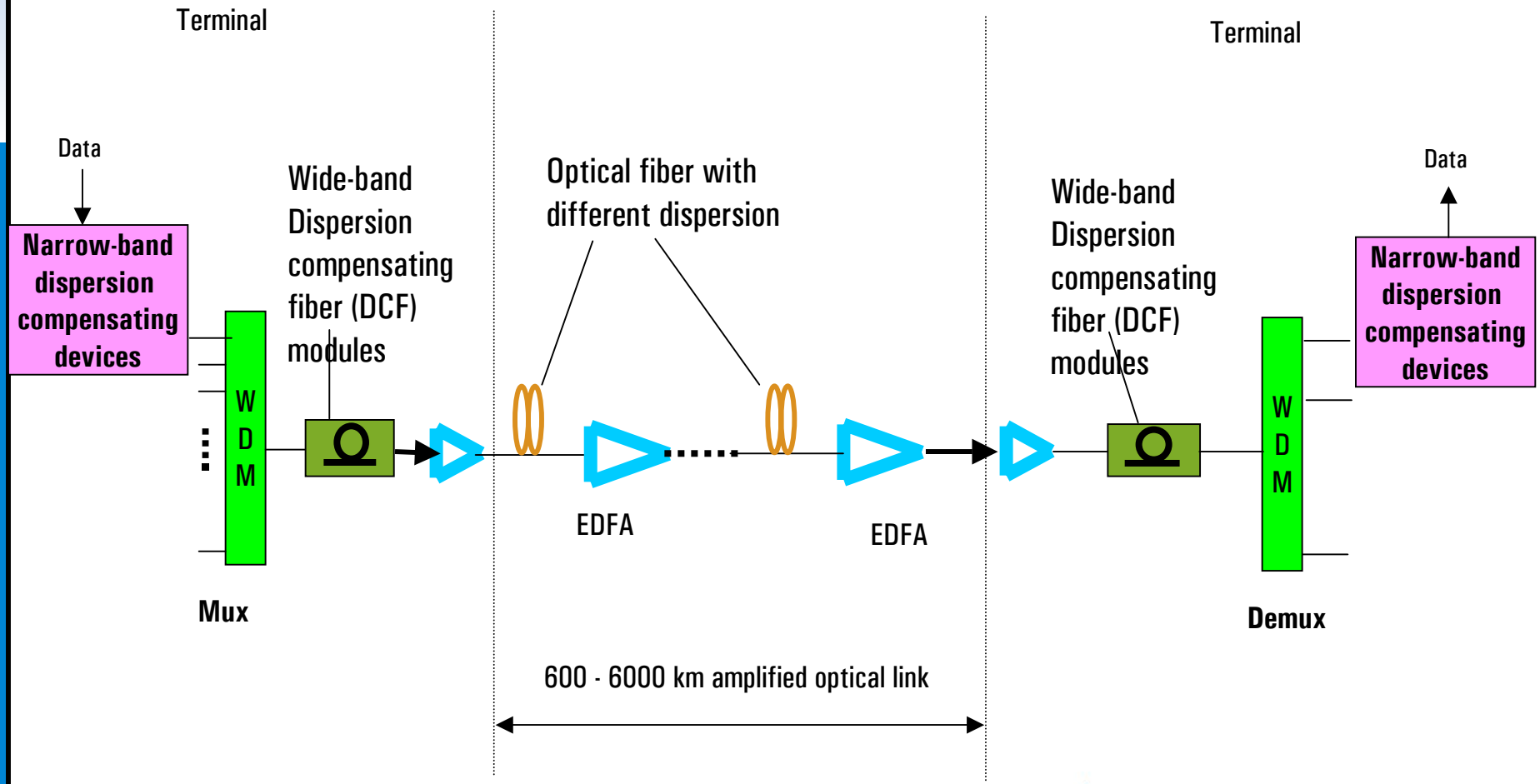


A: Cancel the link DGD with the compensator DGD. This slides the 'fast' & slow' pulses back together.

B: Bring the signal polarization and a PSP into alignment. This darkens the other pol'n mode.

Dispersion Management

Optical network



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Topics

Conceptual review of chromatic and polarization-mode dispersion

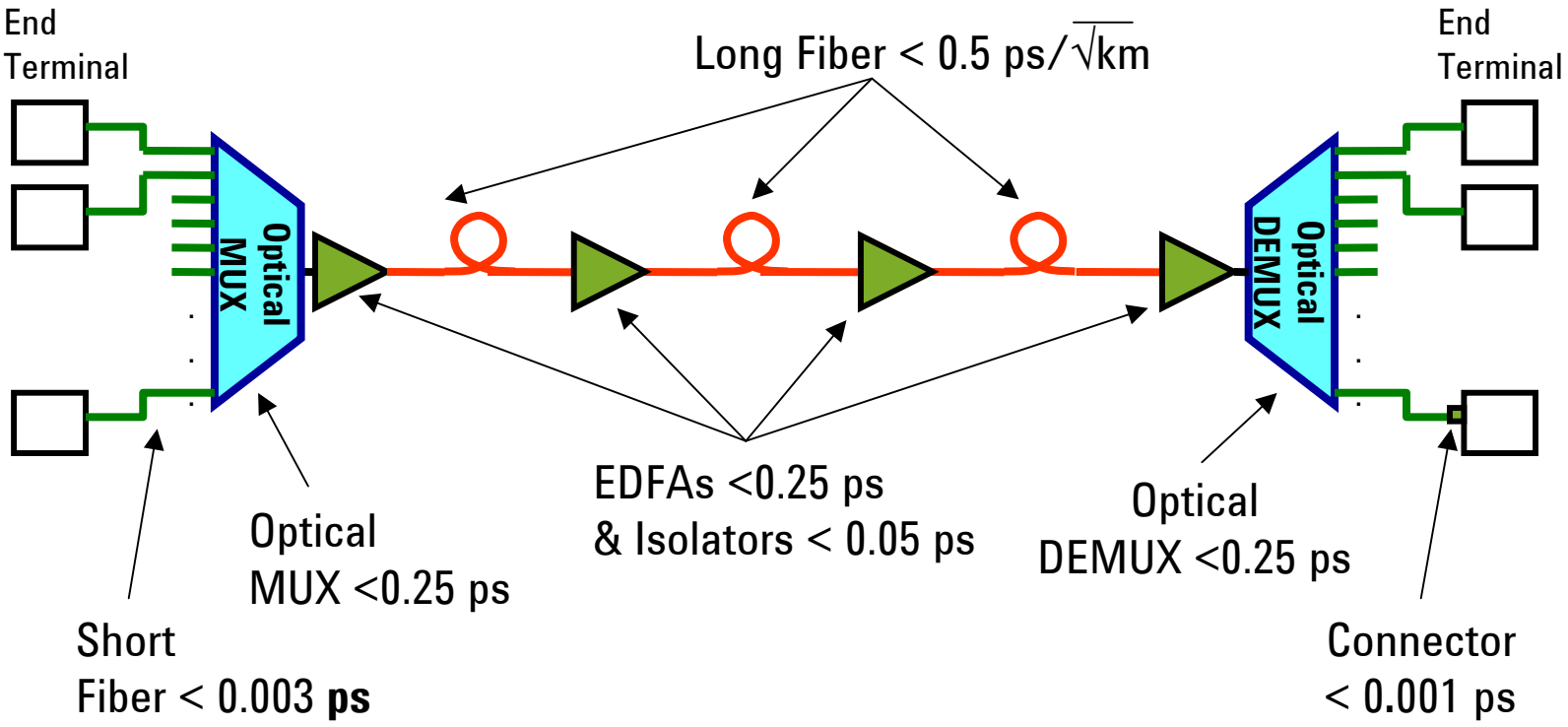
Impact of CD and PMD on high-speed digital lightwave systems

Common CD and PMD measurement methods

New dispersion measurement solutions offered by Agilent

CD and PMD Measurements

All components require CD and PMD to be measured at rates above 10 Gb/s



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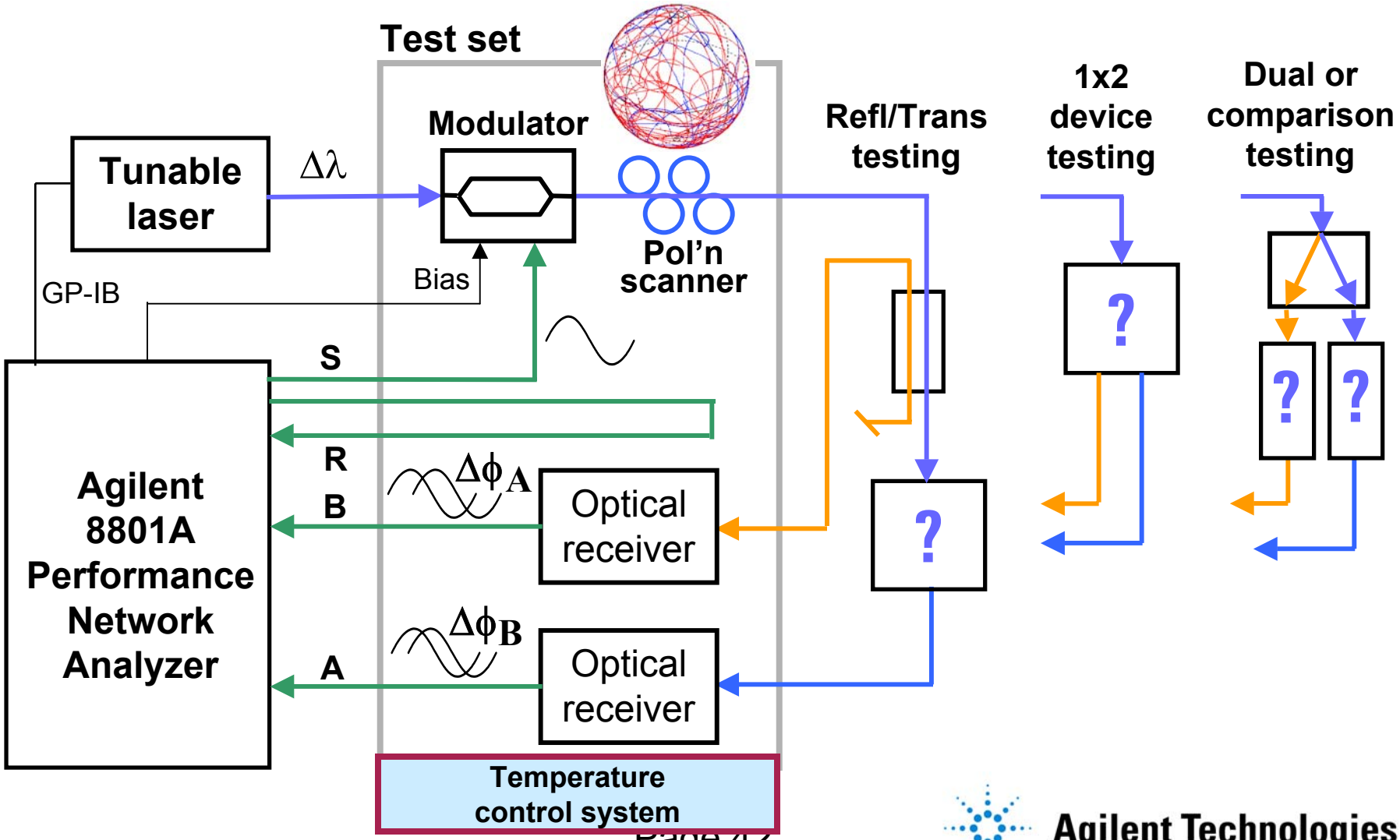
CD measurement methods

- Modulation Phase Shift Method - Agilent 86038A
- Differential Phase Shift Method
- Swept Homodyne Method - Agilent 81910A

CD and PMD Measurements

Modulation Phase Shift method - block diagram



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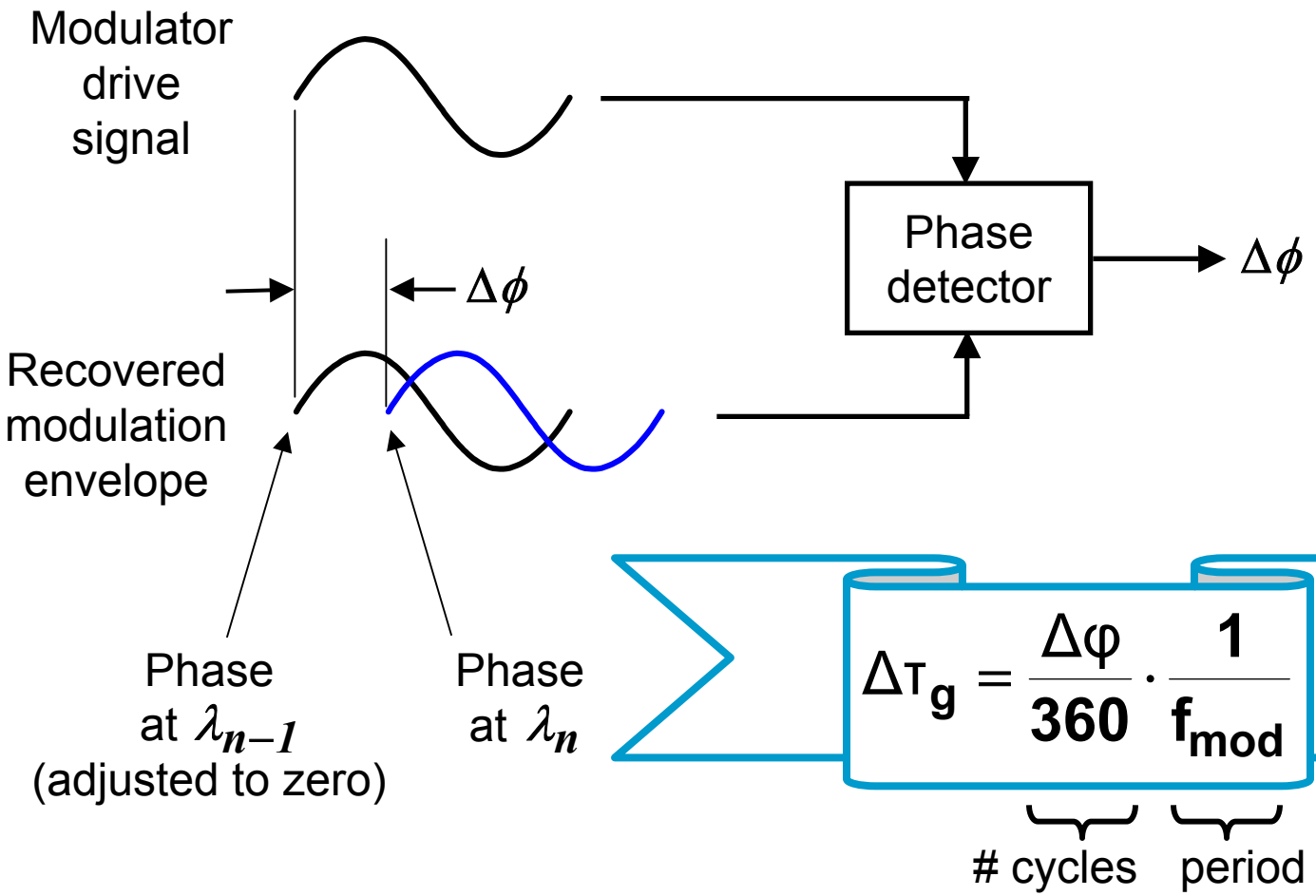
CD and PMD Measurements

How relative group delay is determined



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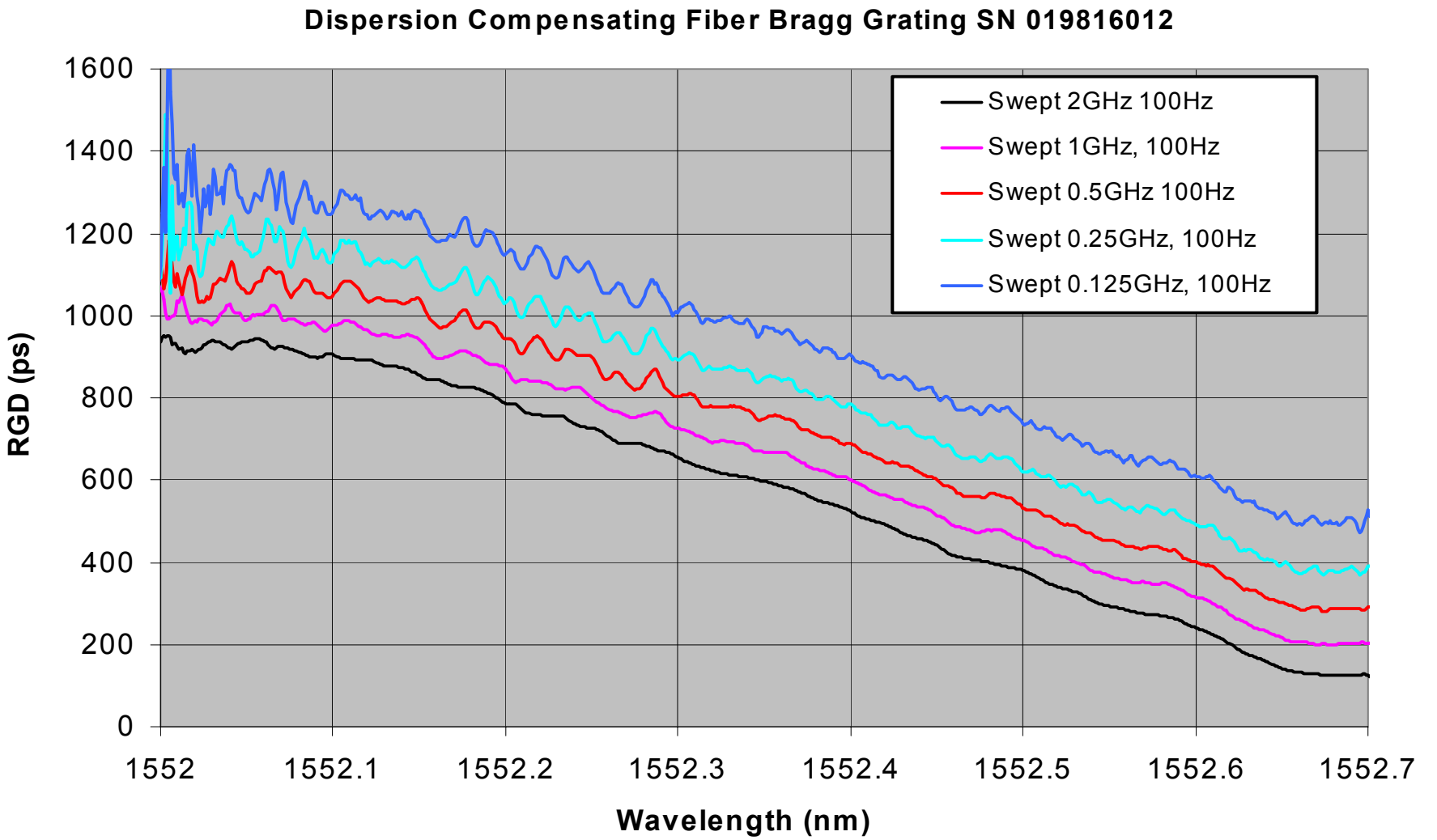
CD and PMD Measurements

Zooming in on group delay ripple



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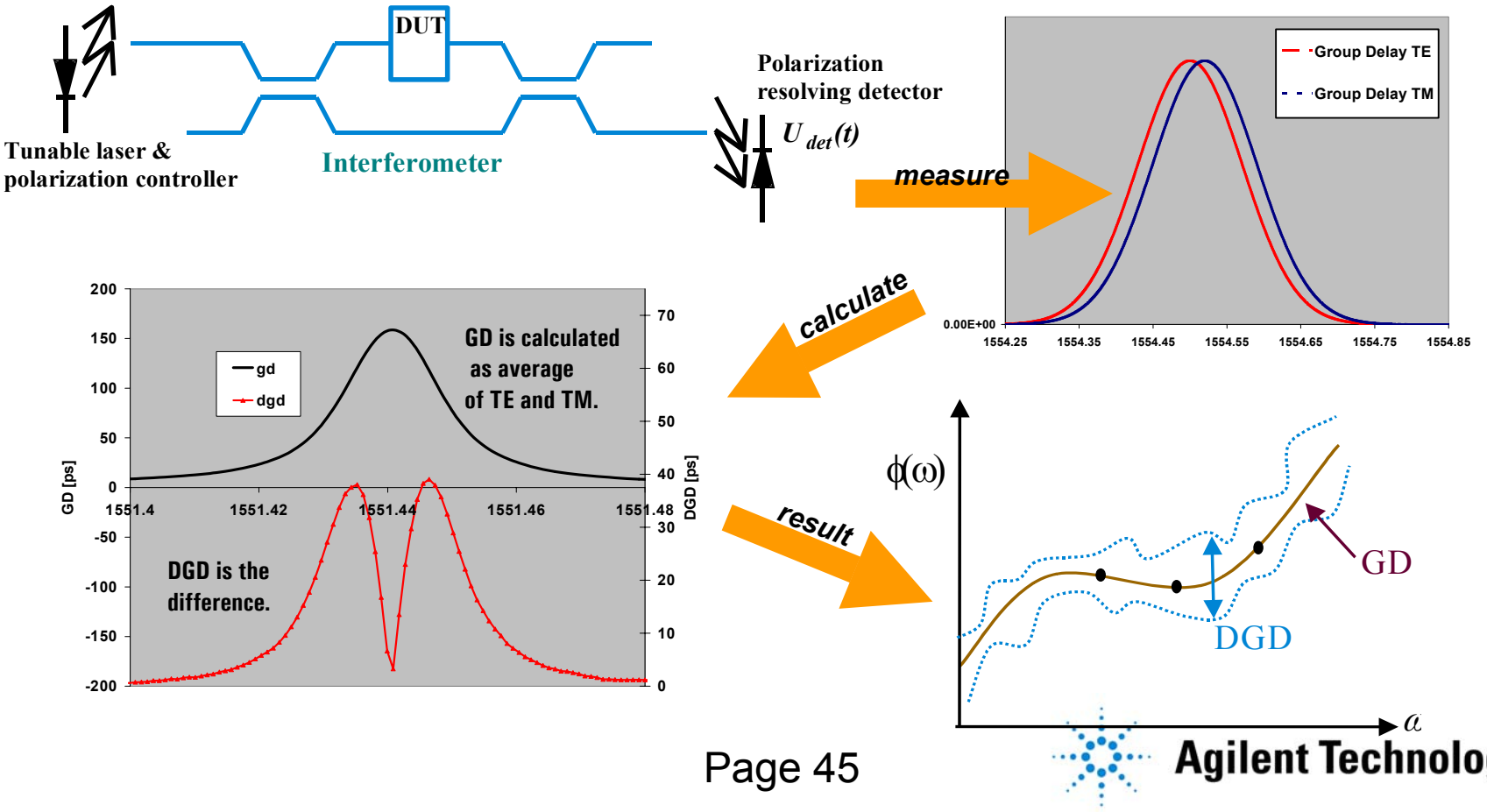
CD and PMD Measurements

Swept Homodyne Method

- Polarization resolved swept homodyne method uses Jones calculus for determination of Group Delay and Differential Group Delay.



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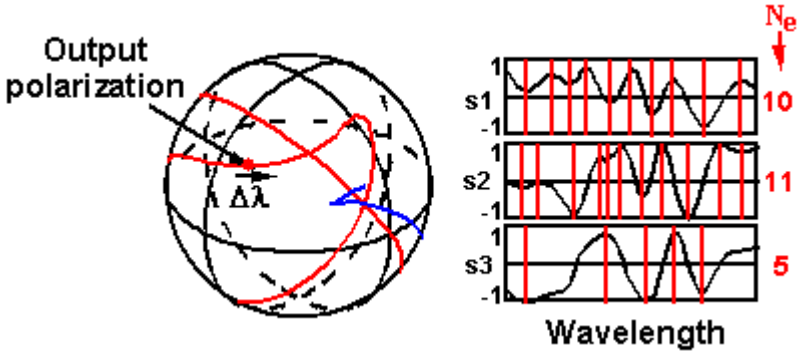
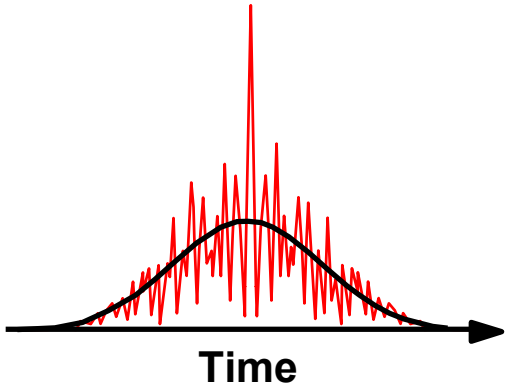
CD and PMD Measurements

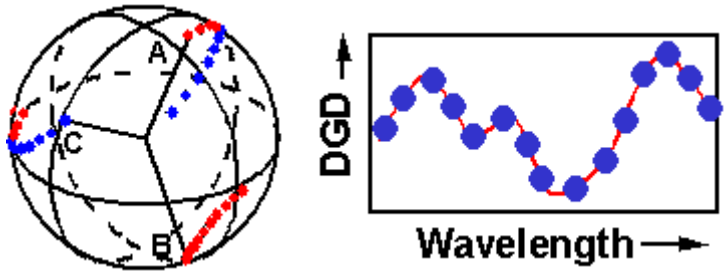
Common PMD measurement methods



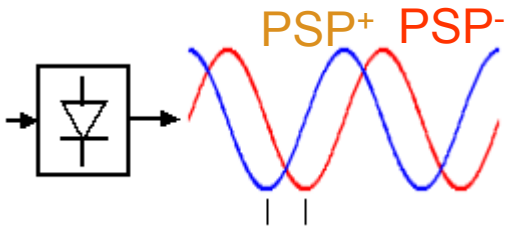
Fixed analyzer (wavelength scanning)



Low coherence interferometry



Polarimetric
(e.g., JME, PSA, Mueller matrix)



$$DGD(\lambda_0) = \frac{\Delta\varphi}{360} \cdot \frac{1}{f_{mod}}$$

Modulation phase shift

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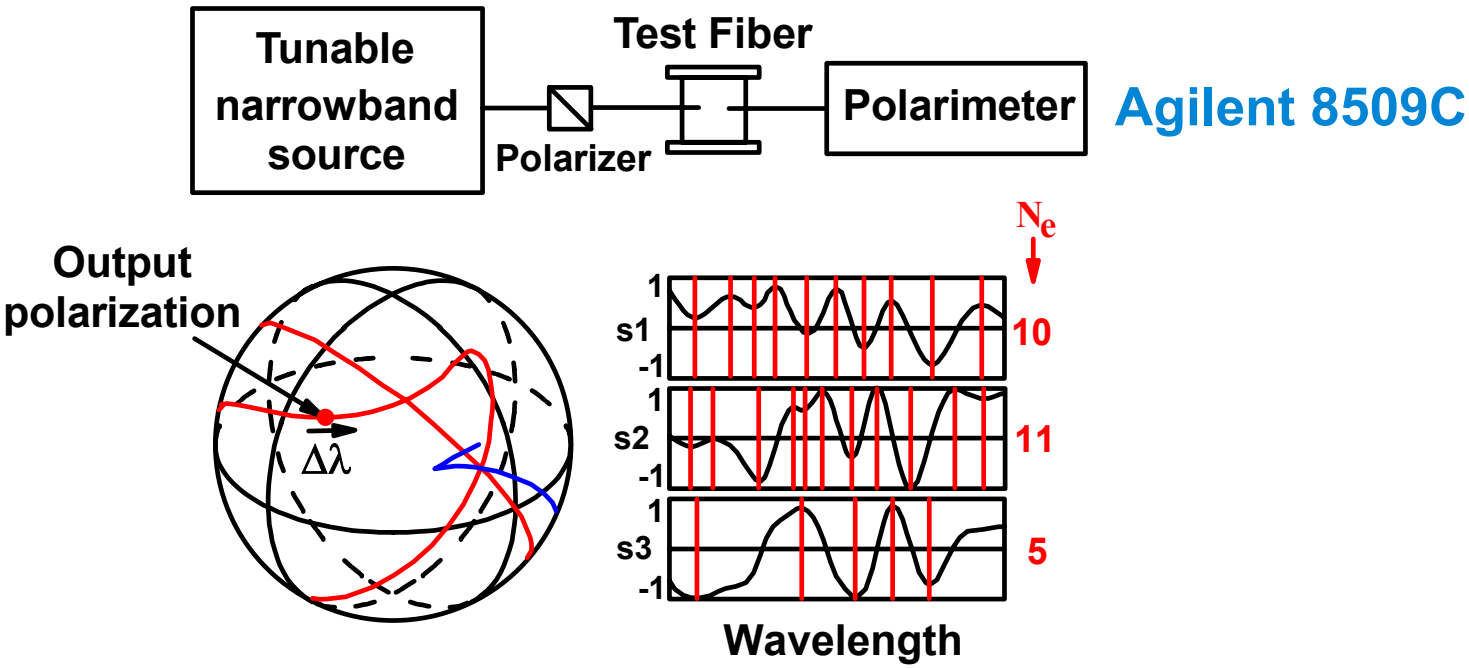
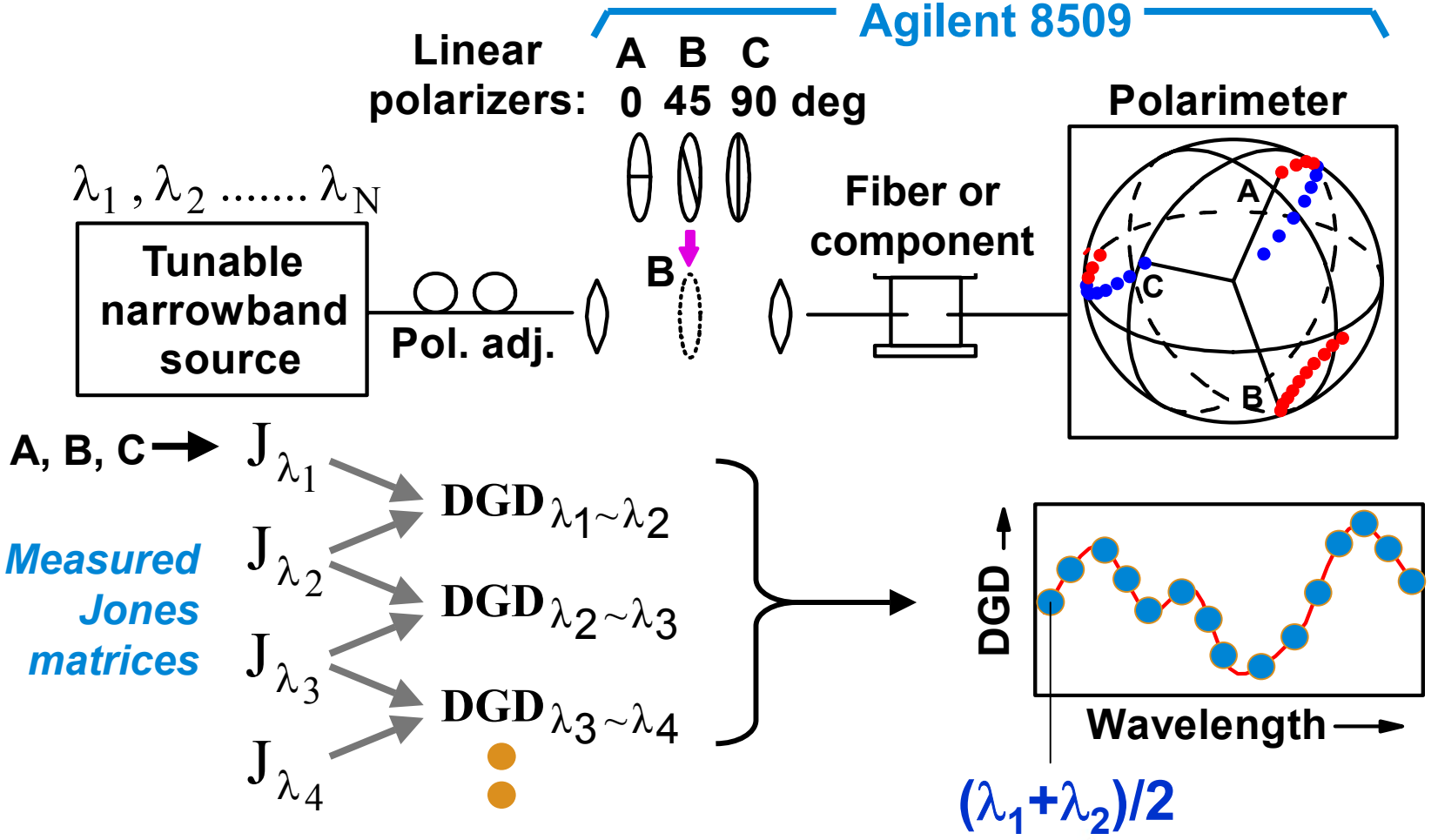
Fixed Analyzer PMD measurement method



- Fully measures the evolving output polarization.
- Analyzes the ***normalized*** Stokes parameters:

CD and PMD Measurements

JME method (Jones Matrix Eigenanalysis)



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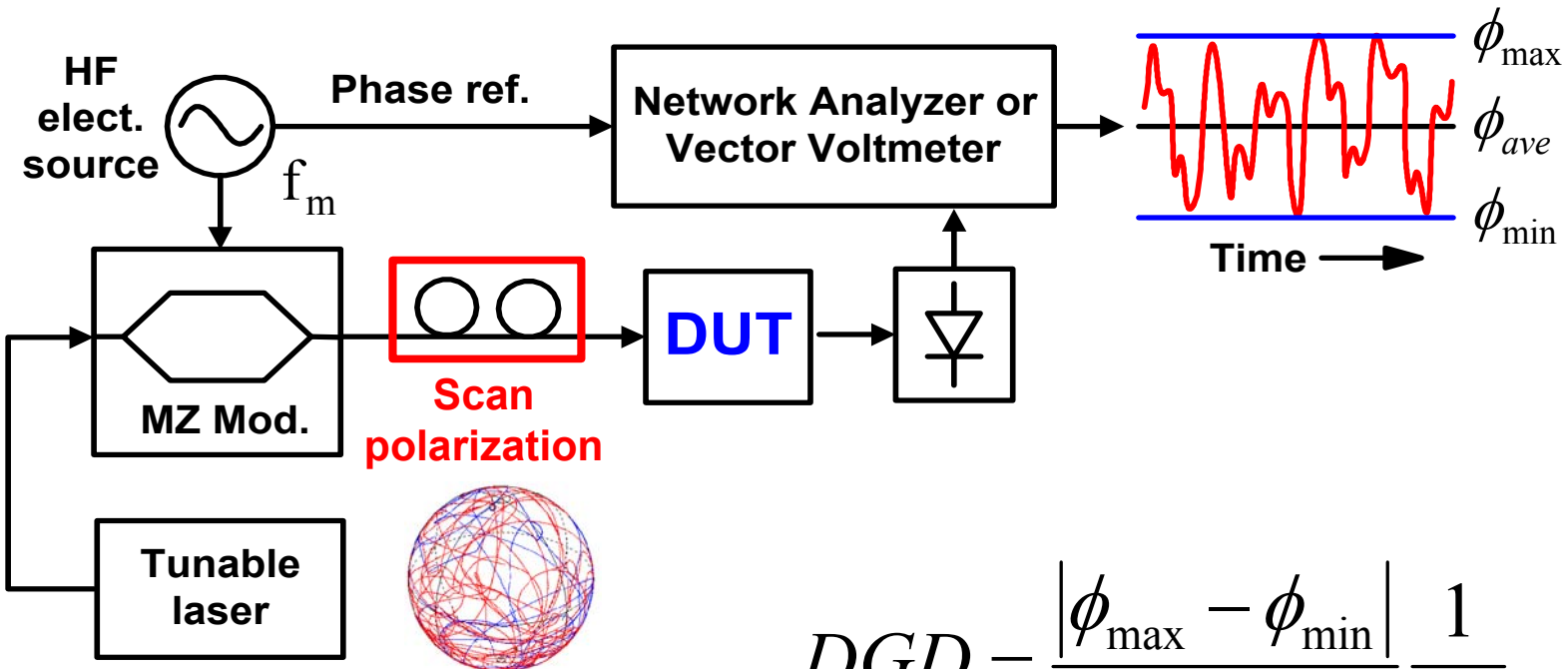
CD and PMD Measurements

MPS method with random polarization scanning



$$DGD = \frac{\left|\phi_{max} - \phi_{min}\right|}{360} \frac{1}{f_m}$$

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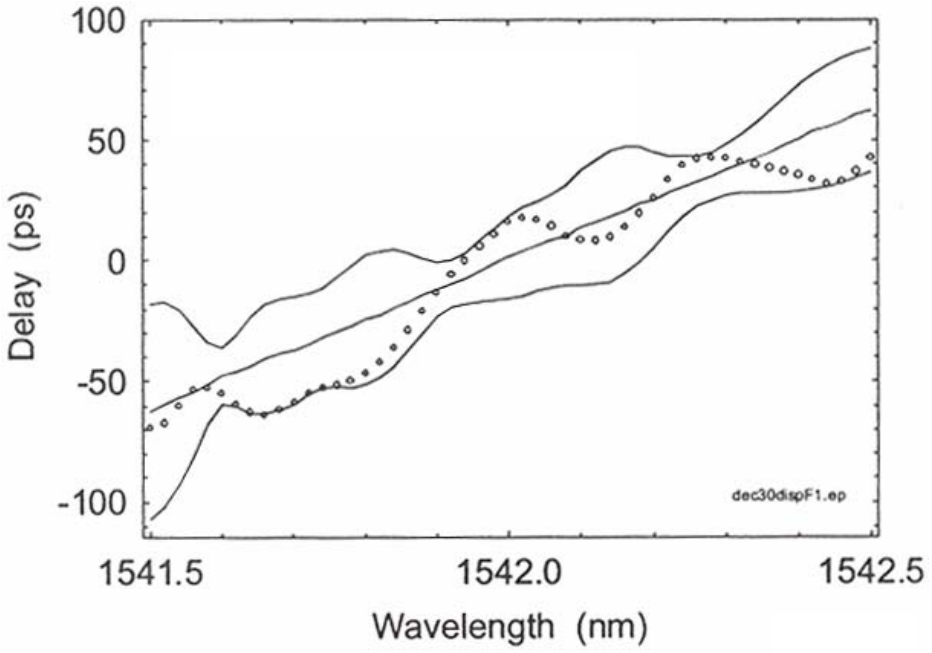
CD and PMD Measurements

Accuracy of CD measurements is affected by PMD



R.M.Jopson
"Measurement issues
for dispersion compensation"
Symp. Optical Fiber Meas.
SOFM'2000, p177.

- Places a limit on dispersion compensation, due to change of PMD with time
- Becomes an issue at high bit rates (10Gb/s, mainly 40+Gb/s)

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Topics

Conceptual review of chromatic and polarization-mode dispersion

Impact of CD and PMD on high-speed digital lightwave systems

Common CD and PMD measurement methods

New dispersion measurement solutions offered by Agilent

Agilent Measurement Solutions

Agilent 86038A - Simultaneous measurements of PMD, CD, GD, PDL and IL

Narrowband devices, fiber, amplifiers and systems

New!

CD measurements corrected for PMD artifacts

2 ports for multiple DUT measurements

S,C and L band coverage 1370-1640nm

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Agilent 86038A Preliminary Specifications

Group delay accuracy (CD) (100MHz to 2GHz)	**<± 0.05 ps (50 fs) ***
Group delay resolution	**1fs**
Differential group delay accuracy (PMD) (100MHz to 2GHz)	**<± 0.05 ps (50 fs)***
Insertion loss accuracy	**< ± 50 mdB**
Polarization Dependent Loss accuracy (PDL)	**< 100 mdB**
Dynamic range	**> 50 dB**
Measurement Speed for CD / IL	**< 3 ms/point**
Wavelength accuracy (with integrated 86122A wavemeter)	**±0.3 pm***

*** Industry leading accuracy**

Agilent Measurement Solutions

rAPTOr 81910A Photonic All-parameter Analyzer

- What happened in 1999? Critical components moved into DWDM.
- Agilent invented a laser with unprecedented wavelength accuracy and signal purity.

1999 → **2002**

- What happens today? In addition to loss, dispersion measurement is required for critical components as well.
- Agilent combines its laser performance with a high resolution dispersion measurement to the 81910A: optimized for all-parameter test.

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Agilent Measurement Solutions

rAPTOr 81910A Photonic All-parameter Analyzer

Insertion Loss
- < ±10mdB uncertainty
- > 55dB dynamic range

industry leading

PDL
- < ± 30mdB uncertainty

All parameters are measured simultaneously in transmission and reflection

Group Delay
- < ± 50fs uncertainty

@ 10pm resolution

Differential Group Delay
- < ± 50fs uncertainty for narrow-band devices
- < ± 100fs uncertainty else

⇨ Thorougly measure spectral loss, PDL, group delay and DGD with high accuracy and throughput
⇨ Advances and integrates the industry standard for spectral loss measurement
⇨ Swept performance of all measurements for highly accurate, hi-throughput test and characterization
⇨ Removes uncertainty for Loss and Group Delay by averaging over polarization dependency
⇨ Integrated optical bench - device connected once for all parameters - single setup, one button test
⇨ Upgrading already existing tunable laser based loss setups saves prior investment.

Agilent 86038A and Agilent 81910A

Both Agilent 86038A and 81910A provide :

✓ Accurate measurements of all 4 device parameters IL, PDL, GD, DGD with single connection and a single button approach both in transmission and reflection from 1370 – 1640nm.

✓ Reduced cost of test, increased throughput, and maximum yield by measuring all device parameters using just a single test setup.

86038A and 81910A: Product specific features

Product specific features of 86038A:

- ✓ Successor of golden standard 86037C CD test system
- ✓ Best optimized for dispersion measurements
- ✓ Best optimized for broadband components with good leverage into narrow-band devices

Product specific features of 81910A:

- ✓ Member of Agilent Lightwave Measurement System
- ✓ Best optimized for all-parameter test
- ✓ Best optimized for narrow-band components with good leverage into broadband devices

The Road to 40 Gbit/s

Conclusions

- **CD and PMD limit the performance of high speed networks.**

- **Overcoming CD and PMD will likely be the biggest barrier in deploying 40 Gbit/s DWDM networks.**

- **Dynamic CD and PMD compensation may be required in lowering 40Gbit/s network costs for commercialization.**

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