Introduction to Dispersion

ISO 9001

Introduction To Dispersion

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Contents

- Definition of Dispersion
- Chromatic Dispersion
- Polarization Mode Dispersion

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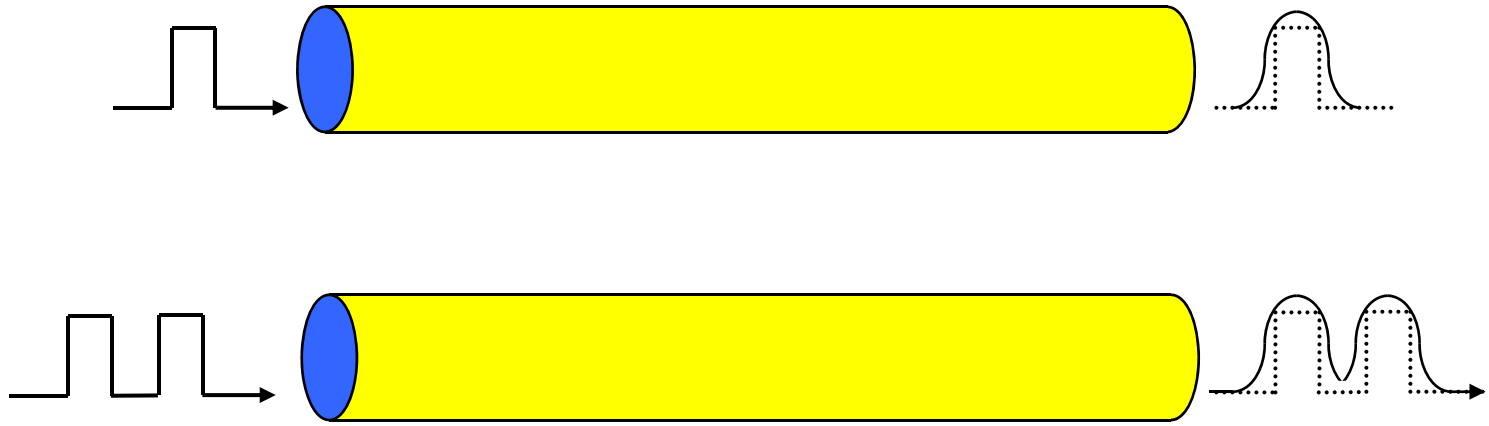
Outline

- Introduction to Dispersion
- Chromatic Dispersion
- Why measure Chromatic Dispersion in the field?
- FD-440 Chromatic Dispersion Measurement System

What is Dispersion?

- Dispersion is the spreading or broadening of light pulses as they propagate through the fiber
- Too much dispersion gives rise to bit-errors at the receiver (i.e., the inability to distinguish a 0 from a 1)



Dispersion is Caused by Differential Delay

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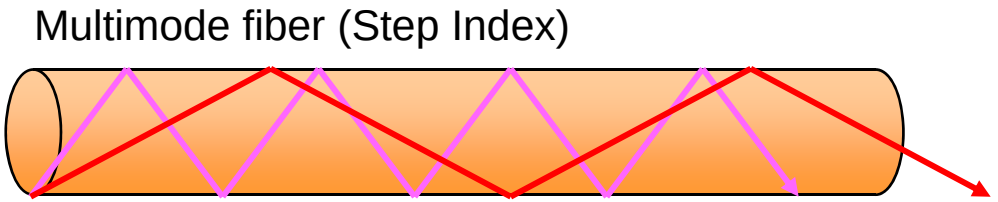
- What is differential delay?
  - Signal is made of two or more components
  - Each component travels at different speeds
  - Different components arrive at different times
  - Difference in arrival time at receiver is the differential delay
- Dispersion is a fundamental limiting factor in transmission links:
  - Limit data rate on long fibers
  - Limit length on high data rate fibers
- Common system design rule:
  - To minimize the effects of dispersion (i.e., keep bit-errors to an acceptable level), limit total differential delay to 10% of bit rate

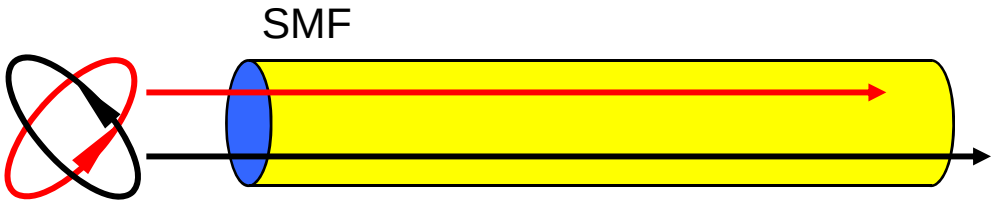
Types of Dispersion

- **Intermodal Dispersion**
  - In multimode fiber, is caused by the different path lengths of the different modes. Different lengths result in different arrival times



- **Chromatic Dispersion**
  - Caused by non-zero spectral width of light source (i.e., more than one wavelength of light). Different wavelengths travel at different speeds.

- **Polarization Mode Dispersion**
  - Caused by orthogonal polarization modes traveling at different speeds.



Digital Communication Bit Times

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SONET	SDH	Transmission Rate	Bit Time	Dispersion Limit [1]
OC-1		51.84 Mb/s	19.29 ns	2 ns
OC-3	STM-1	155.52 Mb/s	6.43 ns	640 ps
OC-12	STM-4	622.08 Mb/s	1.61 ns	160 ps
OC-24		1244.16 Mb/s (1.2 Gb/s)	803.76 ps	80 ps
OC-48	STM-16	2488.32 Mb/s (2.4 Gb/s)	401.88 ps	40 ps
OC-192	STM-64	9953.28 Mb/s (10 Gb/s)	100.47 ps	10 ps
OC-768	STM-256	39,813.12 Mb/s (40 Gb/s)	25.12 ps	2 ps

[1] Dispersion is typically limited to 10% of the bit time

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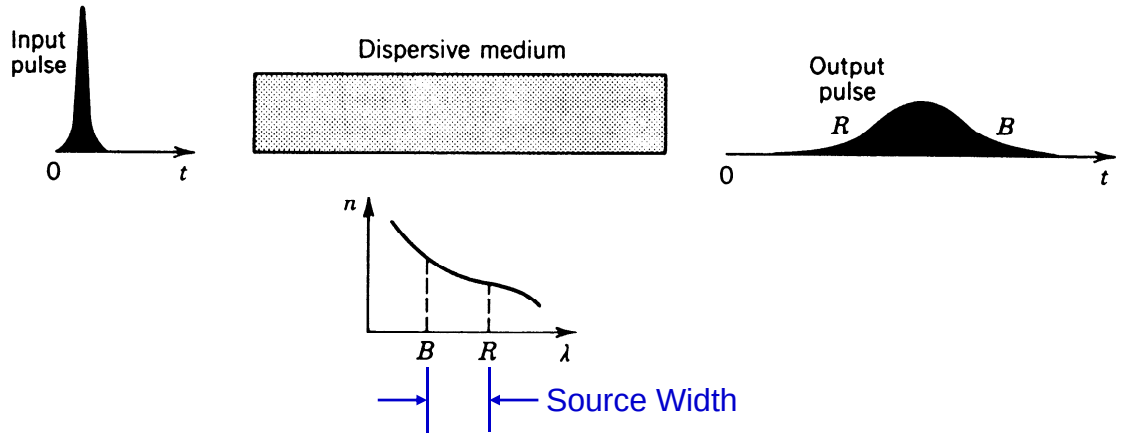
Chromatic Dispersion

- Pulse Spreading due to the fact that different wavelengths of light travel at different speeds.
- Since source is not mono-chromatic (a single wavelength), each wavelength component travels at a slightly different speed.



Understanding Specifications

- Chromatic Dispersion (D) specified in ps/nm*km
  - differential delay (in ps)
  - per wavelength spread (in nm) of the source width (laser line width)
  - per length of route (in km)
- D > 0: indicates that slightly longer wavelengths travel faster
- D = 0: indicates that slight changes in wavelength do not affect propagation speed
- Common specs include:
  - *zero dispersion point*
  - *zero dispersion slope*

Chromatic Dispersion Effects

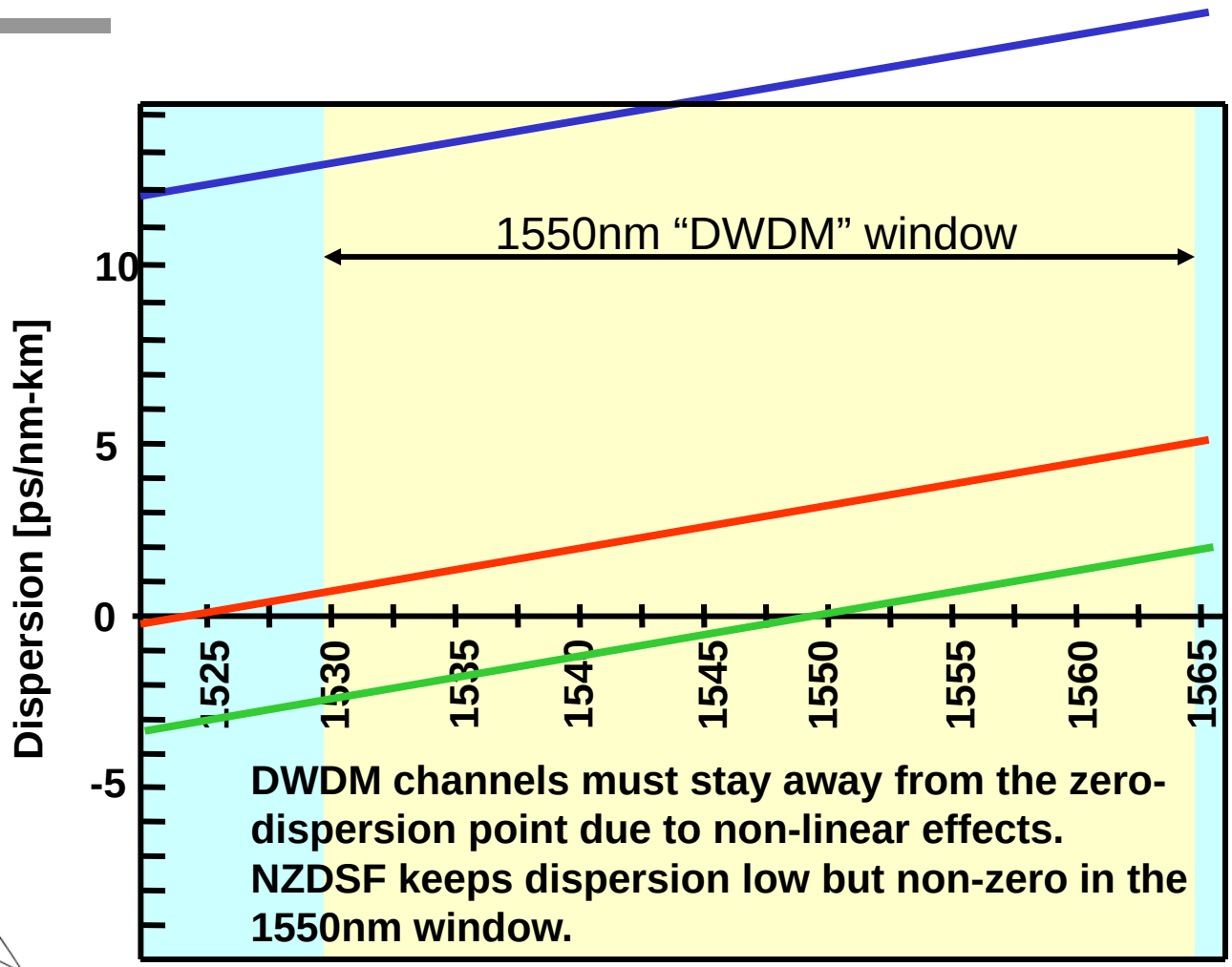
- Two effects contribute to the total chromatic dispersion:
  - material dispersion
  - waveguide dispersion
- Material dispersion depends on glass type (impurities, etc.)
- Waveguide dispersion depends on fiber's refractive index profile
  - can be engineered to specify location of zero dispersion point and slope
  - allows manufacture of specialty fibers with desired dispersion profile

Fiber Types

	Attenuation (dB/km)		Chromatic Dispersion (ps/nm*km)	
Fiber Type	**1310 nm**	**1550 nm**	**1310 nm**	**1550 nm**
9/125 Conventional (SMF-28)	0.35	0.25	0	17
9/125 Dispersion Shifted	0.35	0.25	-15	0
9/125 WDM Optimized	0.35	0.25	-12	3

- Conventional fiber ("SMF") known as "Unshifted"
- Dispersion Shifted fiber has zero dispersion point "shifted" to 1550 nm
- "WDM Optimized" fiber is known as Non-Zero Dispersion Shifted Fiber (NZDSF)

Dispersion Profile of Fiber Types



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CD Measurements in the Field

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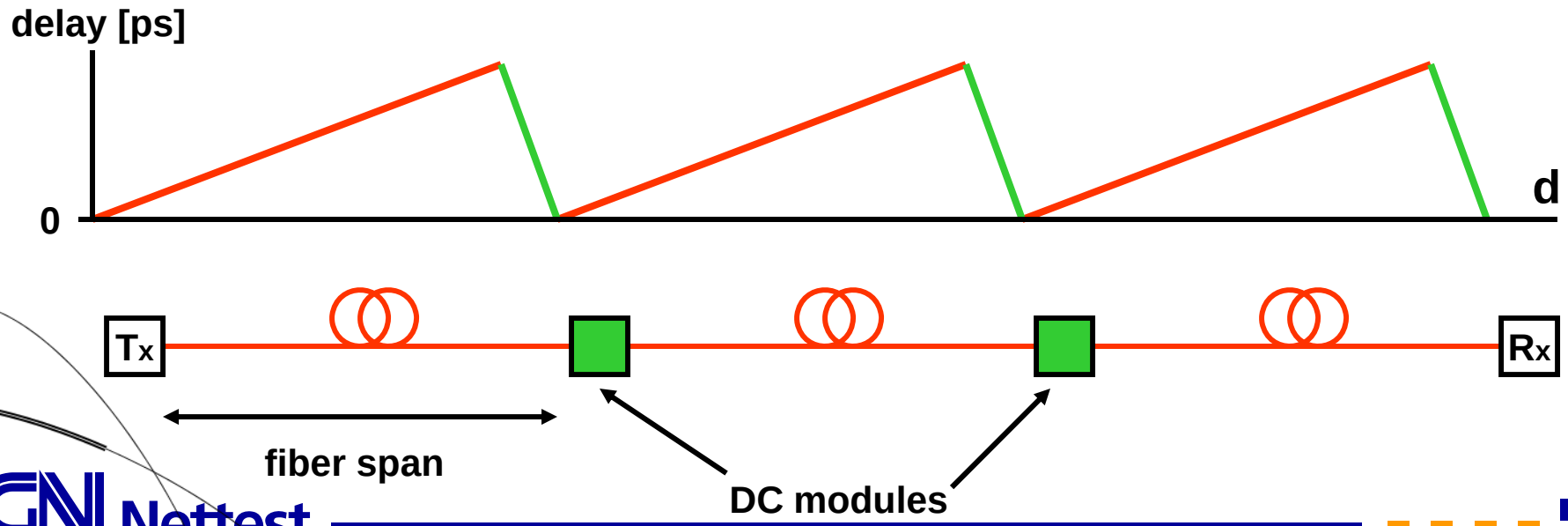
- Several uses for dispersion measurements in the field:
  - Measure fiber type
    - verify installed fiber type for bandwidth or DWDM upgrade
    - verify fiber zero point and slope for new installation
    - some fiber types incompatible with DWDM systems
  - Double-check dispersion compensation plan
    - at installation
    - during troubleshooting
  - Careful dispersion engineering for WDM system installation
    - dispersion compensation is wavelength dependent

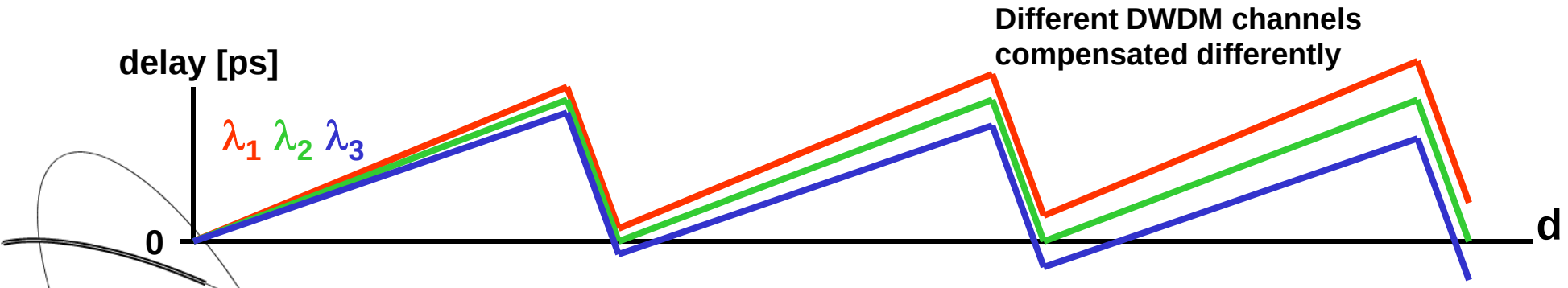
Dispersion Compensation

- The Good News: CD is stable, predictable, and controllable
  - Dispersion zero point and slope obtained from manufacturer
  - Dispersion compensating fiber (“DC fiber”) has large negative dispersion
  - DC fiber modules correct for chromatic dispersion in the link



Dispersion Compensation for DWDM

- Dispersion compensation modules can only compensate exactly for one wavelength
- DWDM system design requires knowledge of end-to-end CD as a function of wavelength… especially for long-haul
- FD440 used in field to measure actual wavelength dependence of link dispersion



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FD440 Chromatic Dispersion Analyzer

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- Portable, Easy to Use, Field Test Set
- 32dB Dynamic Range quickly tests spans over 120km
- Covers both 1310 nm and 1550 nm windows
- Direct dispersion measurements — *does not rely on curve fitting to just 3 or 4 data points*
- Windows 95/98 PC interface simple and intuitive
- Optional Spectral Attenuation Measurement

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Dispersion Measurement Procedure

- Testing Guidelines:
  - Two-ended test
  - Two fibers used: one for communications, one fiber under test
  - For accurate per-km value, known fiber length needed
- Ease of Use:
  - One-button testing
  - All testing parameters stored in a “test file”
  - Multiple test files stored on instrument
  - Easy editing of test files
  - Automatic file save, file naming, connection check available

Typical (SMF-28) Chromatic Dispersion

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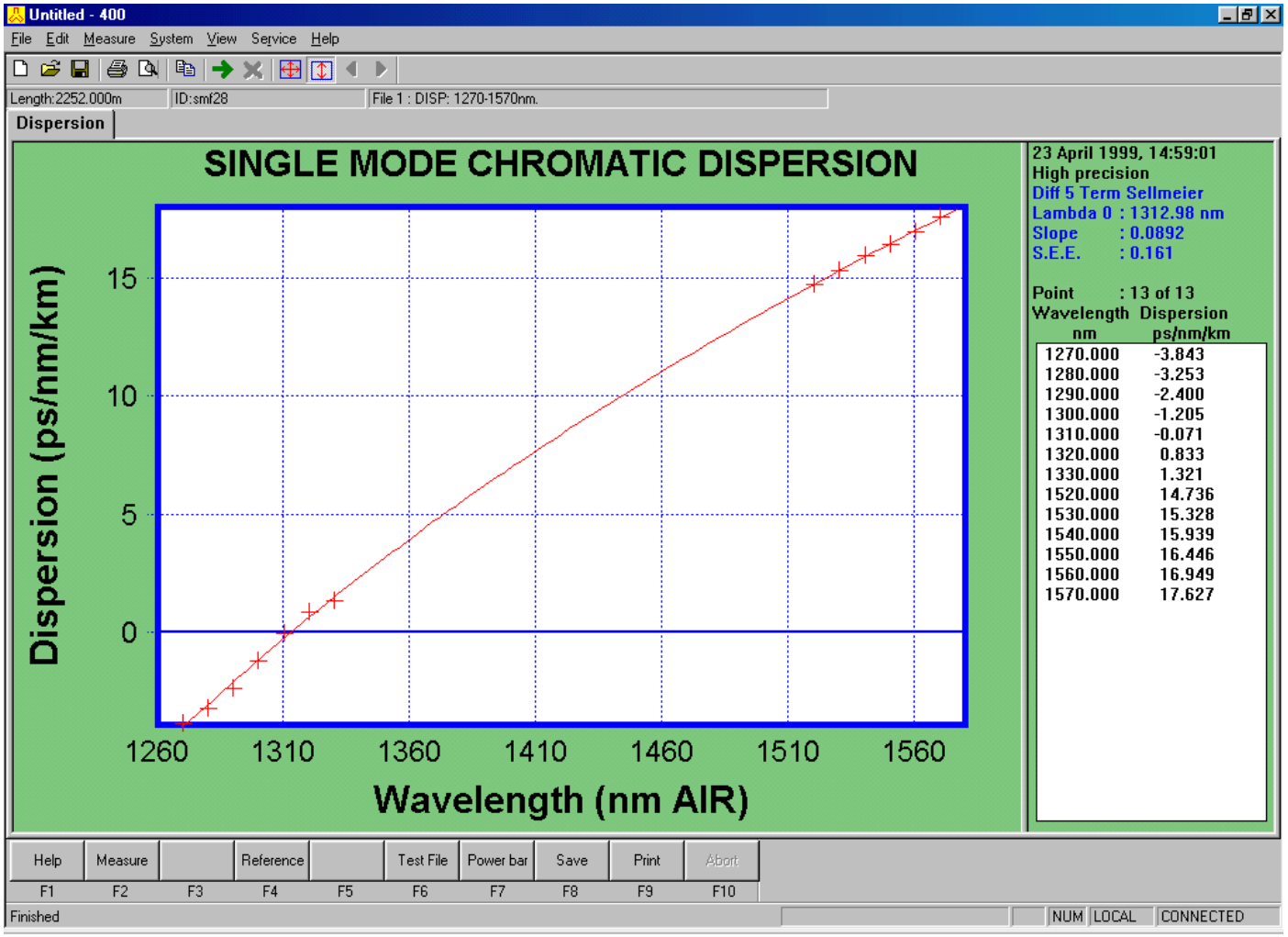
- Main results screen
- Typical SMF dispersion profile shown



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Spectral Attenuation Option

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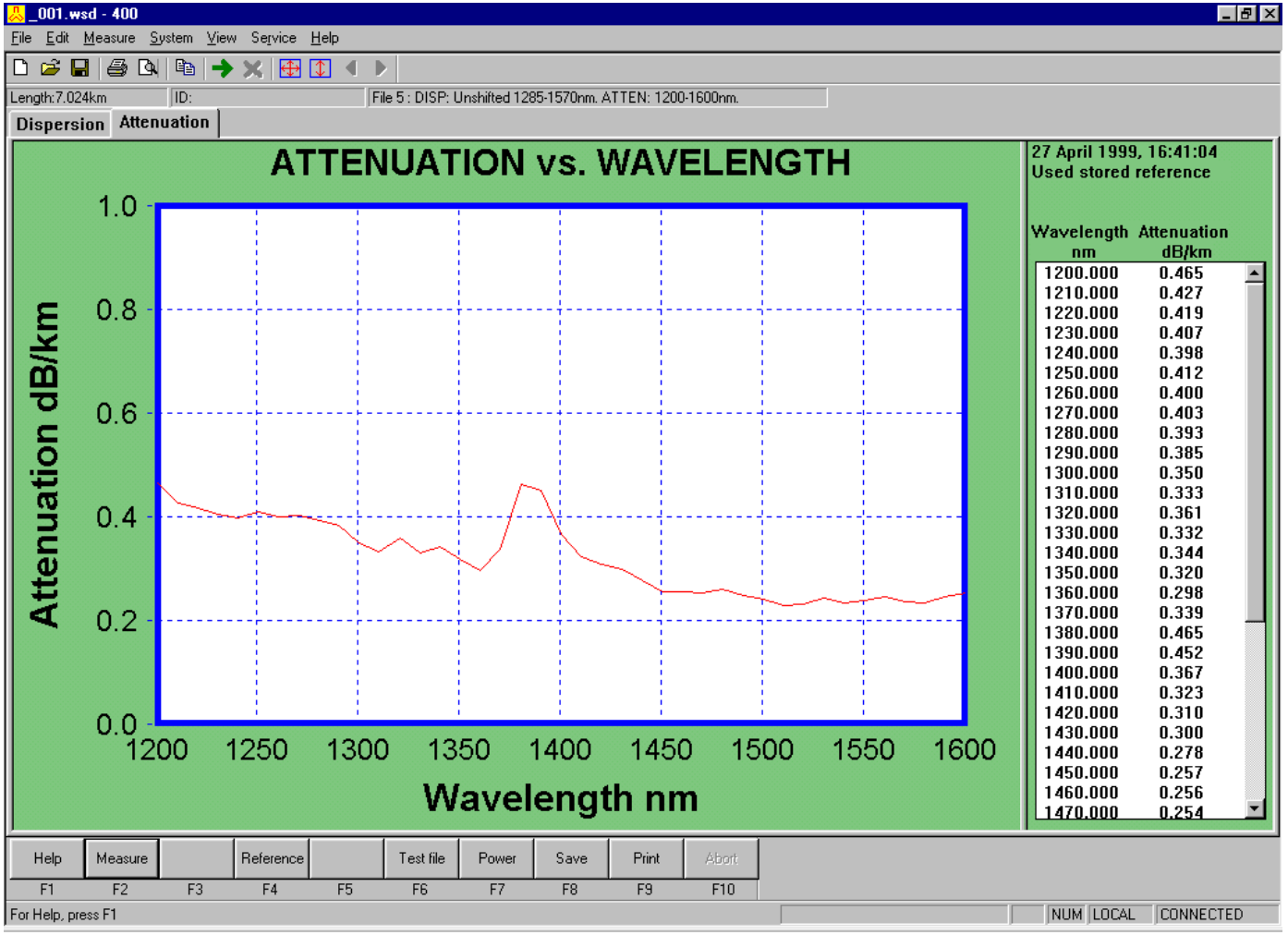
- Optional spectral attenuation measurement
- Note water peak near 1385 nm



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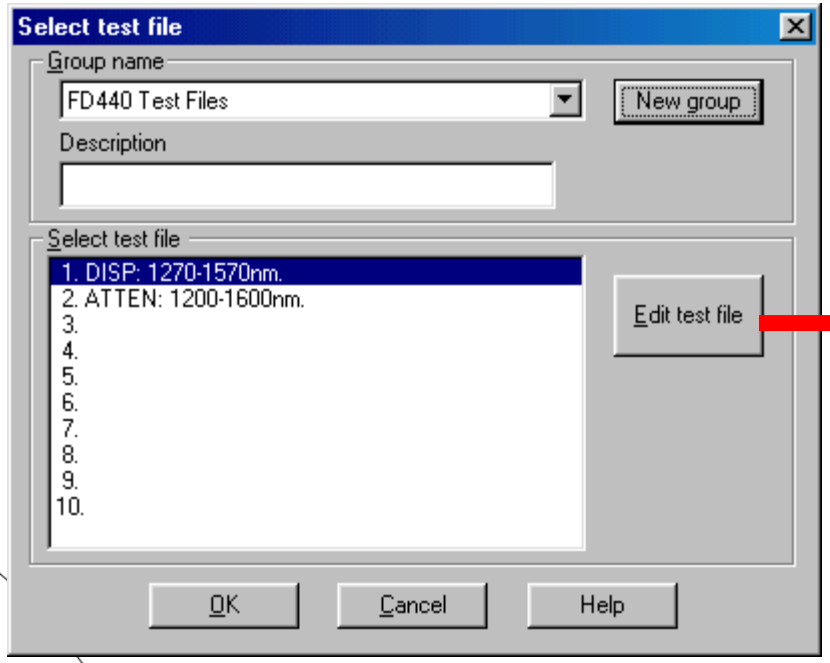
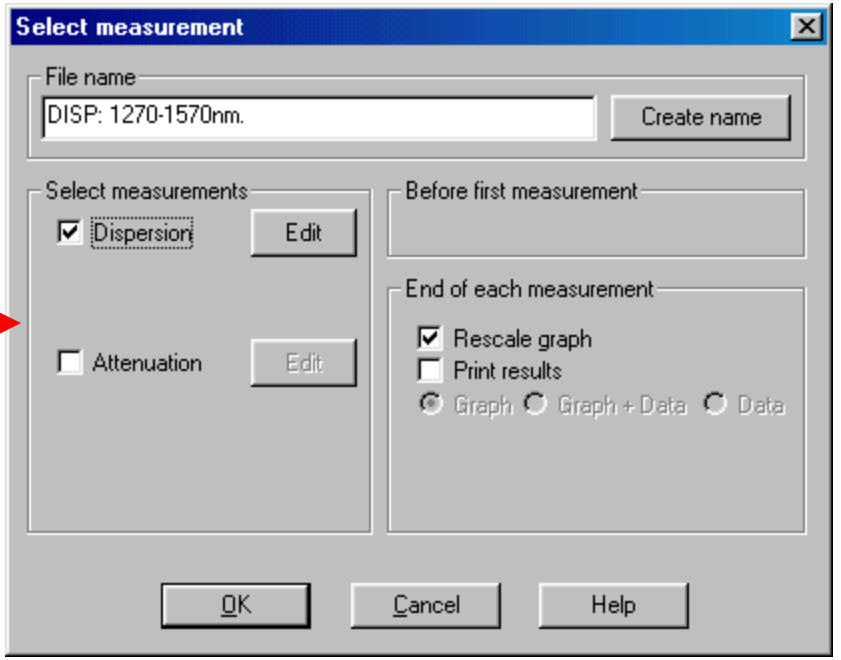
Choosing and Editing Test Files

- Test files appear in a list
- Test file contains dispersion and/or attenuation measurements
- Auto naming of test files available





Setting Test File Parameters

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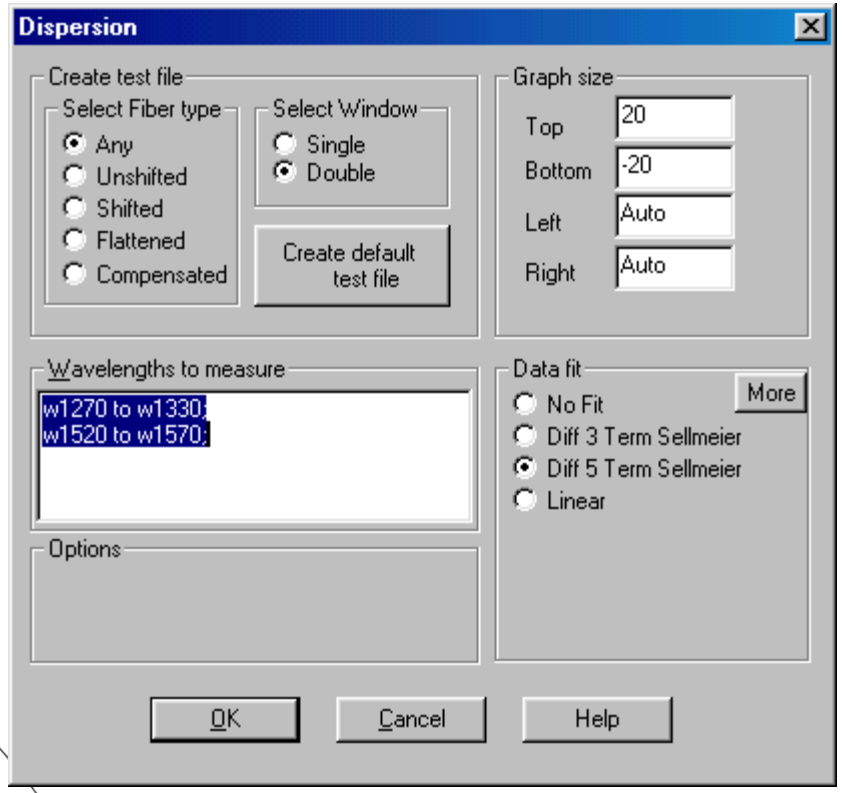
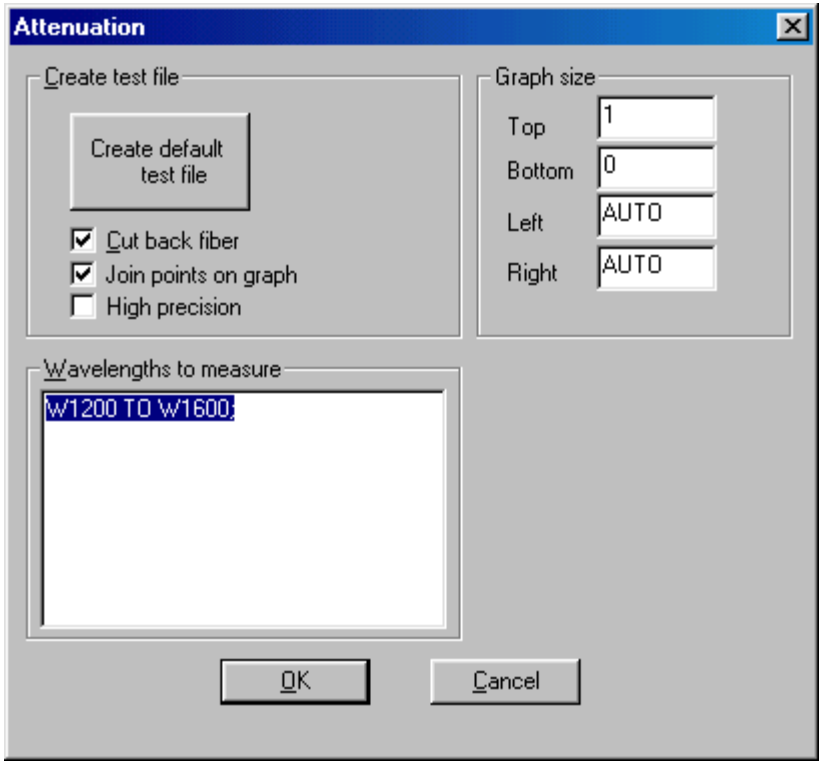
- Dispersion test parameters



- Spectral Attenuation test parameters



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Outline

- What is PMD?
- Why measure PMD in the field?
- PMD-440 PMD Measurement System

Polarization of Light

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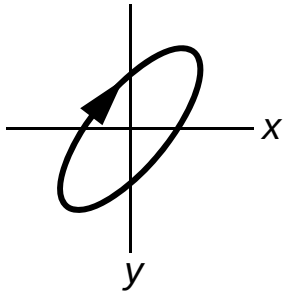
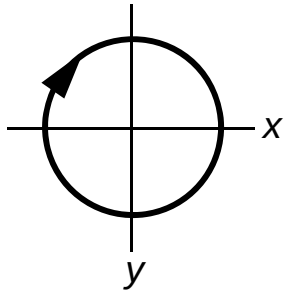
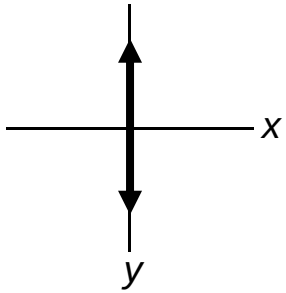
Right hand elliptical polarization

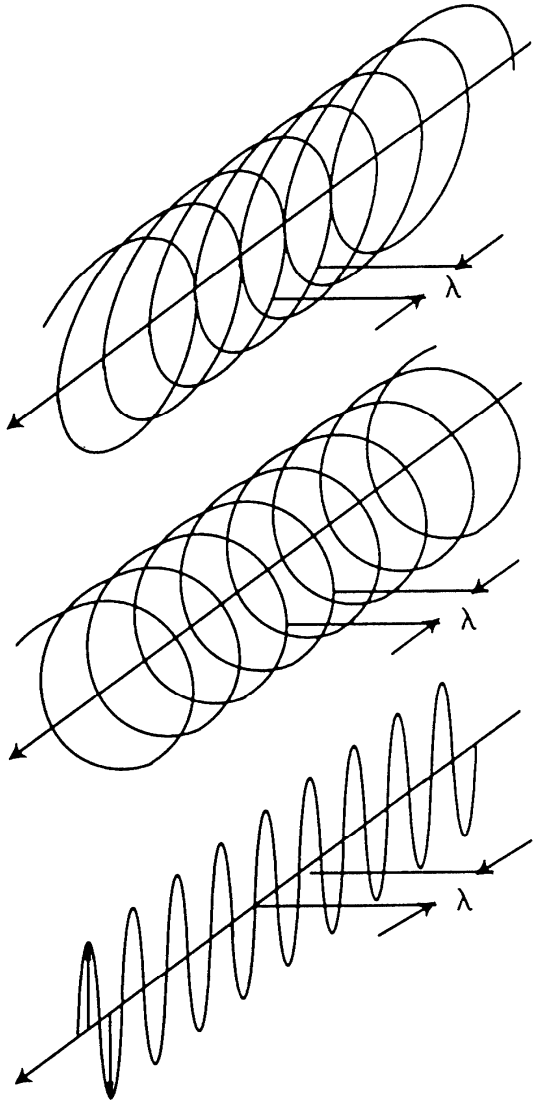


Right hand circular polarization



Vertical linear polarization





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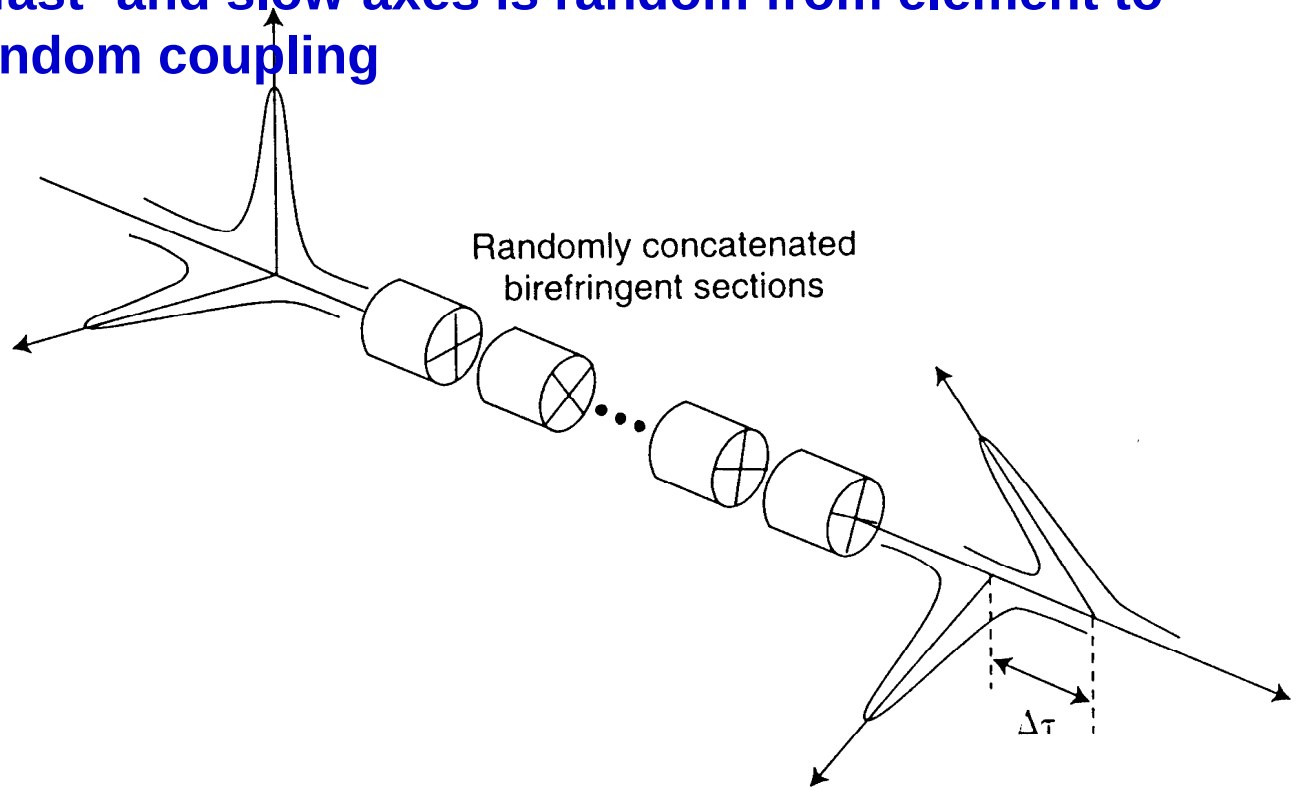
Optical Fiber is "Birefringent"

- Irregularities in the structure of the optical fiber create a 'fast' axis of propagation and a 'slow' axis of propagation
- Component of light polarized along the slow axis arrives later than the light traveling along the fast axis *(i.e., the fast and slow axis have different indexes of refraction)*
- ***Birefringence*** is defined as the difference between these indexes

Origin of PMD in Optical Fiber

- Optical fiber acts like many short birefringent elements stacked together
- Alignment fast- and slow-axes is random from element to element: random coupling



Origin of Birefringence and Units of PMD

- PMD will vary with fiber stresses which affect geometry of the fiber
- PMD varies along the fiber resulting in a random distribution of time delays
- Because of the random nature, statistical measures are used
- Is specified in picoseconds per square-root kilometer (ps/$km^{½}$).
  - $km^{½} = \sqrt{km} = SquareRoot(km)$

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PMD Trouble Zones

- Planning Bandwidth upgrades on older routes
  - increasing bit rates
  - increasing route length (repeater bypass)
- New routes with high bit rates
- Longer routes are more susceptible to effects of PMD
- Cables subject to varying stress conditions
  - Physical -- Stretching, swaying, twisting, bending
  - Thermal -- Heating, cooling
  - Aging

The Bad News About PMD

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- It is not a stable measure since it will vary with stresses on fiber and cable
  - *PMD varies with time*
  - *PMD measurement instruments report the average PMD*
- Different fibers in same cable can have totally different PMD levels
- Statistical measurement -- long term monitoring needed to determine PMD values

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PMD440
Polarization Mode Dispersion Analyzer

solutions beyond the box

- Portable, Easy to Use, Field Test Set
- Fast PMD measurements
- One-button PASS/FAIL testing
- 32dB Dynamic Range quickly tests spans over 120km (40 dB option available)
- Full 0.1 to 145 ps measurement range
- Remote operation for long term monitoring and recording of measurements
- Measures PMD at both 1310nm and 1550nm

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Dispersion Measurement Procedure

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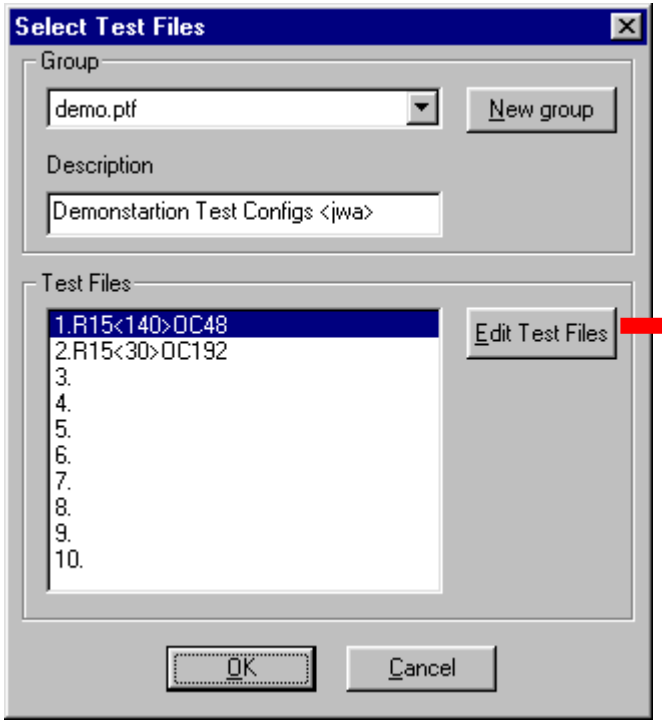
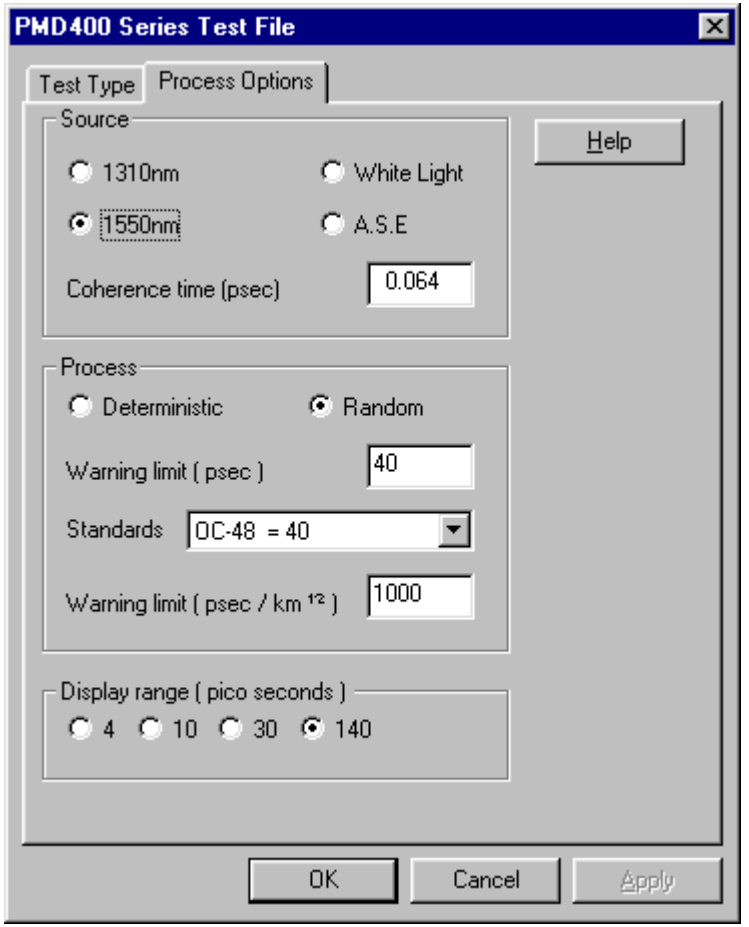
- **Testing Guidelines:**
  - 15-30 sec. per test
  - Two-ended test
  - For accurate per-km value, known fiber length needed
- **Ease of use:**
  - One-button testing
  - All testing parameters stored in “test file”
  - Multiple test files stored on instrument
  - Easy editing of test files
  - Automatic file save, file naming, connection check, and test sequencing available

Choosing and Editing Test Files

- Test files appear in a list
- Warning limit determines PASS/FAIL
- Standard warning limits available from pop-up menu





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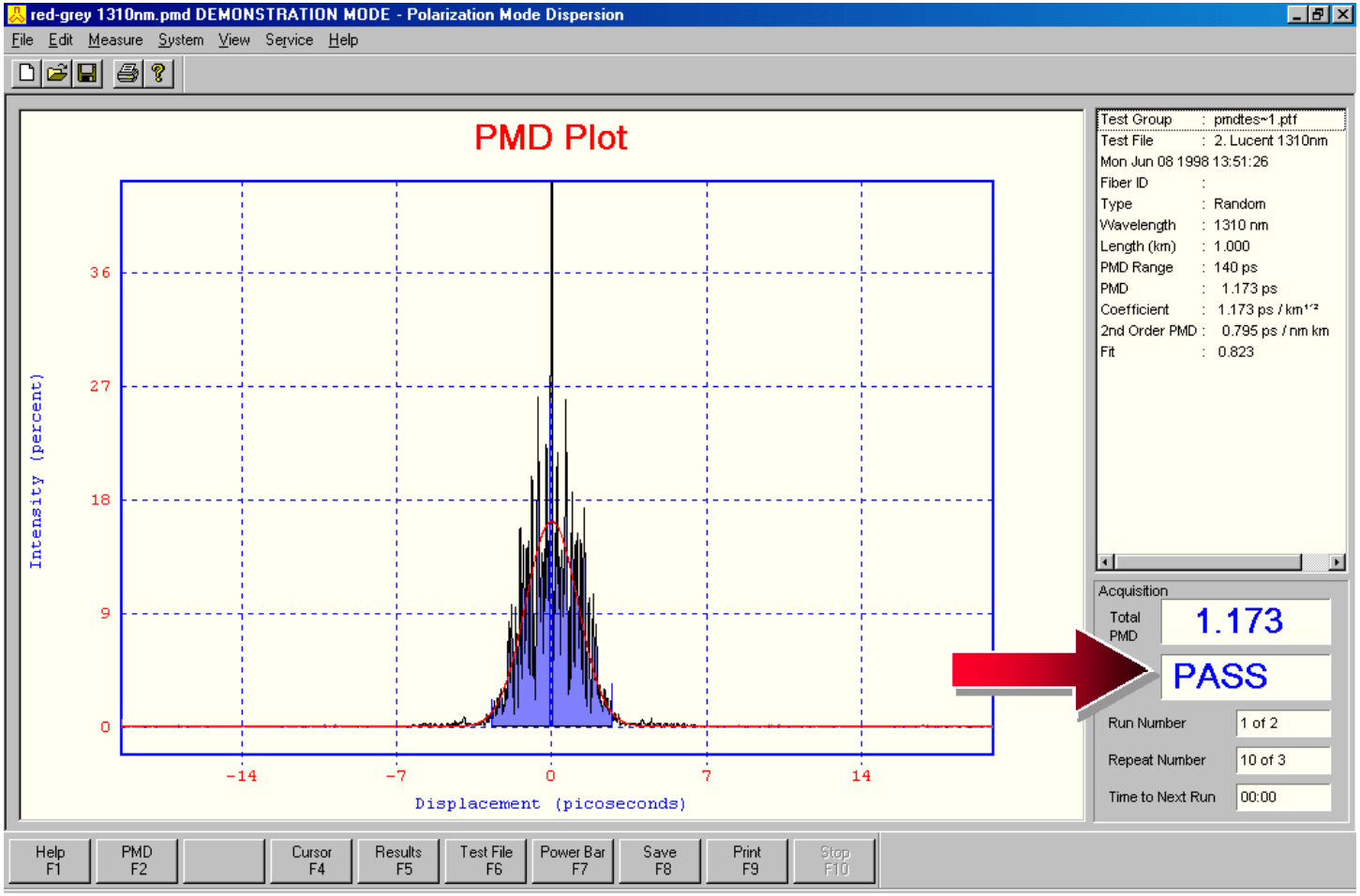
“Good” PMD

- PMD is “width” of the statistical plot of PMD values
- Results shown in results window
- “Good PMD”: PMD value falls below alarm threshold



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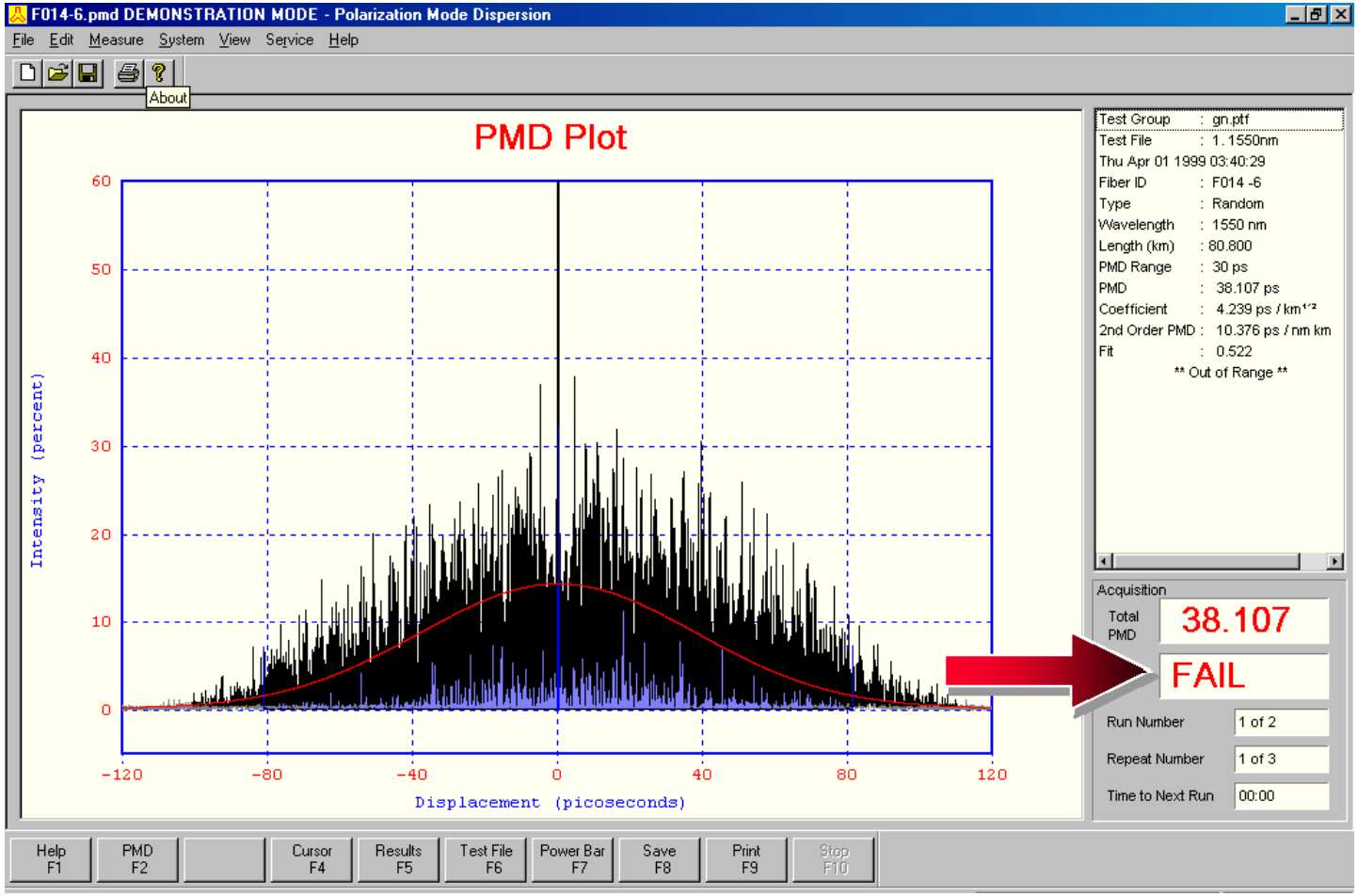
“Bad” PMD

- **“Bad PMD”: PMD value falls above alarm threshold**



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Thank You.

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