How to Test and Characterize Conventional and Specialty Optical Fibers

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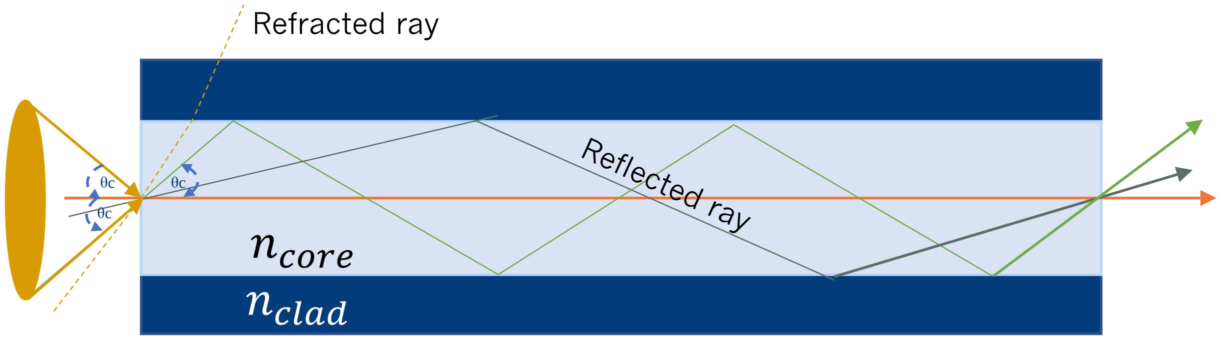
- Introduction
- Key Optical Performance Parameters
- Testing Solutions
- Show Cases
- Summary

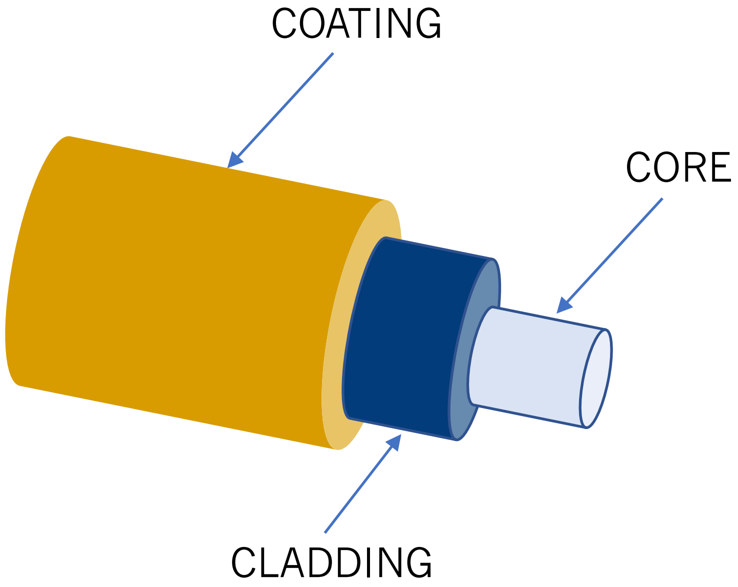
Optical Fiber Basics

- A cylindrical waveguide of silica glass
- Used as a means to transmit light
- Uses the principle of total internal reflection to propagate



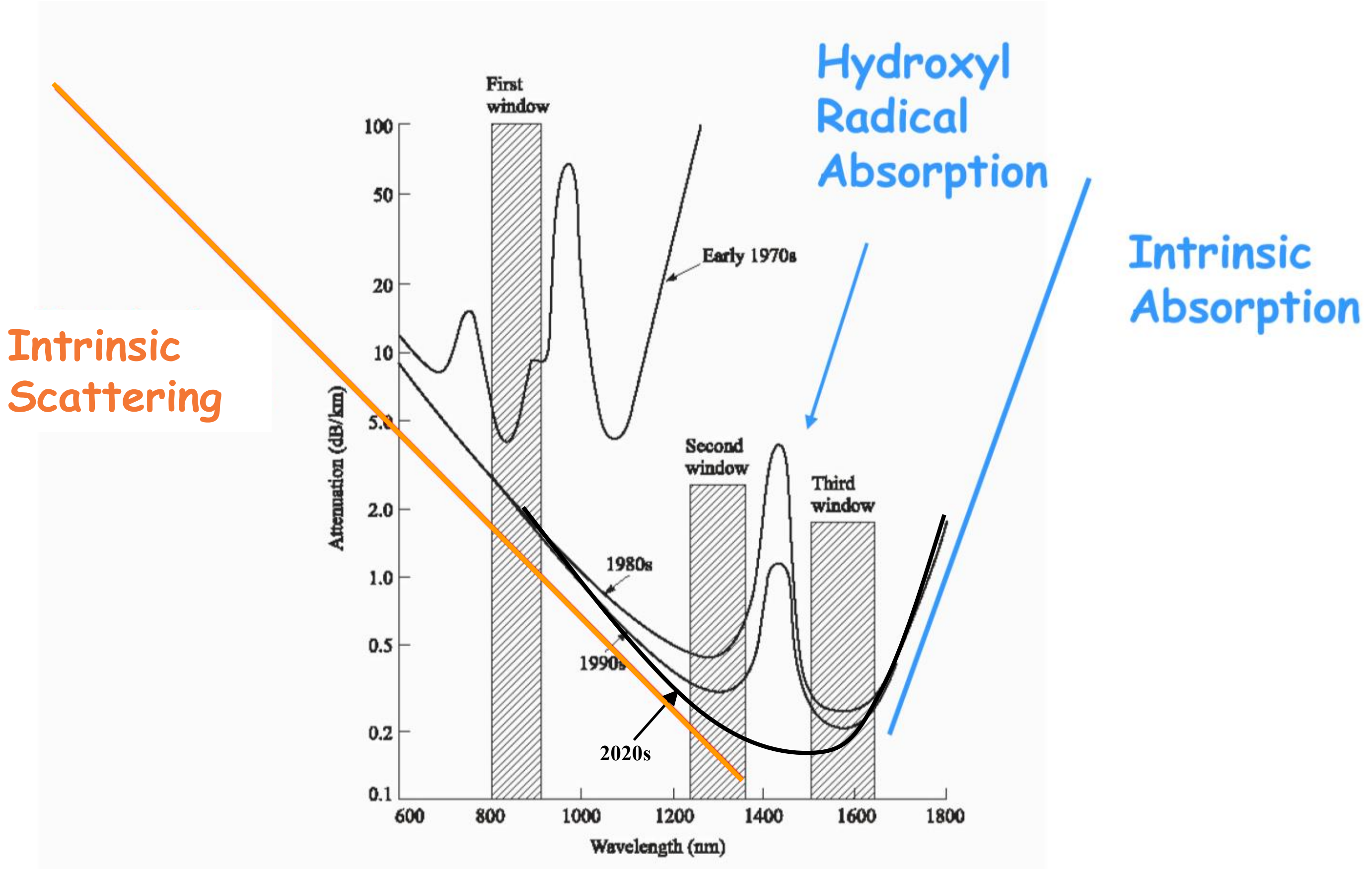
$$Numercal\ Aperture$$

$$NA = \sin(\theta_c) = \sqrt{n_{core}^2 - n_{clad}^2}$$



Development Of Fiber Optic Technology

- The most commonly used model for the spectral loss, α, in dB/km is*: $\alpha = A\frac{1}{\lambda^4} + B + C(\lambda)$



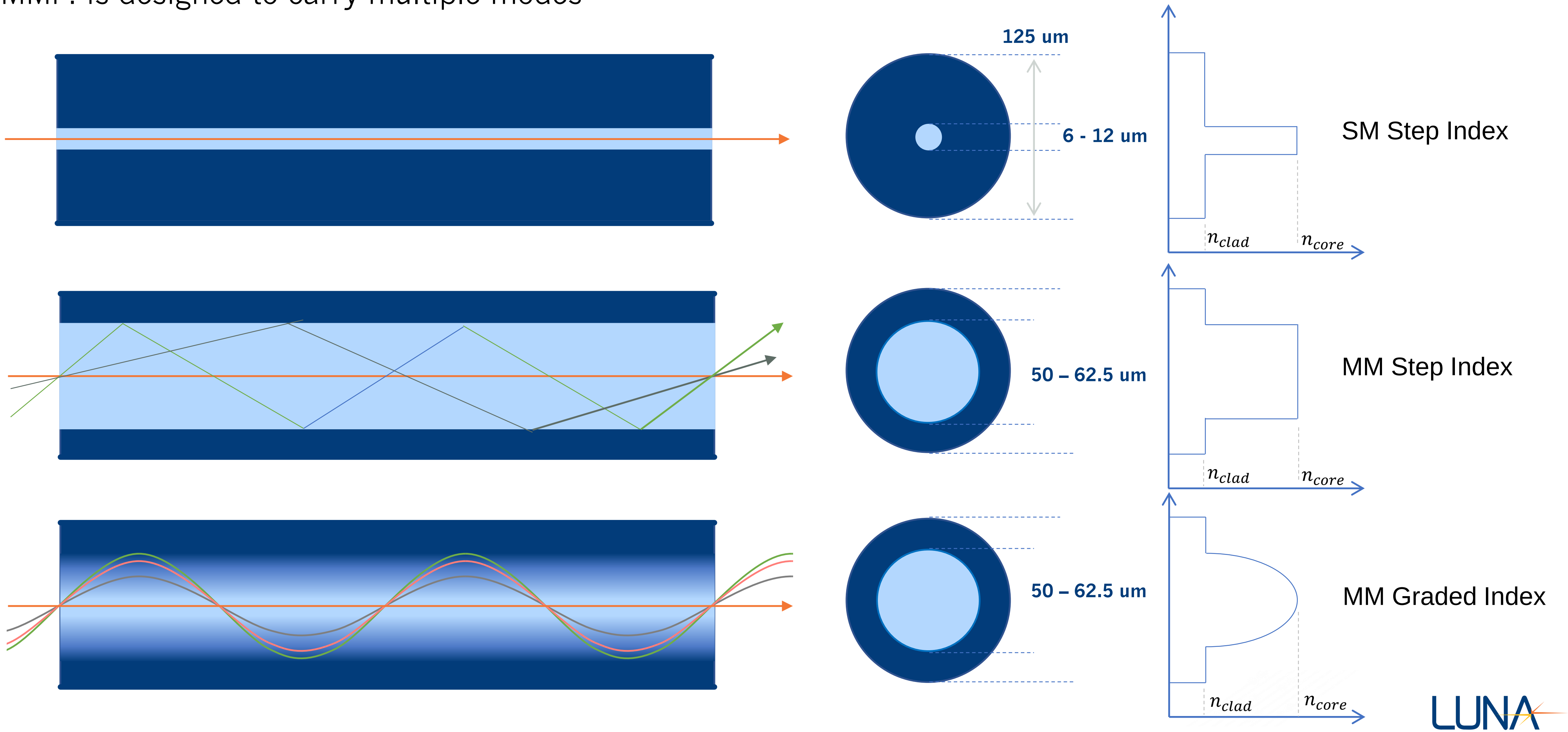
Attenuation Constant in Single Mode Optical Fiber

The first optical cable made for communications in the 1970s [Corning Inc., courtesy AIP Emilio Segrè Visual Archives, Hecht Collection]

*Méndez, A. and T. Morse. "Specialty optical fibers handbook." (2007).

Single Mode Fiber vs. Multi Mode Fiber

- SMF: only one mode propagates through the fiber
- MMF: is designed to carry multiple modes

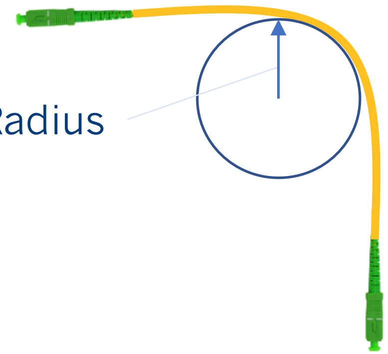


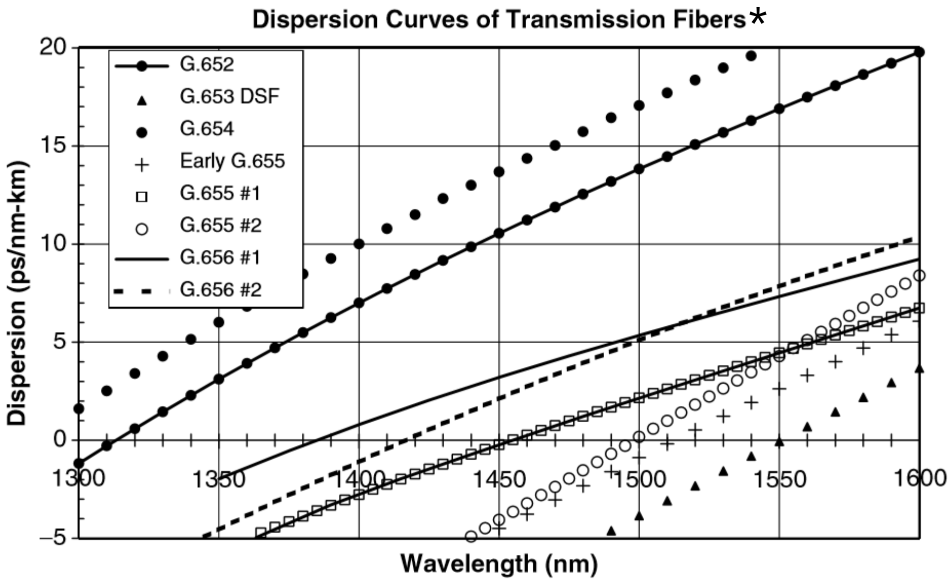
Evolution of Specialty Optical Fibers

- New requirements imposed by the broad variety of new applications have resulted in the evolution of a new subset of custom-tailored optical fibers

New, More Specialized Single Mode (SM) Fibers

- Zero-dispersion wavelength (ZDW)
- Dispersion-shifted fiber (DSF)
- Non-zero dispersion-shifted fibers (NZDFs)
- Dispersion Flattened Fibers (DFF)
- Bend insensitive Fiber
- Thin fiber (reduced cladding diameter)
- Large Mode Area Fibers
- Hollow Core Photonic Crystal Fibers





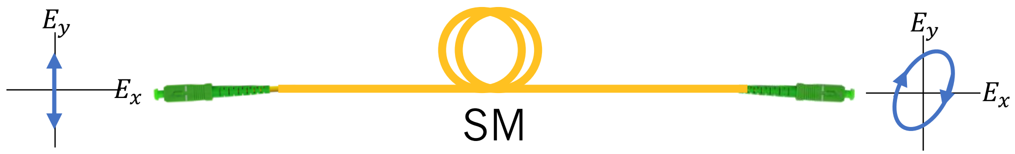
For 10 mm Bend radius:

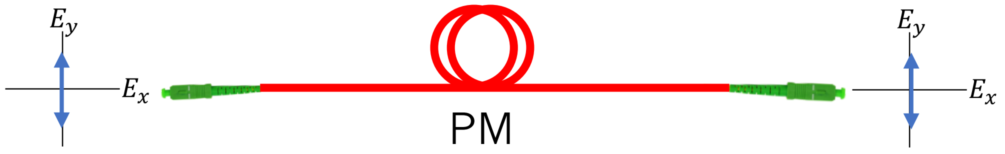
- Stannard SMF has < 0.5 dB/km
- Bend insensitive SMF has < 0.3 dB/km

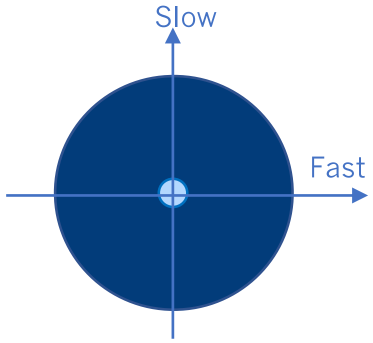
*Méndez, A. and T. Morse. "Specialty optical fibers handbook." (2007).

Polarization Maintaining (PM) Fiber

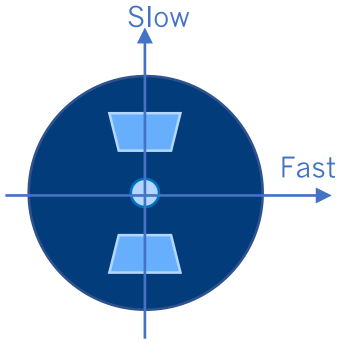
- PM fibers are more difficult to fabricate than fibers that are circularly symmetric.
- The highest degree of optical anisotropy is obtained through the insertion of stress rods (PANDA) and anisotropic doping (Bowtie)



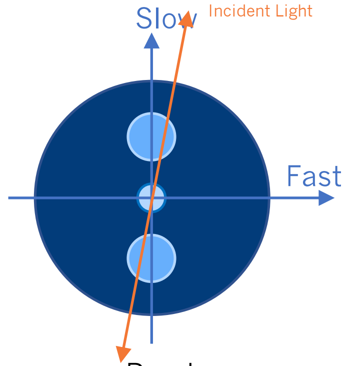




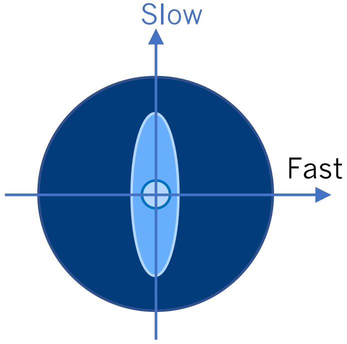
SM Fiber



Bowtie



Panda

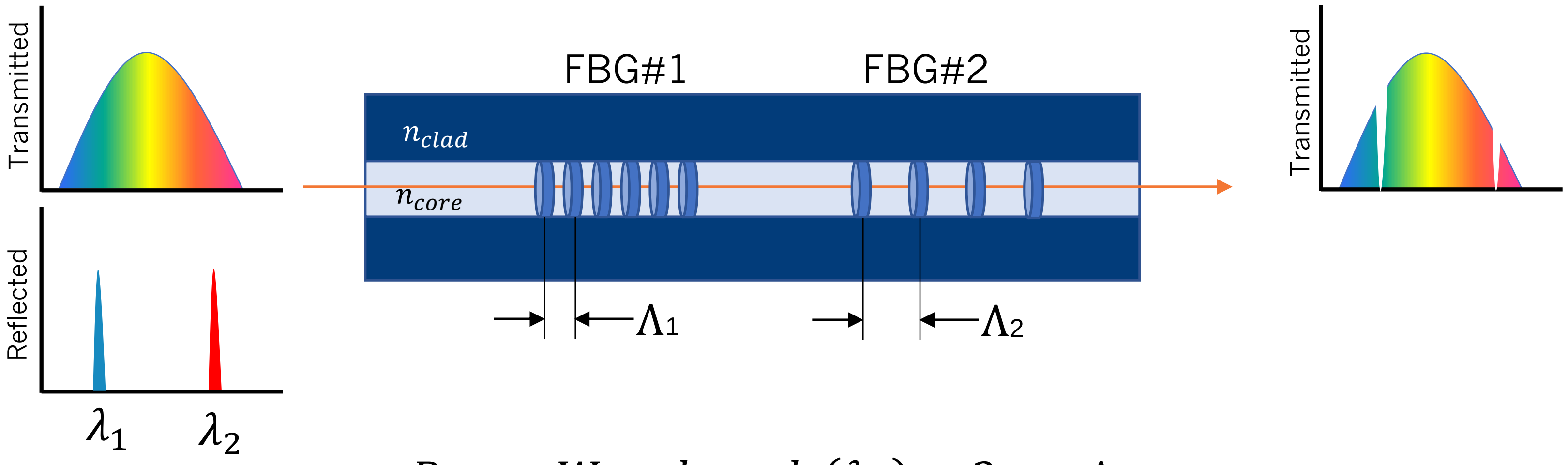


Elliptical Cladding

Exotic Variant of PM fiber: Microstructure (''Holey'') Fibers. Polarizing Fiber, Spun fiber

Fiber Brag Grating (FBG) Fiber

- FBG fiber has a periodic variation (photo-induced modulation) of the refractive index of the fiber core along the length of the fiber
  - It operate as wavelength selective mirrors
  - It reflects a single specific wavelength and transmit all others
  - Bragg wavelength increase linearly with increasing the grating period or effective refractive index



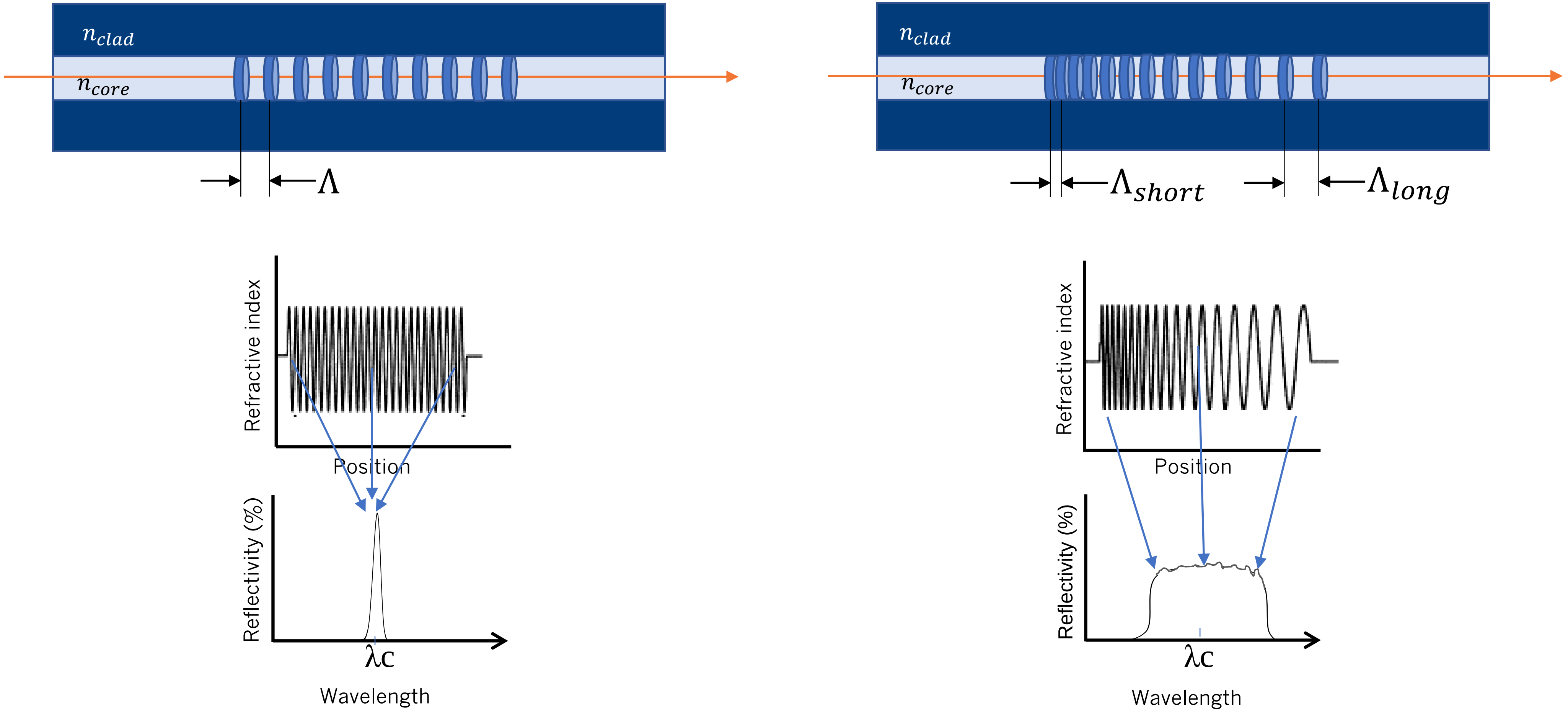
$$Bragg\ Wavelength\ (\lambda_B) = 2n_{eff}\Lambda$$

Uniform FBG vs. Chirped FBG Fibers

$$\lambda_B = 2n_{eff}\Lambda$$

$$\Delta\lambda_{chirp} = 2n_{eff}(\Lambda_{long} - \Lambda_{short})$$

$$\Delta\lambda_{chirp} = 2n_{eff}\Lambda_{chirp}$$

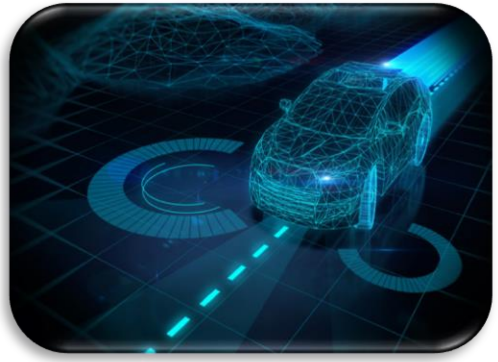


Y. Okabe, R. Tsuji, N. Takeda, Application of chirped fiber Bragg grating sensors for identification of crack locations in composites, Composites Part A: Applied Science and Manufacturing, Volume 35, Issue 1, January 2004, Pages 59-65, ISSN 1359-835X,.

Specialty Optical Fiber is An Enabling Technology

- As the need for optical fiber sensors and specialized components increases, so too will the demand for specialty fibers.


Telecommunication


Industrial (Automotive)


Aerospace and Aviation


Energy and Infrastructure


Defense


Fiber Lasers and Amplifiers


Biomedical

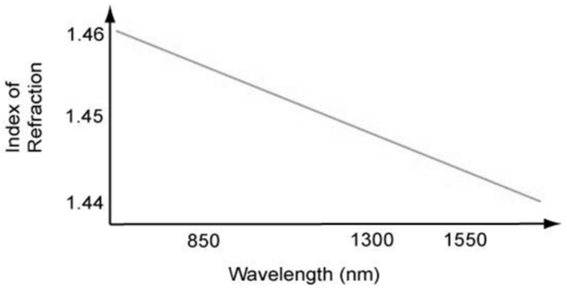

Harsh Environment

Some Fiber Parameters of Interest .I

- Group Delay (**GD**) is the derivative of the phase with respect to frequency → $GD(\omega) = \frac{d\phi(\omega)}{d\omega}$
- Chromatic Dispersion (**CD**) is the derivative of group delay with respect to wavelength → $CD = \frac{dGD}{d\lambda}$

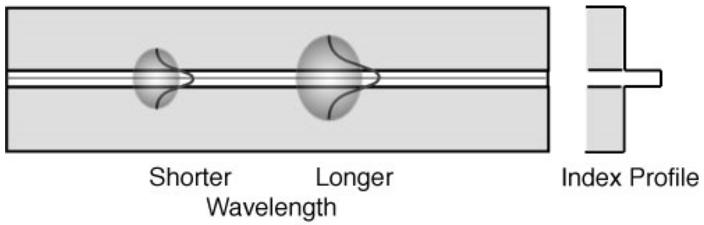
Material dispersion*

$$refractive\ index \propto \frac{1}{wavelength}.$$

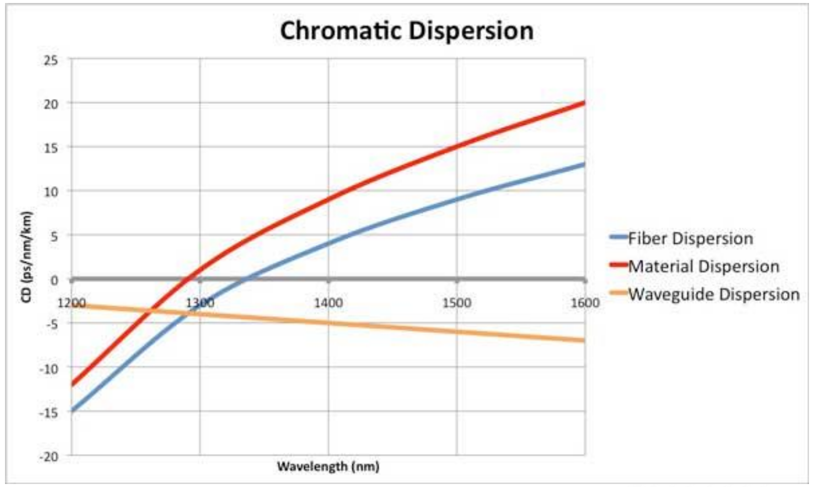


Waveguide dispersion*

$$Mode\ Field\ Diameter\ (MFD) \propto wavelength.$$



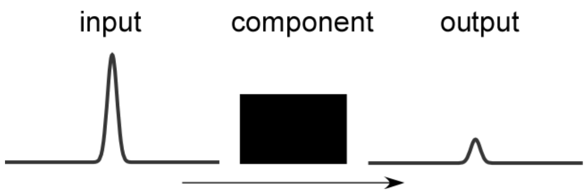
Lower wavelength components having lower group velocities.



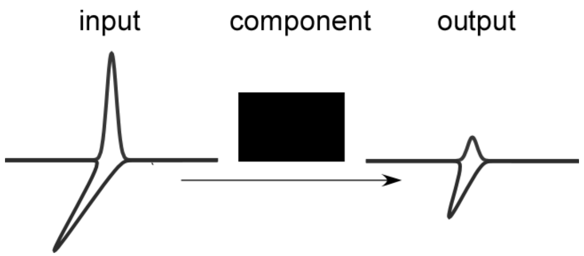
*http://www.thefoa.org/tech/ref/testing/test/CD_PMD.html

Some Fiber Parameters of Interest .II

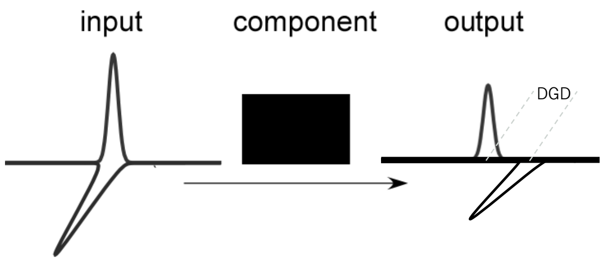
- Insertion Loss (**IL**) is the ratio of optical power output by the fiber to the optical power input to the fiber, and is expressed in dB. IL is wavelength dependent.
- Polarization Dependent Loss (**PDL**) is the difference in maximum and minimum IL due to polarization effects as a function of wavelength.
- Polarization Mode Dispersion (**PMD**) is the difference in propagation time between fastest-travelling and the slowest-travelling polarization modes. Sometimes called differential group delay (DGD).



$$IL_{dB} = 10 \times \log_{10}\left(\frac{Power_{out}}{Power_{in}}\right)$$



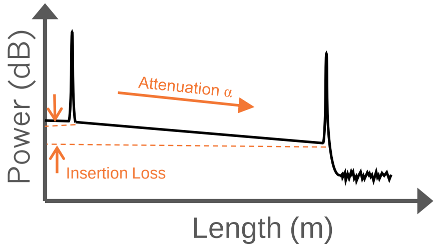
$$PDL_{dB} = 10 \times \log_{10}\left(\frac{Power_{max}}{Power_{min}}\right)$$

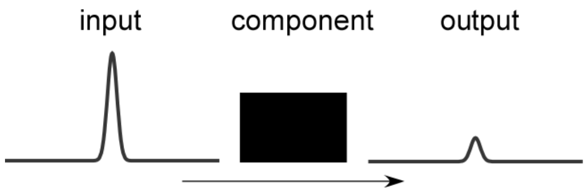


$$PMD_i[ps] = \left.\frac{d\phi_i(\omega)}{d\omega}\right|_{max} - \left.\frac{d\phi_i(\omega)}{d\omega}\right|_{min}$$

Total vs. Distributed Optical Measurement

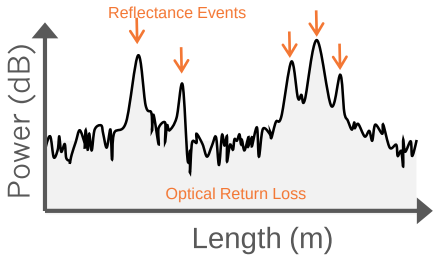
- Attenuation vs Insertion loss

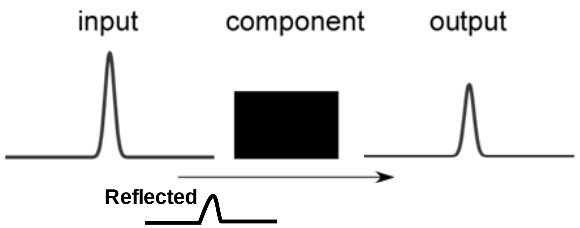




$$IL = 10 \times \log_{10}\left(\frac{Power_{out}}{Power_{in}}\right)$$

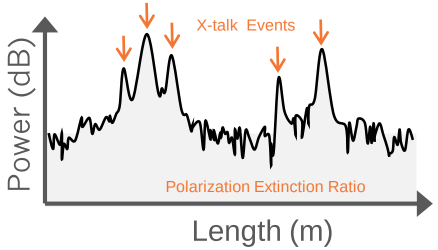
- Reflectivity/Reflectance vs. Optical Return loss (ORL)

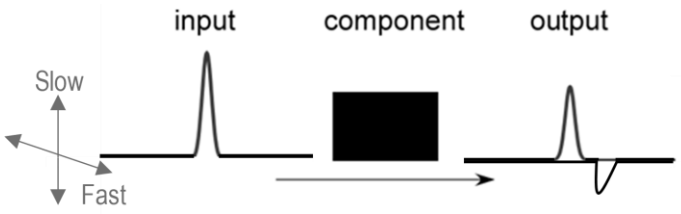




$$RL = 10 \times \log_{10}\left(\frac{Power_{ref}}{Power_{in}}\right)$$

- Polarization Cross-Talk (X-talk) vs. Polarization Extinction Ratio (PER)





$$PER = 10 \times \log_{10}\left(\frac{Power_{slow}}{Power_{fast}}\right)$$

Key Optical Performance Parameters

- Each fiber has specific key performance parameters which are also application dependent

SM/MM	PM	FBG
▪ Attenuation ▪ Insertion Loss (IL) ▪ Bending loss ▪ Phase response ▪ Group Delay ▪ Chromatic Dispersion ▪ Polarization Mode Dispersion Polarization Dependent Loss ▪ Scattering level ▪ Reflection ▪ Return Loss ▪ Spectral parameters	▪ Attenuation ▪ Insertion Loss ▪ Bending loss ▪ Phase response ▪ Group Delay ▪ Differential Group Delay ▪ Scattering level ▪ Return Loss ▪ Reflection ▪ Beat Length ▪ H-parameter ▪ Polarization Extinction Ratio ▪ Polarization Cross-talk ▪ Temperature dependent performance	▪ Attenuation ▪ Insertion Loss ▪ Bending loss ▪ Phase response ▪ Group Delay ▪ Chromatic Dispersion ▪ Polarization Mode Dispersion ▪ Polarization Dependent Loss ▪ Scattering level ▪ Reflection ▪ Return Loss ▪ Transmission and Reflection Spectra ▪ Grating Profile ▪ FBG Length ▪ Wavelength Tolerance ▪ Bandwidth (FWHM) ▪ Sidelobe Suppression Ratio (SLSR) ▪ Polarization dependent frequency shift ▪ Chirp rate ▪ Temperature sensitivity

New Fibers Bring New Challenging Testing Requirements

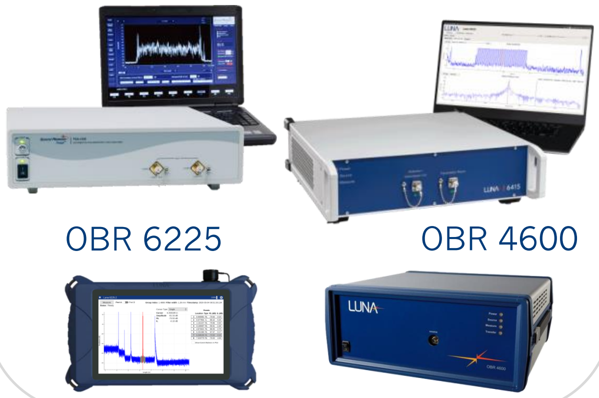
Spectral Analysis

LCA 500 OVA 5000

PSGA-101

Time Domain/Distributed Analysis

PXA-1000 Luna 6415



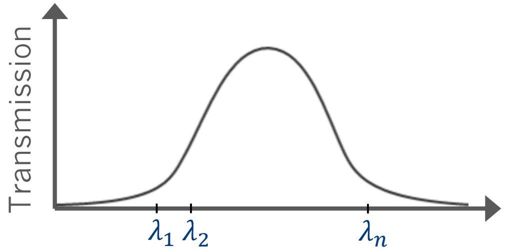
OBR 6225 OBR 4600

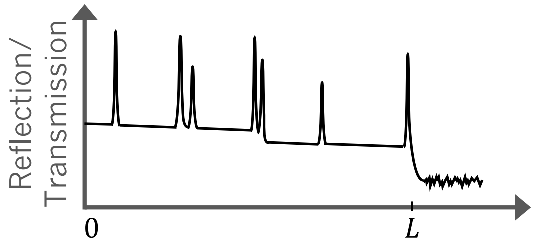
Polarization Analysis

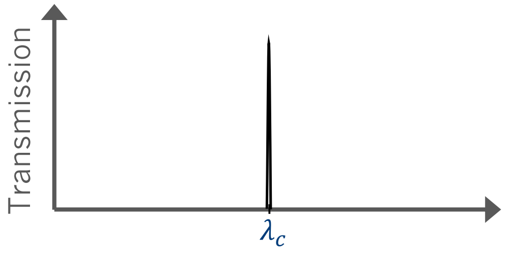
POD-201

PDL-201

PER-202





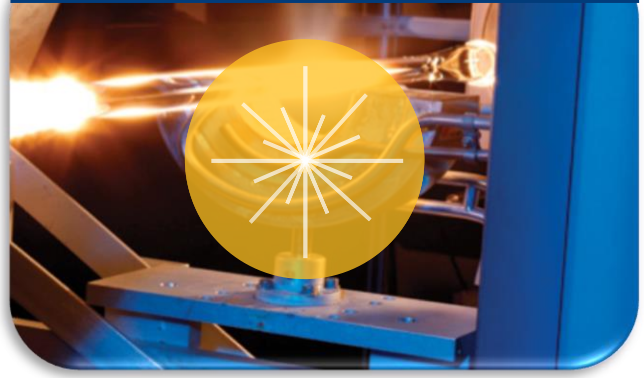


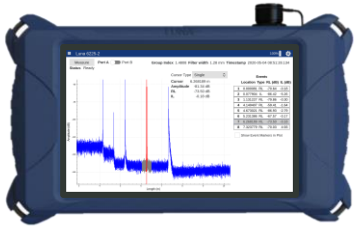
Different Solutions for Different Needs and Applications

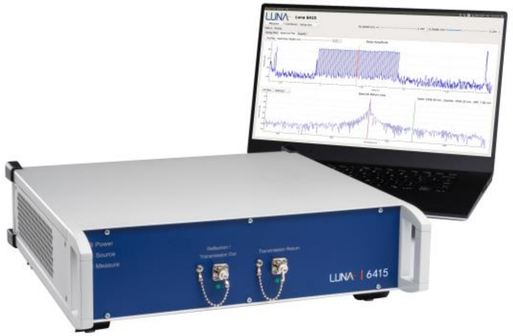
Field Applications

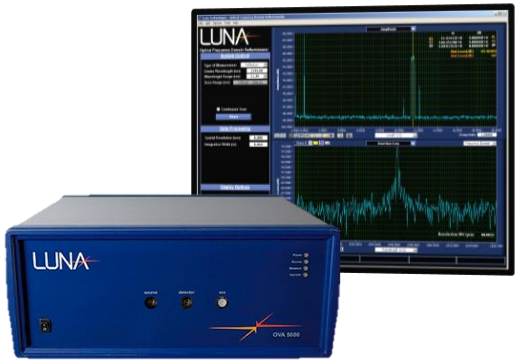
Manufacturing Environment

R&D and Labs

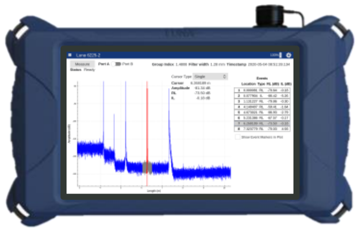


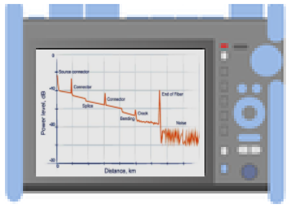






OFDR Vs. OTDR Technology





	OFDR	OTDRs
Light Source Type	Swept Laser	Laser
Wavelength Range	C, C/L, O bands	1310 and 1550 nm, others
Measurement Range	Up to 2 km	100s of km
Sampling Resolution	µm	cm to m
Dead Zone	No	Yes: meters
Measurement speed	Up to 12 Hz (raw data acquisition)	sec to min
Sensitivity	- 140 dB	- 110 dB
Others	Discriminates the location and wavelength of reflected photons	Discriminates the location only of reflected photons

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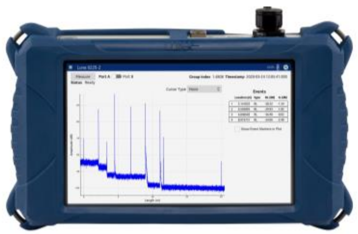
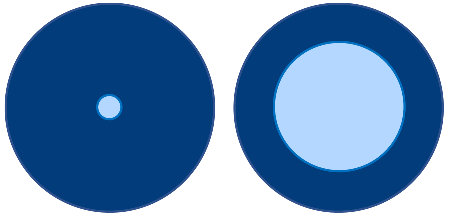
Demo Summary

DEMO #1

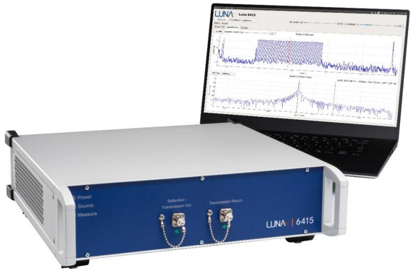


OBR 6225

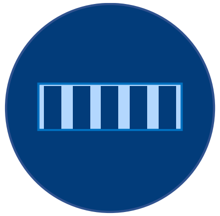


SMF MMF

DEMO #2



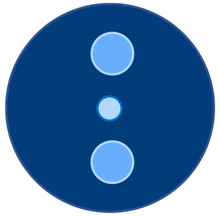
Luna 6415



Uniform FBG

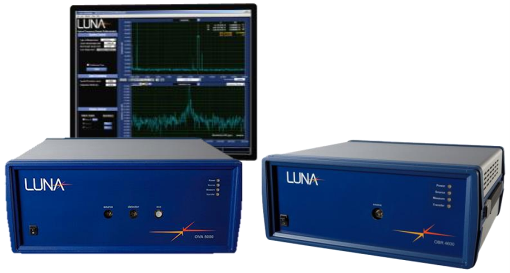
DEMO #3

PXA 1000

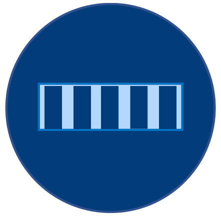


Panda PM

DEMO #4

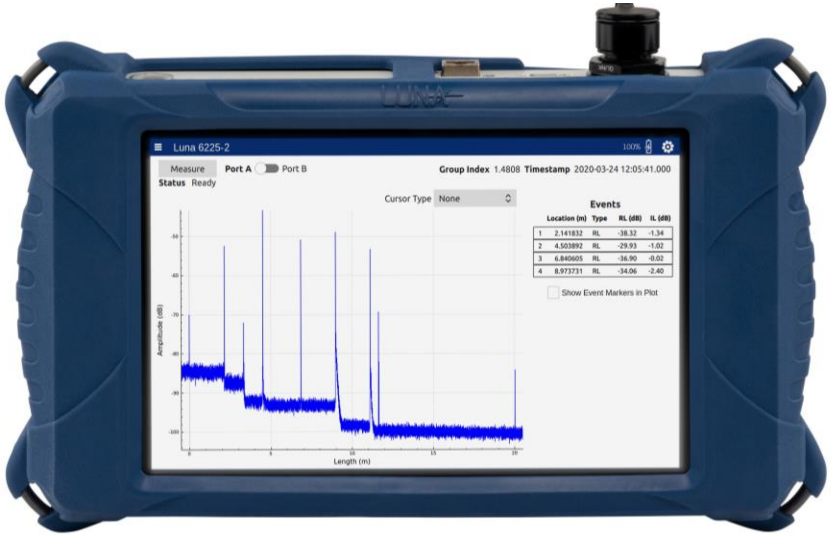


OVA 5000 OBR 4600



Chirped FBG

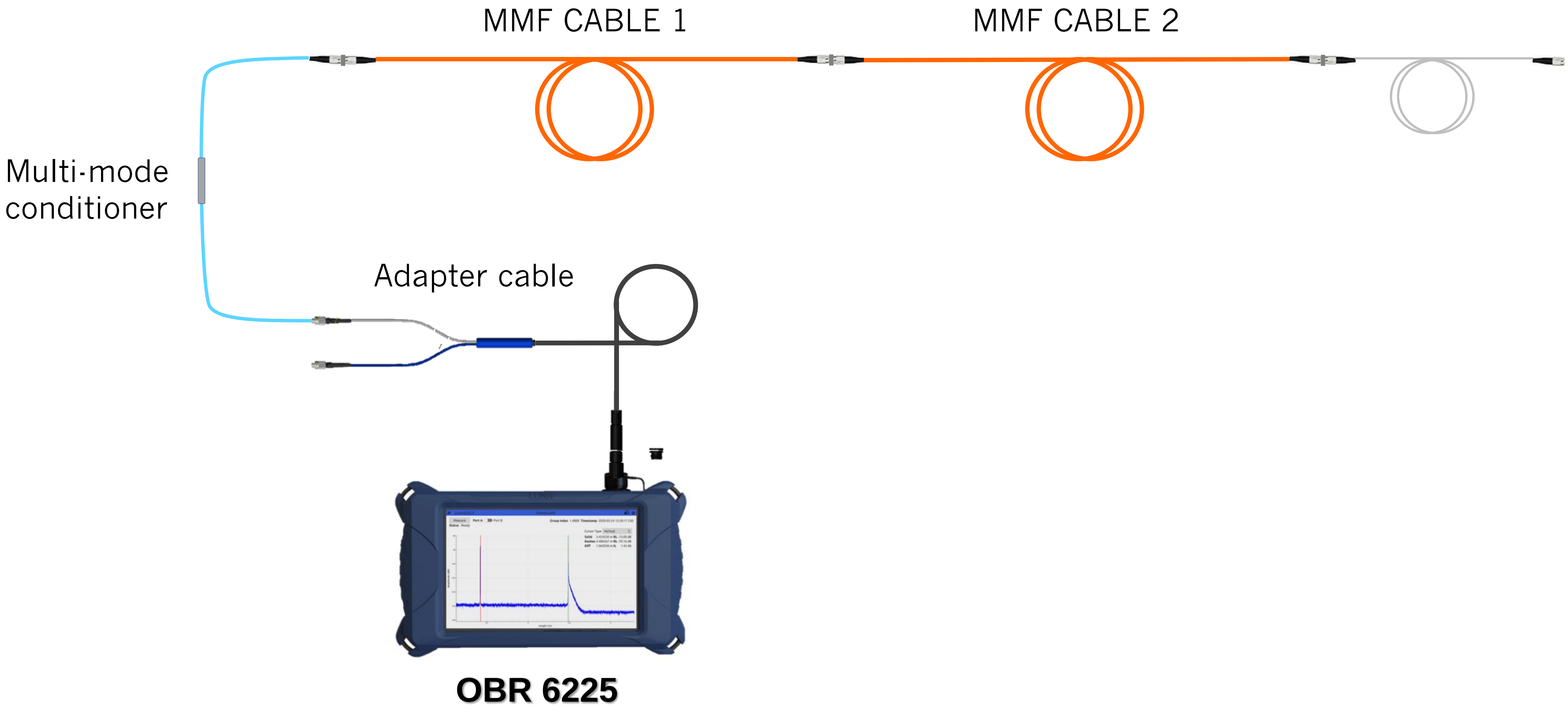
OBR 6225 for Field Test and Maintenance

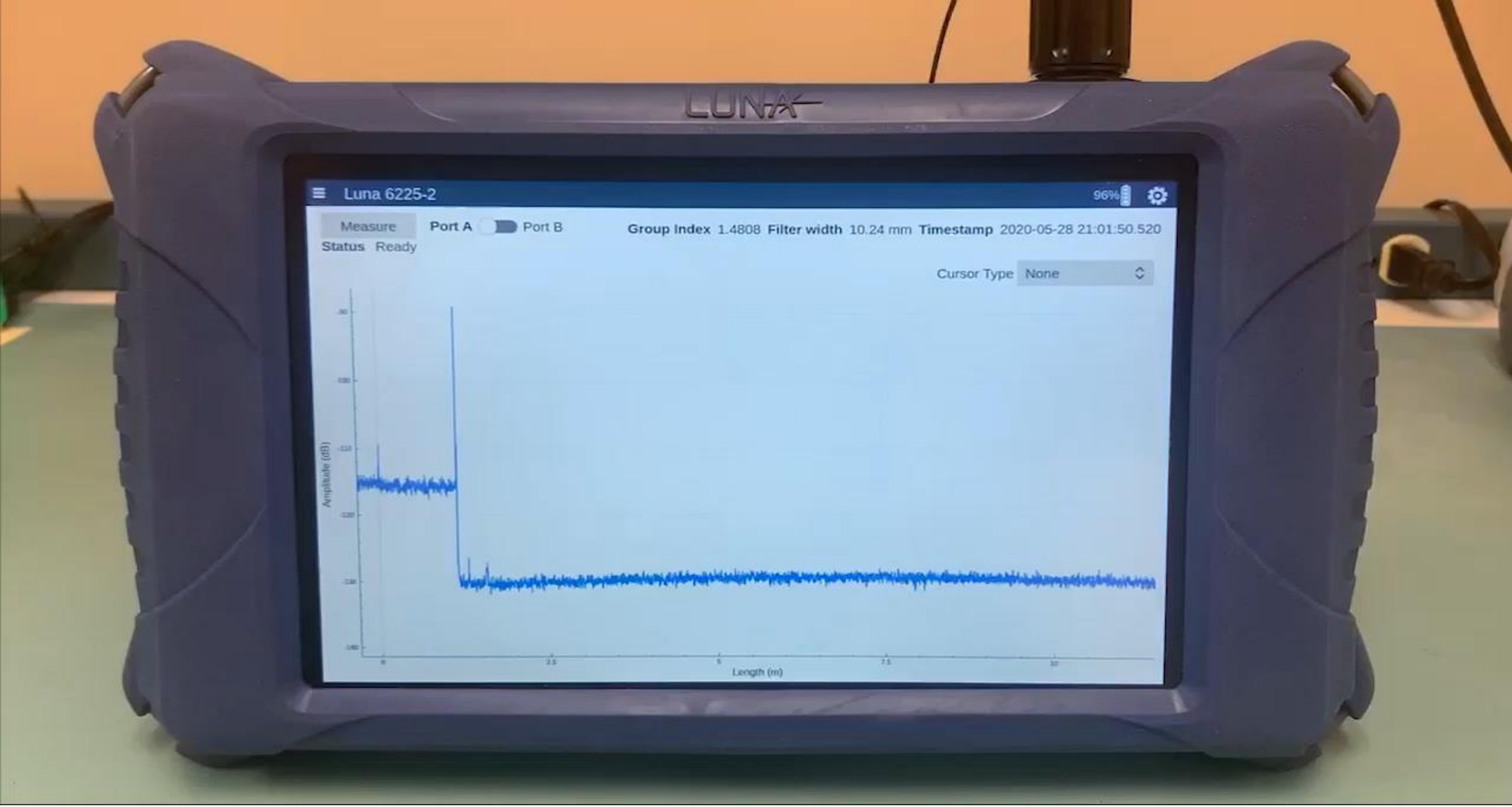


- Distributed RL and IL measurement
- High-resolution reflectometer
  - Sampling resolution down to 80 µm for 20m range
  - No ‘dead zones’
  - Backscatter-level sensitivity (-130 dB)
- Portable and rugged (IP65 and MIL-STD certifications available)
- Measure latency/length with sub-ns precision
- Automatic self-calibration and optical alignment
- Measurement range: 20 m, 50 m ad 100 m

*Sampling resolution: 200 µm for 100m range

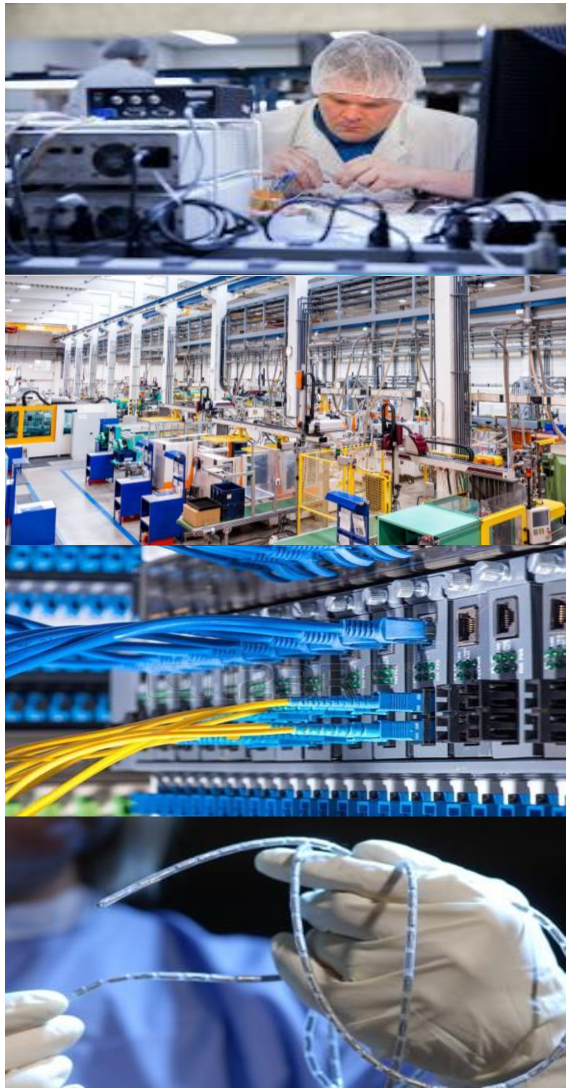
Demonstration of Portable OBR

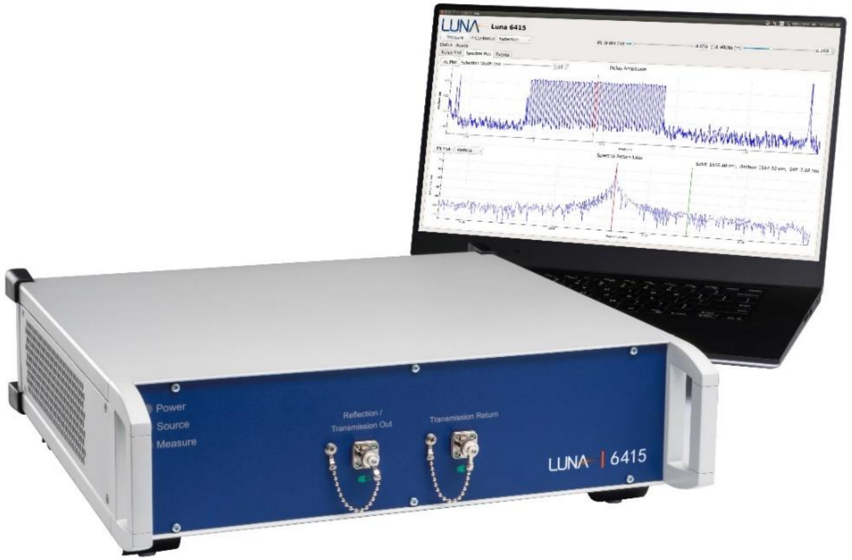




LUNA
Luna 6225-2
96%
Measure
Port A
Port B
Status Ready
Group Index 1.4808 Filter width 10.24 mm Timestamp 2020-05-28 21:01:50.520
Cursor Type None
Amplitude (dB)
Length (m)

Luna 6415 for Production Environment

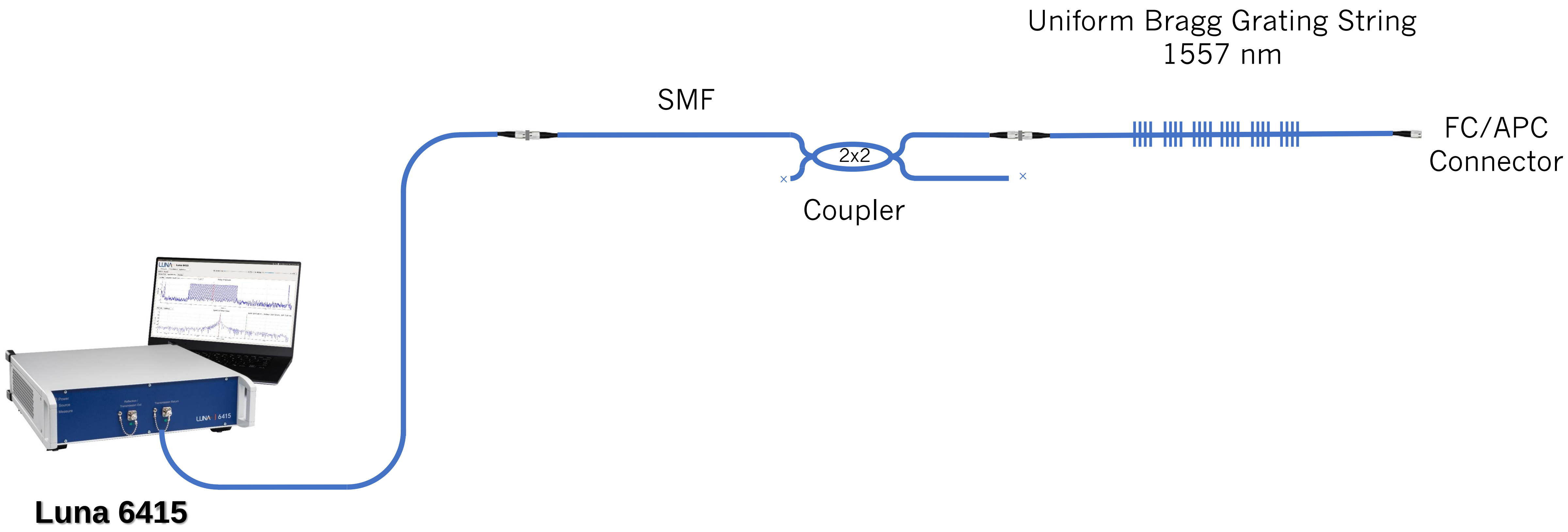




- **Analyze optical loss in reflection and transmission**
- High-resolution reflectometer
  - Sampling resolution down to 20 µm
  - No 'dead zones'
  - Backscatter-level sensitivity (-130 dB)
- Time-domain and spectral analysis
- IL and RL (distributed) measurements **at 12 Hz**
- Measure latency/length with sub-ns precision
- Automatic self-calibration and optical alignment
- Measurement range: 100m (reflection), 200m (Transmission)

*Sampling resolution: 200 µm for 100m range

Demonstration of Luna 6415



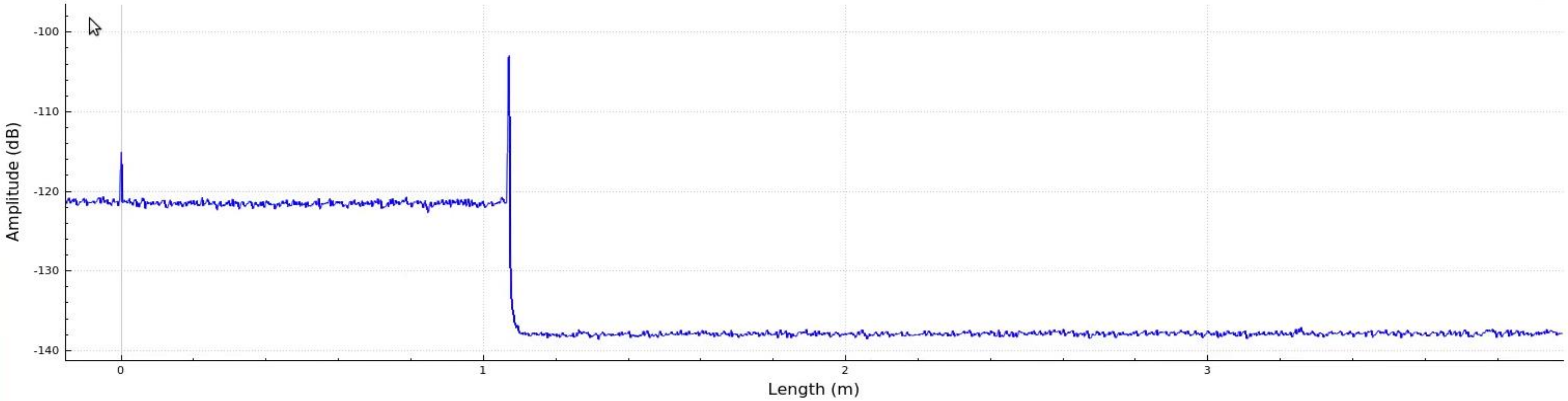
Luna 6415

Stop | Continuous | Reflection

Measurement Type Reflection **Group Index** 1.4808 **Filter** 10.24 mm **Timestamp** 2020-10-09 17:19:55.440

Status Adjusting gains

Cursor Type None

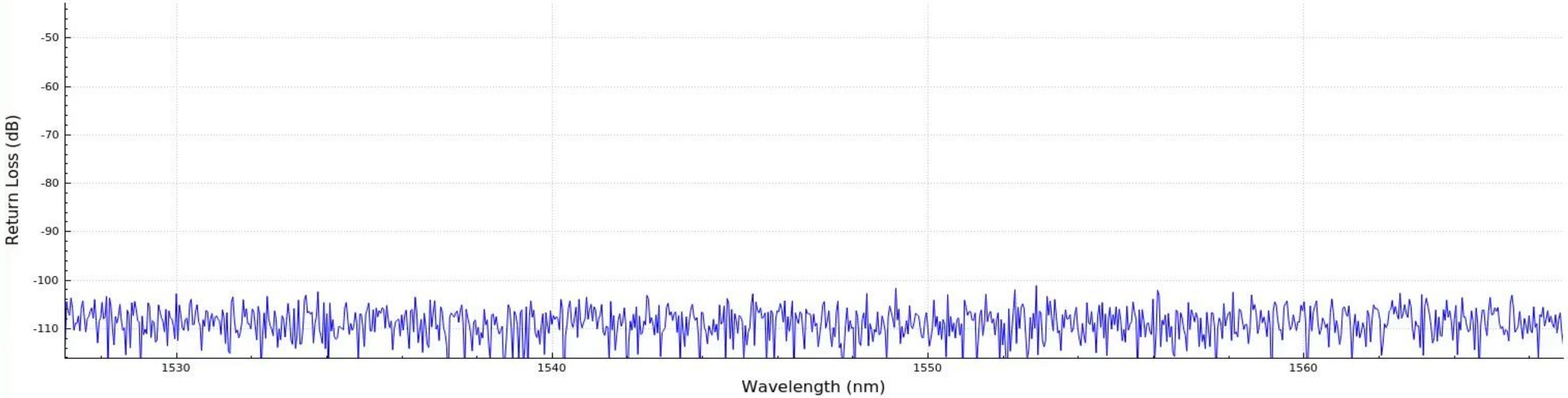


Events

	Location	Type	RL (dB)	IL (dB)
1	1.069620	RL	-80.66	-7.59

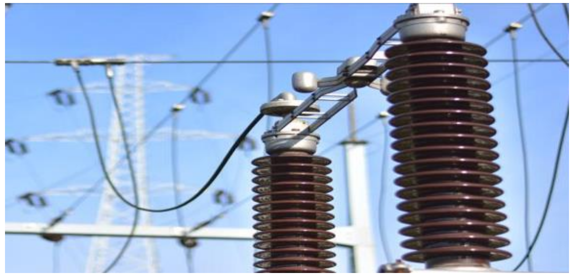
Show Event Markers in Plot

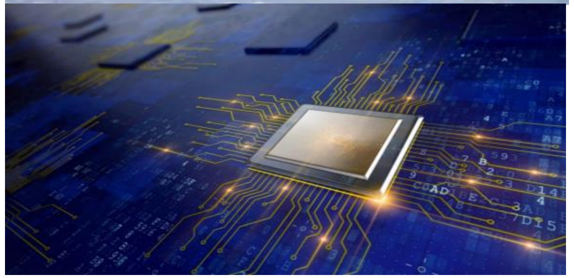
Cursor Type None



LUNA

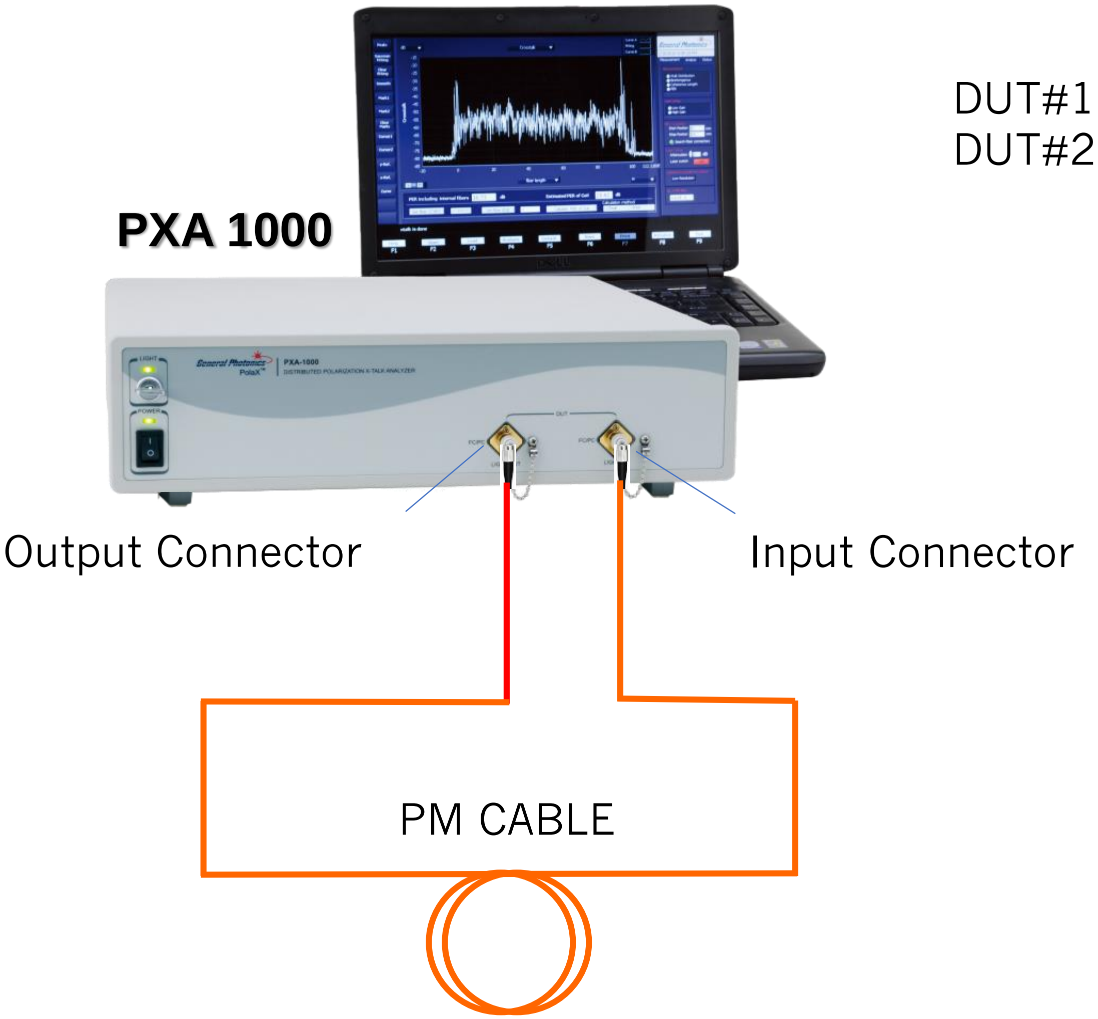
PXA 1000 for Polarization Maintaining Fiber Characterization





- Distributed Polarization Cross-Talk, Birefringence, Beat Length and PER measurements
- High crosstalk sensitivity: -80 dB (typical)
- High spatial resolution: 6 cm (in PM fiber)
- Large fiber measurement range: 3.1 km

Demonstration of PXA 1000

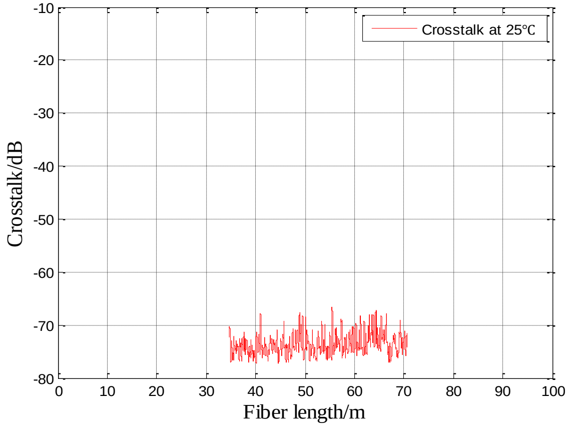


DUT#1 PM Fiber Jumper + two splices ~ 3 m
DUT#2 PM Fiber Coil ~ 1028 m

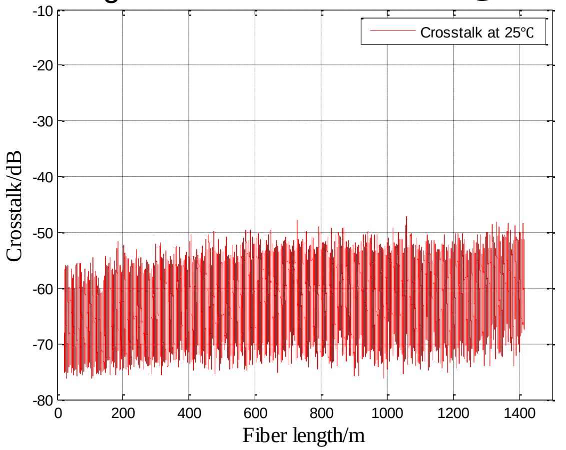
Polarization Marinating Fiber PM Fiber Jumper Testing with Two Splices ~3 m

Temperature Dependence of Polarization X-Talk in PM Fiber

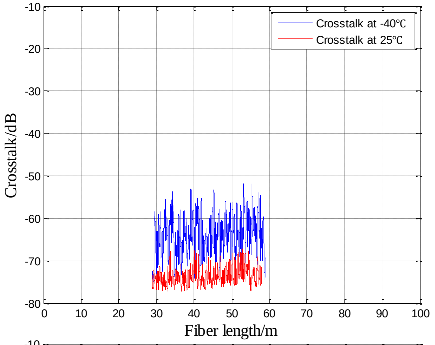
PM fiber#1 @ 1550 nm
Length ~ 35 m
Average Pol X-talk = -73.54 dB @ 25C

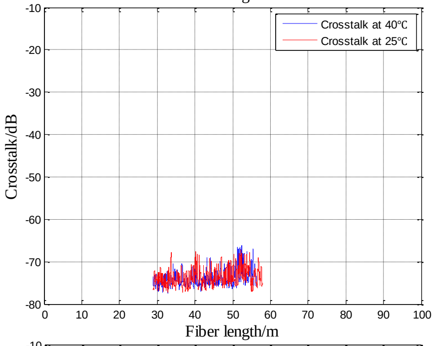


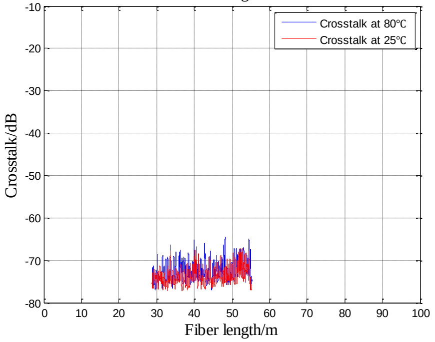
Screening the same fiber
Length ~1400 m
Average Pol X-talk = -61.85 dB @ 25C



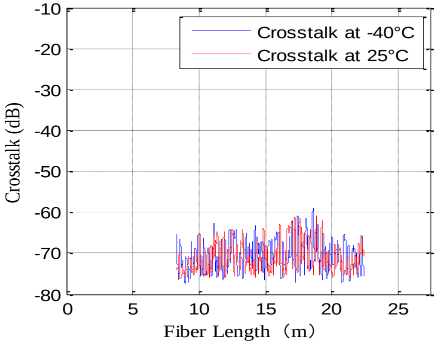
PM fiber#1 @ 1550 nm
Length ~ 30 m
Average Pol X-talk = -73.54 dB @ 25C

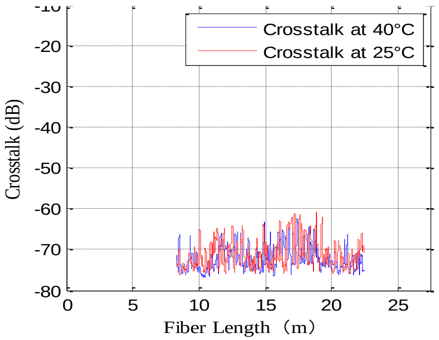


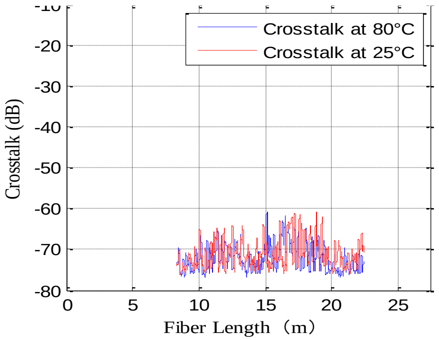




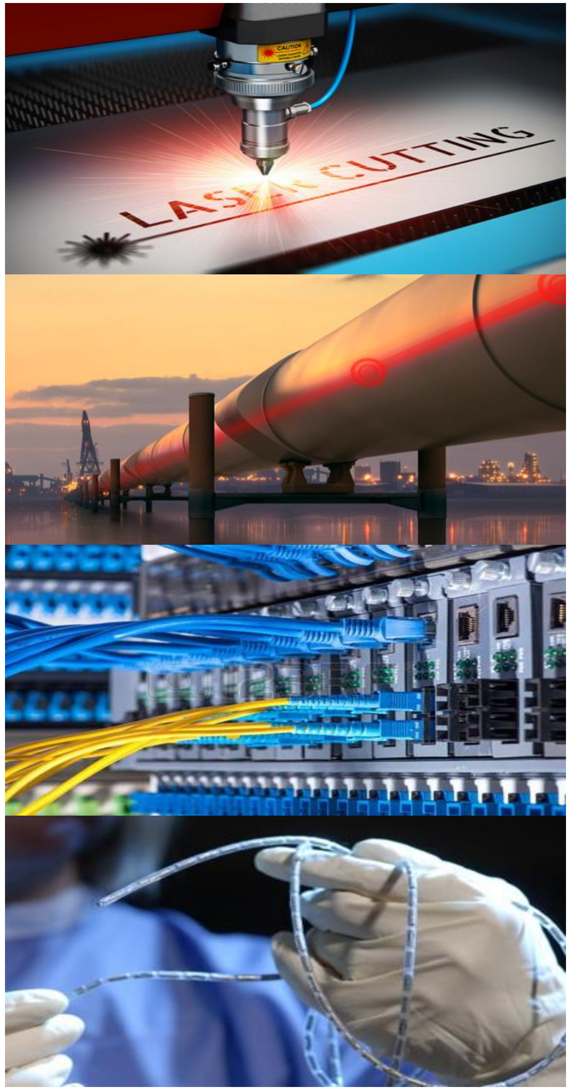
PM fiber#2 @ 1550 nm
Length ~ 25 m
Average Pol X-talk = -71 dB @ 25C







OVA 5000/OBR 4600 for Fiber Bragg Grating Characterization



OVA 5000

- Characterizes All linear parameter of fiber components
- Works in Reflection and Transmission
- High Speed: < 3 sec
- High spatial resolution: 10 μm
- Large fiber measurement range: 150 m
- High Dynamic Range: 80 dB

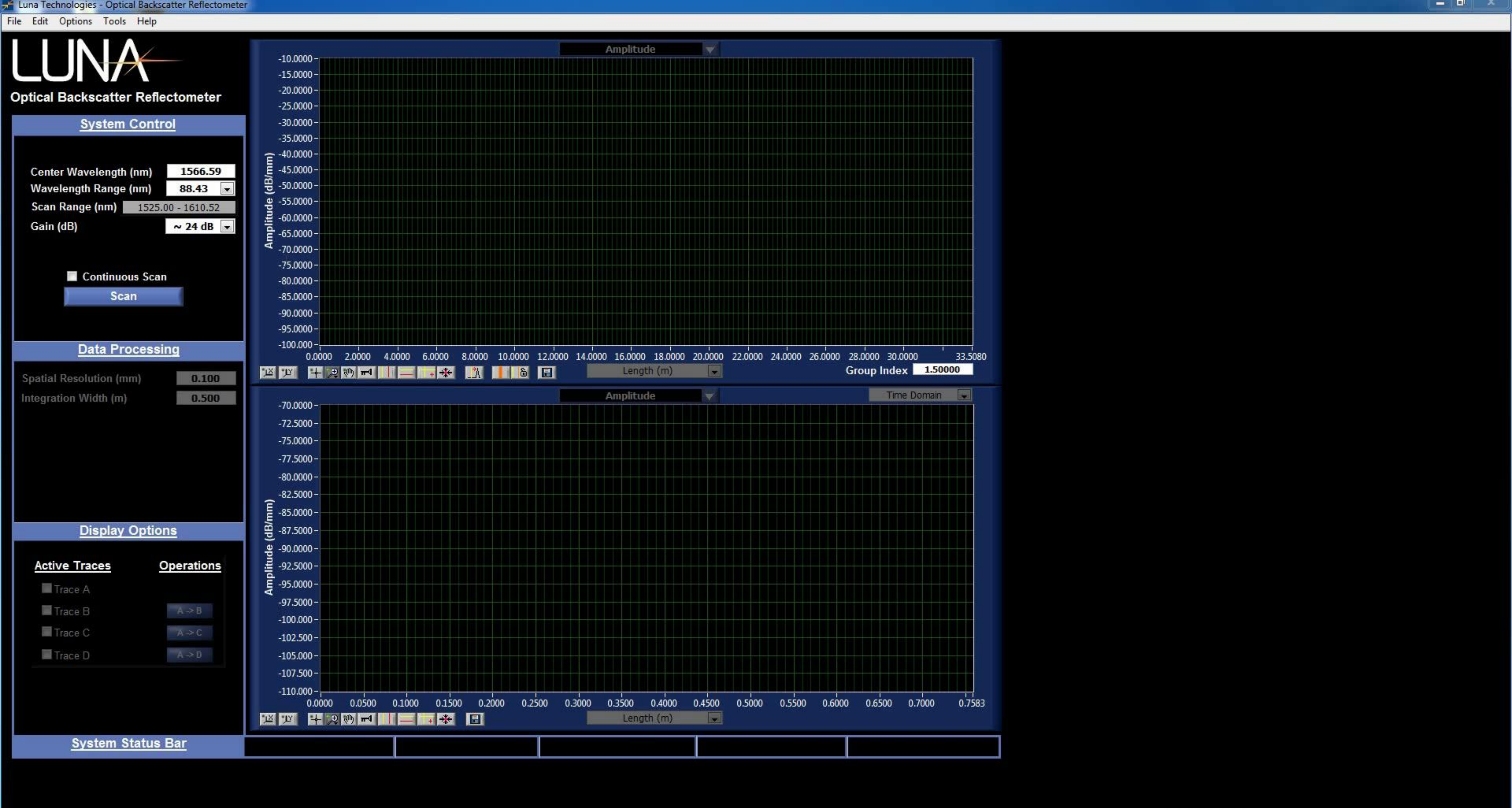
OBR 4600

- Ultra-high resolution reflectometer
- Works in Reflection only
- Sensitivity: -130 dB
- High spatial resolution: 10 μm
- Large fiber measurement range: 2000 m
- High Dynamic Range: 80 dB

Demonstration of OBR 4600 and OVA 5000

OVA 5000 **OBR 4600**

Chirped FBG
D = 2016 ps/nm
S = 6.96 ps/nm^2
$\lambda_0 = 1550\ nm$
1528 nm – 1565 nm
Grating chirp compensates for dispersion in 112k km SMF

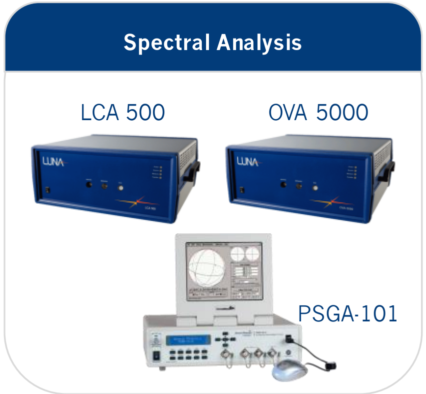


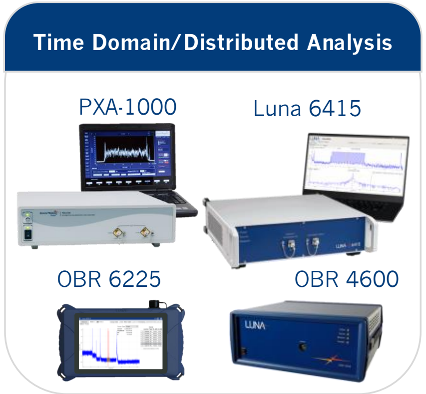
Luna Technologies - Optical Backscatter Reflectometer
File Edit Options Tools Help
LUNA
Optical Backscatter Reflectometer
System Control
Center Wavelength (nm) 1566.59
Wavelength Range (nm) 88.43
Scan Range (nm) 1525.00 - 1610.52
Gain (dB) ~ 24 dB
Continuous Scan
Scan
Data Processing
Spatial Resolution (mm) 0.100
Integration Width (m) 0.500
Display Options
Active Traces
Operations
Trace A
Trace B
Trace C
Trace D
A -> B
A -> C
A -> D
System Status Bar
Amplitude
Amplitude (dB/mm)
Length (m)
Group Index 1.50000
Time Domain

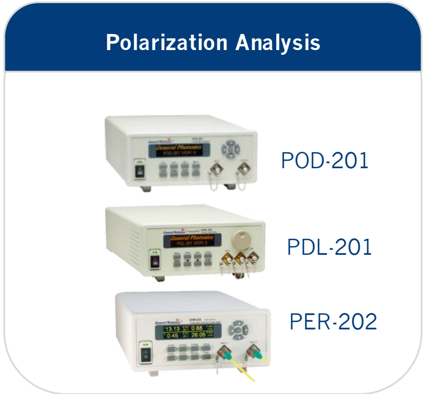

Luna - Optical Vector Analyzer
File Edit Options Tools Help
LUNA
Optical Vector Analyzer
System Control
Type of Measurement Transmission
Center Wavelength (nm) 1550.00
Wavelength Range (nm) 2.54
Scan Range (nm) 1548.69 - 1551.31
DUT Length Find Method Broadband
Find Length of DUT (m) 3.000
Continuous Mode
Enable Averaging # 4
Scan
Data Processing
Filter Resolution BW (pm) 0.00
Apply Filter
Time Domain
Matrix for Res BWs Below
TD Window Res BW (pm) 0.00
Convolved Res BW (pm) 0.00
Display Options
Sync X-Axes To Top
Matrix Memory Functions
Active Matrices
Operations
Matrix A
Matrix B
Matrix C
A -> B
A -> C
System Status Bar
Insertion Loss
Insertion Loss (dB)
Wavelength (nm)
Group Delay
Group Delay (ps)
Wavelength (nm)
Out of Calibration

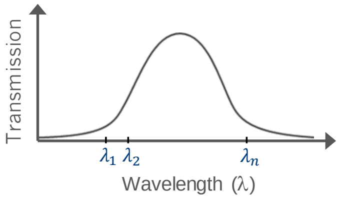
Summary

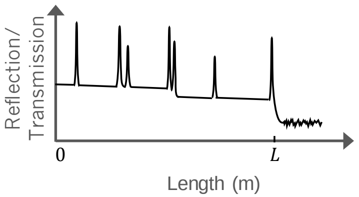
- Specialty and custom fibers enables a new applications
- Different Fibers require unique testing capabilities
- The increasing demand for optical fibers pushes for a high speed measurement solutions

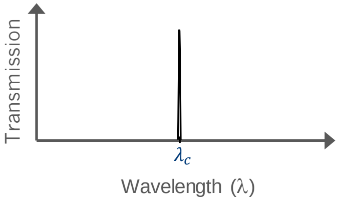












Enabling the Future with Fiber

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