



EXPERTISE REACHING OUT

## Sharing worldwide PMD tests results: are they all meeting international standards specifications?

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2007



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Telecommunications Test and Measurements

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 OUTLINE

- *Definitions*
- *Standards Specifications and How to Use Them*
- *Test Results and the Conclusions*

## PMD Measurements Field Installed Cabled Fibers - Definitions

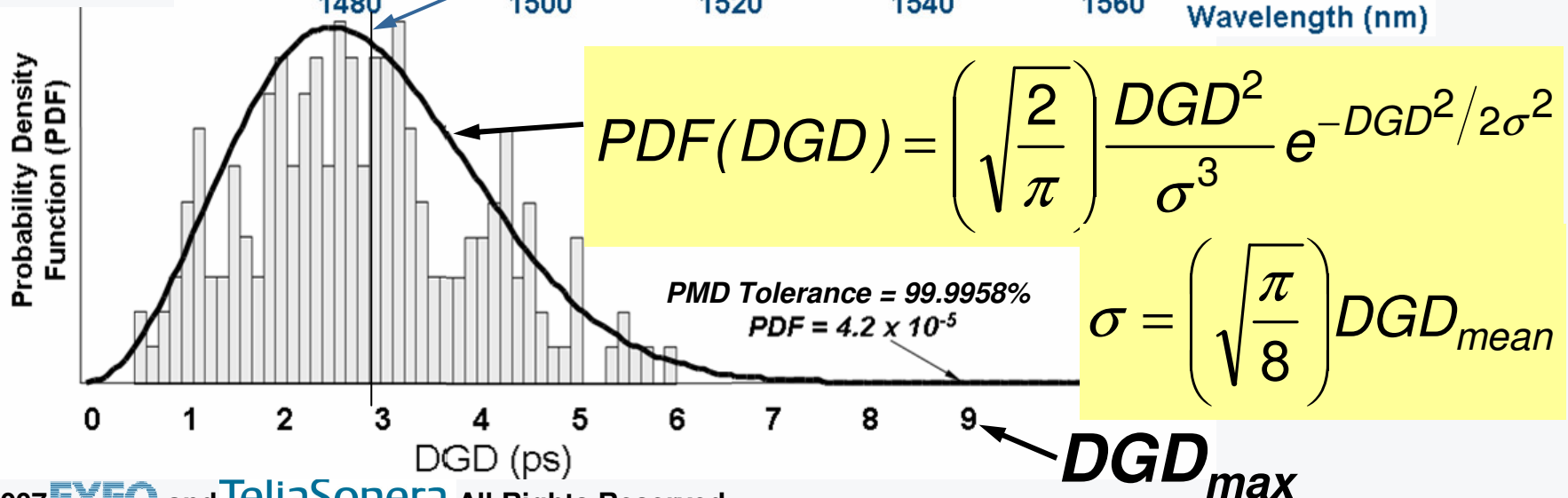
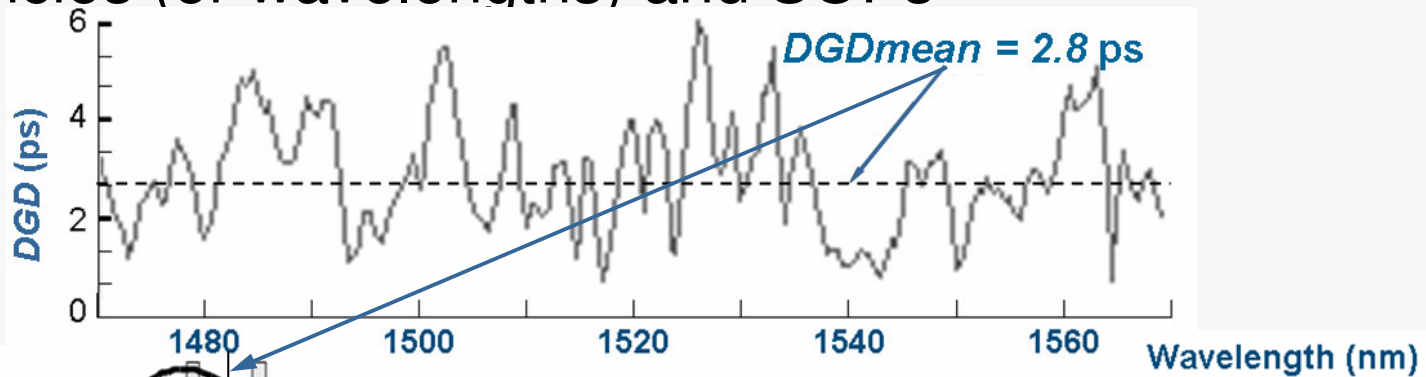
PMD → characterized by  $DGD_{mean}$  or  $DGD_{rms}$

- **$DGD_{mean}$** 
  - Characteristic of *Maxwell distribution* and
  - Useful predictor of  **$DGD_{max}$**  → **SLA/QoS**
- **$DGD_{rms}$** 
  - Practical (true) predictor of *pulse broadening*
  - *Worse case* broadening → System Impairment
- **$PMD_Q$  coefficient =  $DGD_{mean,rms}/km^{1/2}$**

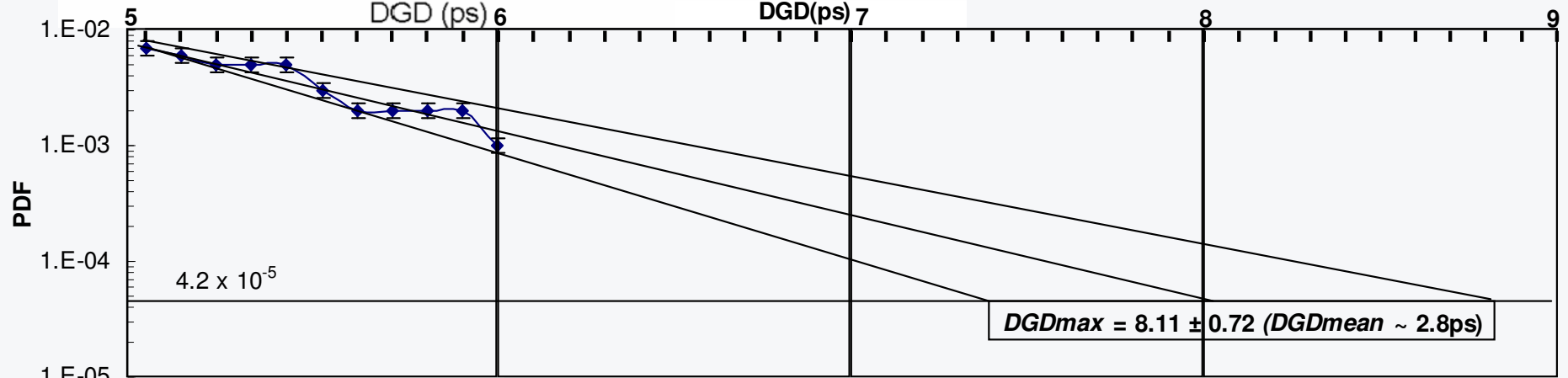
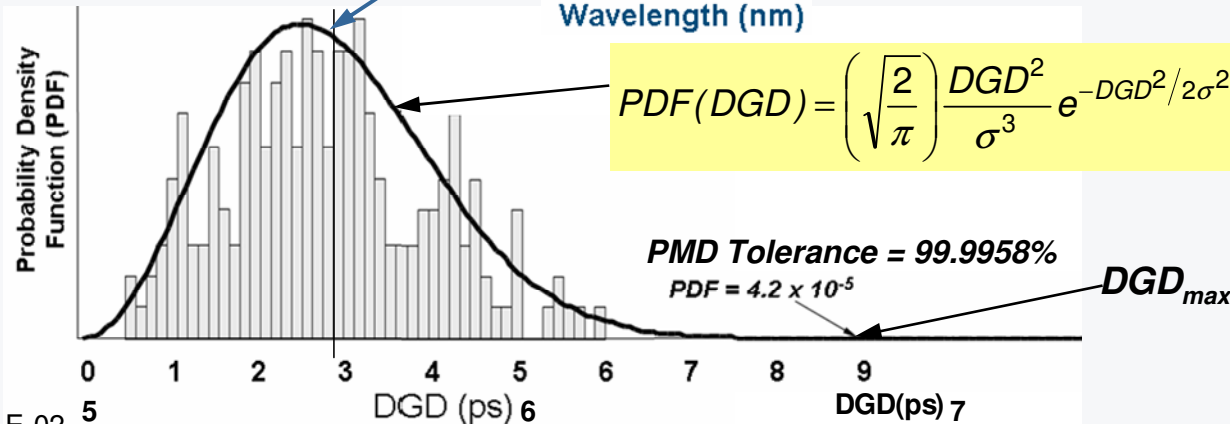
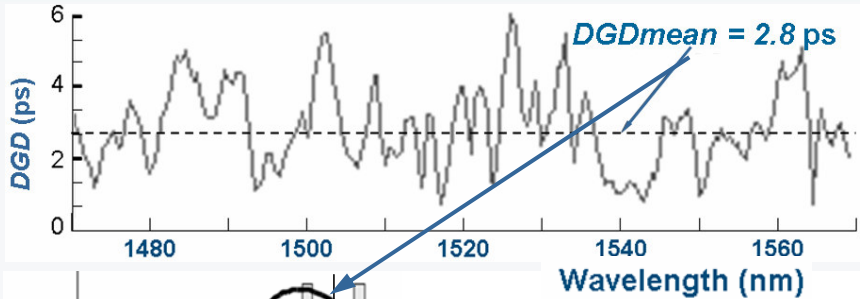
# DGD Measurement Stokes Parameter Evaluation (SPE)

$DGD_{mean}$  is obtained from the SPE Test Method

DGD must be measured over a wide range of optical angular frequencies (or wavelengths) and SOPs



It is difficult to accurately estimate  $DGD_{max}$



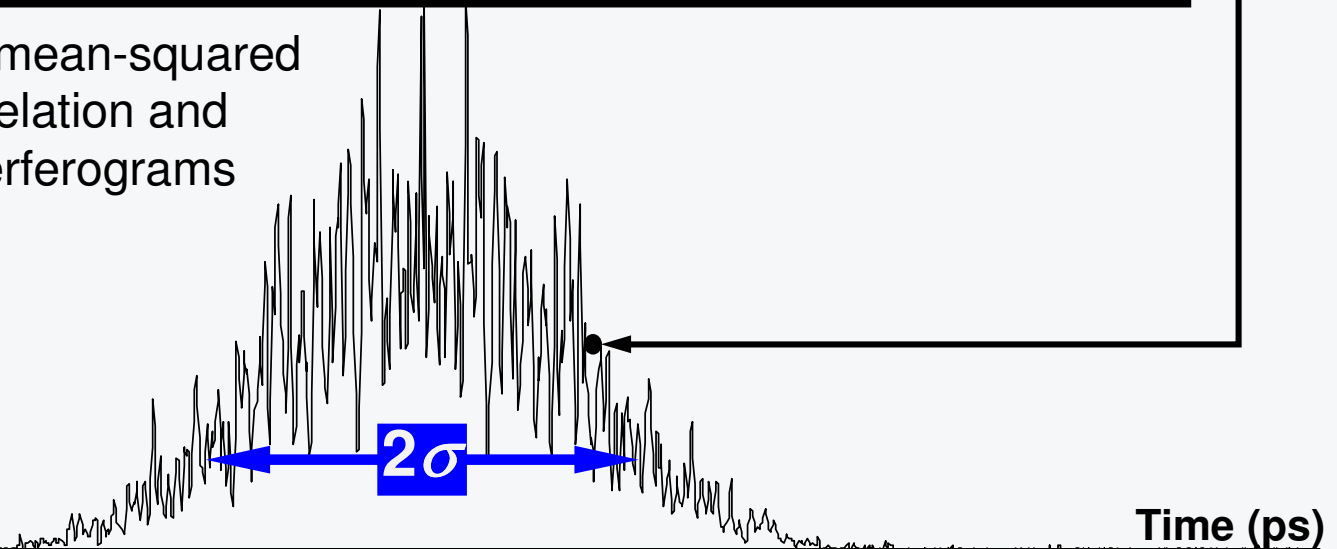
## PMD Measurement Interferometry

$DGD_{rms}$  is obtained from the Cross-Correlation Interferogram of the General Interferometry (GINTY) Test Method

It must be measured over a wide range of optical angular frequencies (or wavelengths) and SOPs

$$\sigma = \langle DGD^2 \rangle^{1/2} = \langle \Delta\tau^2 \rangle^{1/2} = DGD_{rms} = PMD = \sqrt{\frac{3}{2} (\sigma_x^2 - \sigma_0^2)}$$

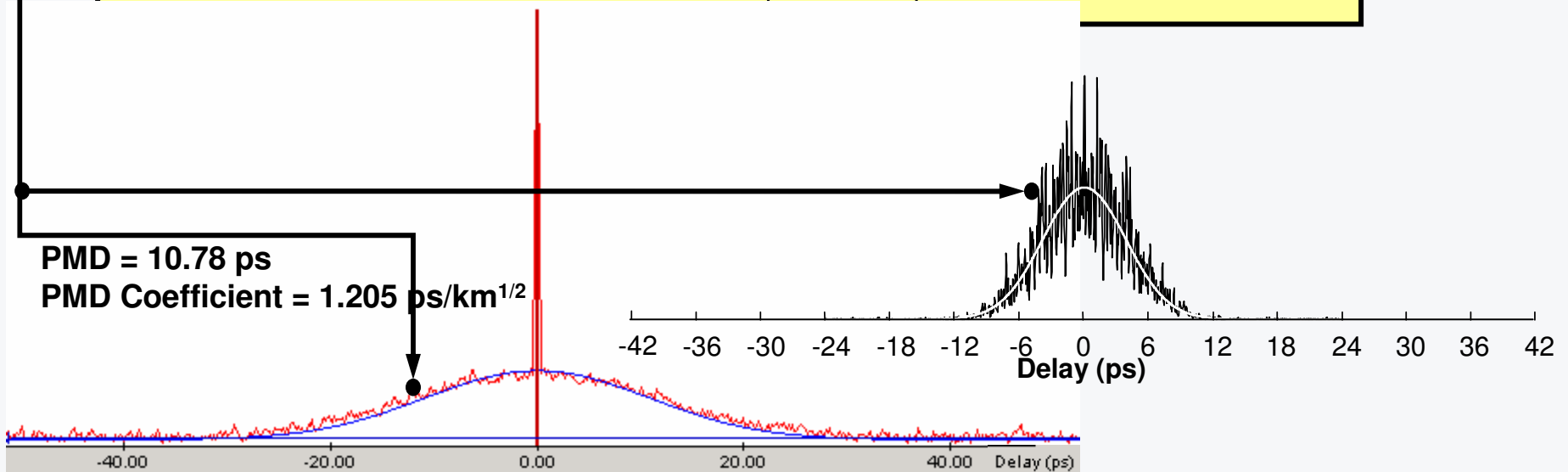
$\sigma_0, \sigma_x$  = rms width of mean-squared envelopes of autocorrelation and cross-correlation interferograms



## Further Definitions

- A **Gaussian** *GINTY* cross-correlation interferogram corresponds to a valid Maxwell assumption ► Ideal random mode coupling
  - Maxwell fit may be applied to PDF histogram
  - *TINTY* used if PMD is large and source perfectly Gaussian (no ripple)

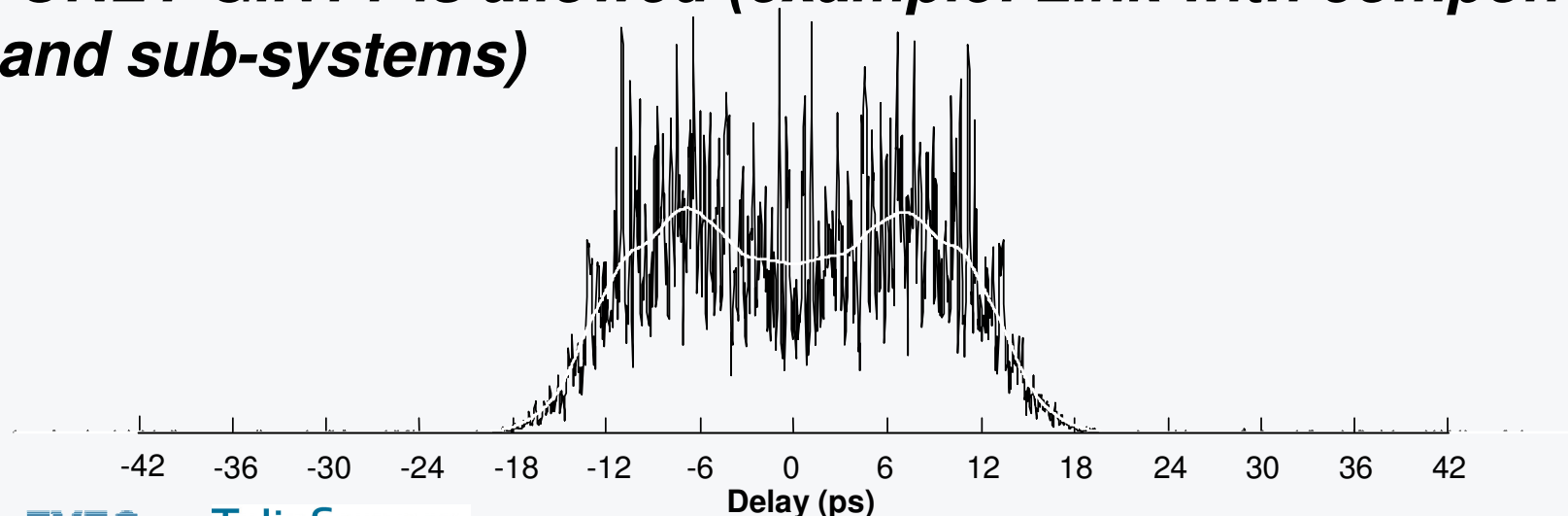
$$DGD_{rms} = \langle \Delta\tau^2 \rangle^{1/2} = \langle \Delta\tau \rangle \cdot \left( \sqrt{\frac{3\pi}{8}} \right) = DGD_{mean} \cdot \sqrt{\frac{3\pi}{8}}$$





## Further Definitions

- A **non-Gaussian** cross-correlation interferogram does not allow a valid Maxwell assumption ► *Semi-random mode coupling or combination of negligible and random mode couplings*
  - ***Maxwell fit does not apply to the histogram***
  - ***TINTY must not be used***
  - ***ONLY GINTY is allowed (example: Link with components and sub-systems)***





# ITU-T Cable PMD Specifications

- PMD Coefficient only
- For Cabled Fibers only
- Per Fiber Types only

			Cabled Fiber Specifications	
			Fiber Types	
			G.652.A/.C	G.652.B/.D
			G.653.A	G.653.B
			G.654.A	G.654.B/.C
			G.655.A/.B	G.655.C/.D.E
				G.656
<b>PMD Coefficient (for Cabled Fibers Only)</b>	Cable	Max PMD <sub>Q</sub> (ps/km <sup>1/2</sup> )	0.5	0.20
	Fiber	Max	Optional value to be specified in support for a particular cable PMD <sub>Q</sub>	

# ITU-T System $DGD_{max}$ Specifications

## NRZ and 1 dB Power Penalty

Attribute	P2P System Specifications (using cabled fibers only)									
	G.652.A/.C/G.653.A/ G.654.A/G.655.A/.B					G.652.B/.D/G.653.B/G. 654.B/.C/				
Bit Rate (Gbit/s)	10		40			10		40		
Fiber Length (km)	40	400	4000	2	400	3000	4000	80	400	
$DGD_{max}$ (ps)	19.0	25.0	12.0	7.5	5.0	19.0	12.0	7.0	5.0	

Attribute	P2P System Specifications (using but not limited to G.652/G.653/G.655 cabled fibers)									
Bit Rate (Gbit/s)	10								40	
Fiber Length (km)	0.6	2	20	25	40	80	120	160	2	80
$DGD_{max}$ (ps)	30.0								7.5	

# Definitions - Maxwell Adjustment Factor S

## NRZ for 1 dB penalty

Mode Coupling	Cross-Correlation	Maxwell Assumpt.	Equivalence	$DGD_{max}$
	$DGD_{rms}$	$DGD_{mean}$		
Random	Gaussian	Valid	$DGD_{rms} = DGD_{mean} \cdot (3\pi/8)^{1/2}$	$S \cdot DGD_{mean}$
Semi-Random	Non-Gaussian	Invalid	None	$S \cdot DGD_{rms}$ (worst case)

PDF	S	9's
$4.2 \times 10^{-5}$	3.0	4
$2.0 \times 10^{-5}$	3.1	4
$9.2 \times 10^{-6}$	3.2	5
$4.1 \times 10^{-6}$	3.3	5
$1.8 \times 10^{-6}$	3.4	6
$7.7 \times 10^{-7}$	3.5	6

PDF	S	9's
$3.2 \times 10^{-7}$	3.6	6
$1.3 \times 10^{-7}$	3.7	7
$6.5 \times 10^{-8}$	3.775	7
$5.1 \times 10^{-8}$	3.8	7
$2.0 \times 10^{-8}$	3.9	7
$7.4 \times 10^{-9}$	4.0	8

$$S = \frac{DGD_{max}}{DGD_{mean}}$$

# How to Calculate PMD from Fiber Spans

## $PMD_Q$ – Cabled Fiber Specification

### 2 cases

1)  $DGD_{mean}$ -Based ([Random Mode Coupling - Valid Maxwell Assumption](#))

$$PMD_Q \text{ Coefficient} = \left[ \sum_{\text{Fiber Spans}} \left( \frac{DGD_{mean S}}{\text{Length}_S^{1/2}} \right)^2 \right]^{1/2}$$

$$DGD_{mean} = DGD_{rms} \cdot \left( \frac{8}{3\pi} \right)^{1/2}$$

2)  $DGD_{rms}$ -Based (all cases – with GINTY)

$$PMD_Q \text{ Coefficient} = \left[ \sum_{\text{Fiber Spans}} \left( \frac{DGD_{rms S}}{\text{Length}_S^{1/2}} \right)^2 \right]^{1/2}$$

Note: Both  $DGD_{mean}$  and  $DGD_{rms}$  are standardized as equivalent

# How to Calculate PMD of a Link

## $DGD_{max}$ – System Specification

**2 cases**  $DGD_{max}$  and  $PMD_Q$  are based on:

- 1)  $DGD_{mean}$  (Random Mode Coupling - Valid Maxwell Assumption – Use of Maxwell Adjustment Factor S)
- 2)  $DGD_{rms}$ -Based (all cases - GINTY – Use of Maxwell Adjustment Factor S)

$$DGD_{maxLink} (ps) = \left[ DGD_{maxF}^2 + S^2 \sum_i PMD_{Ci}^2 \right]^{1/2}$$

$$DGD_{maxF} = S \cdot \left\{ \sum_{Span} \left[ \left( PMD_Q \text{ Coefficient} \right)_{Span} \cdot Length_{Span}^{1/2} \right]^2 \right\}^{1/2}$$

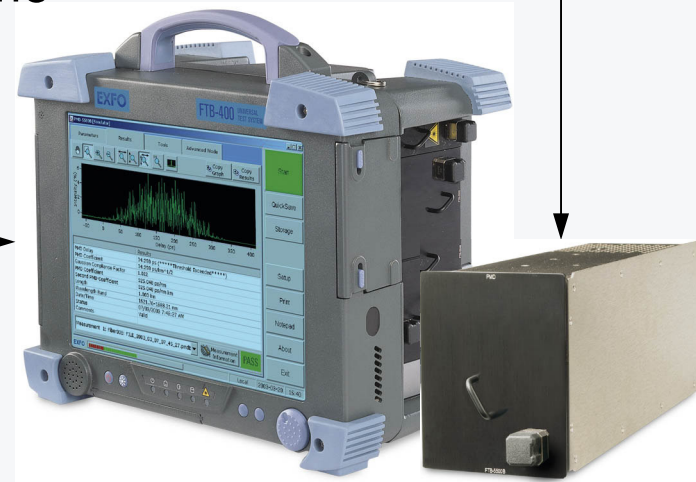
# Examples of PMD Test Results

Equipment used for every example:

FLS-5834, 1550 nm and 1625 nm SuperLEDs (2 SOPs) Source

FTB-5500B, GINTY-Based Test Method Analyzer

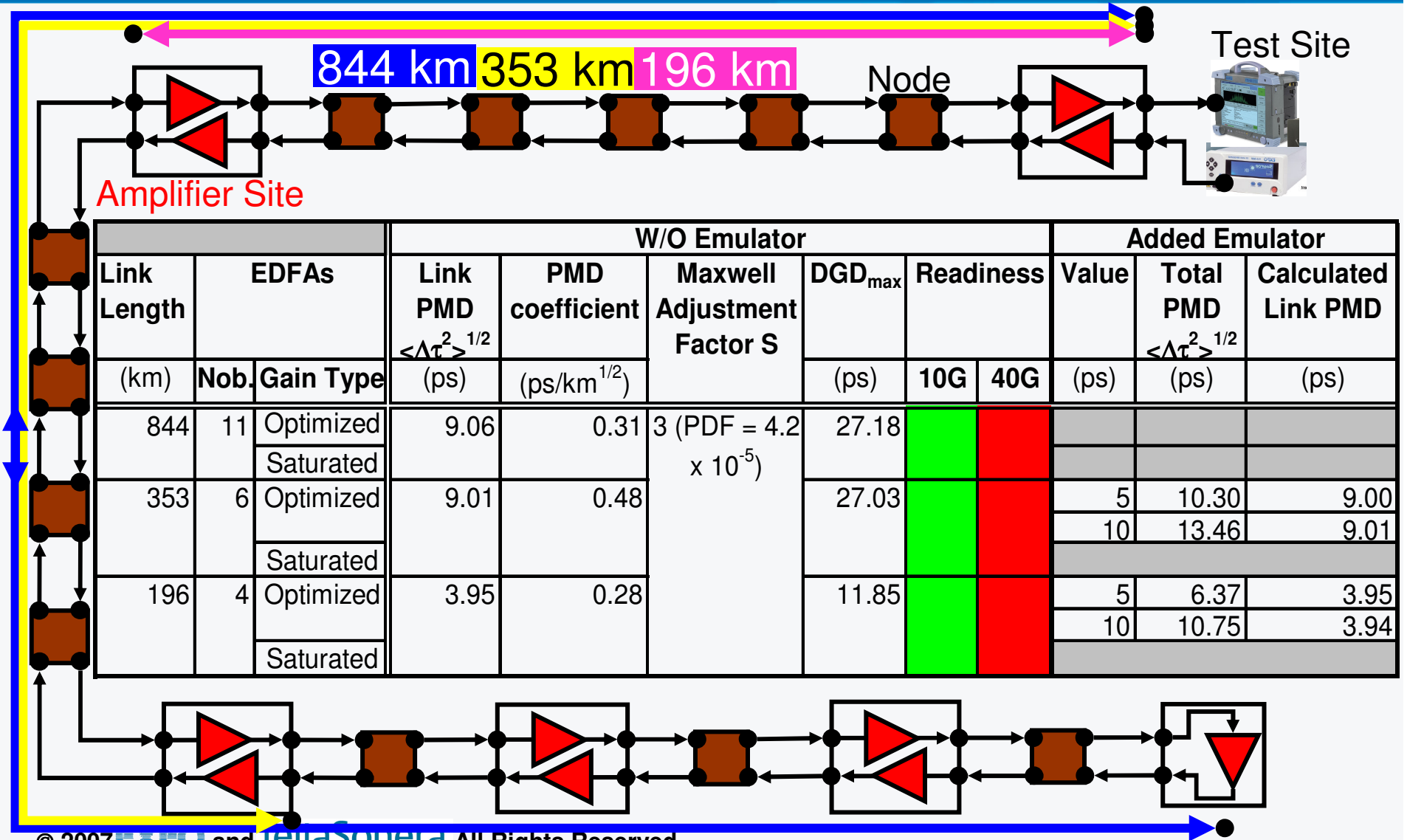
FTB-400 Mainframe



All tests performed after 2002

# PMD Test Results

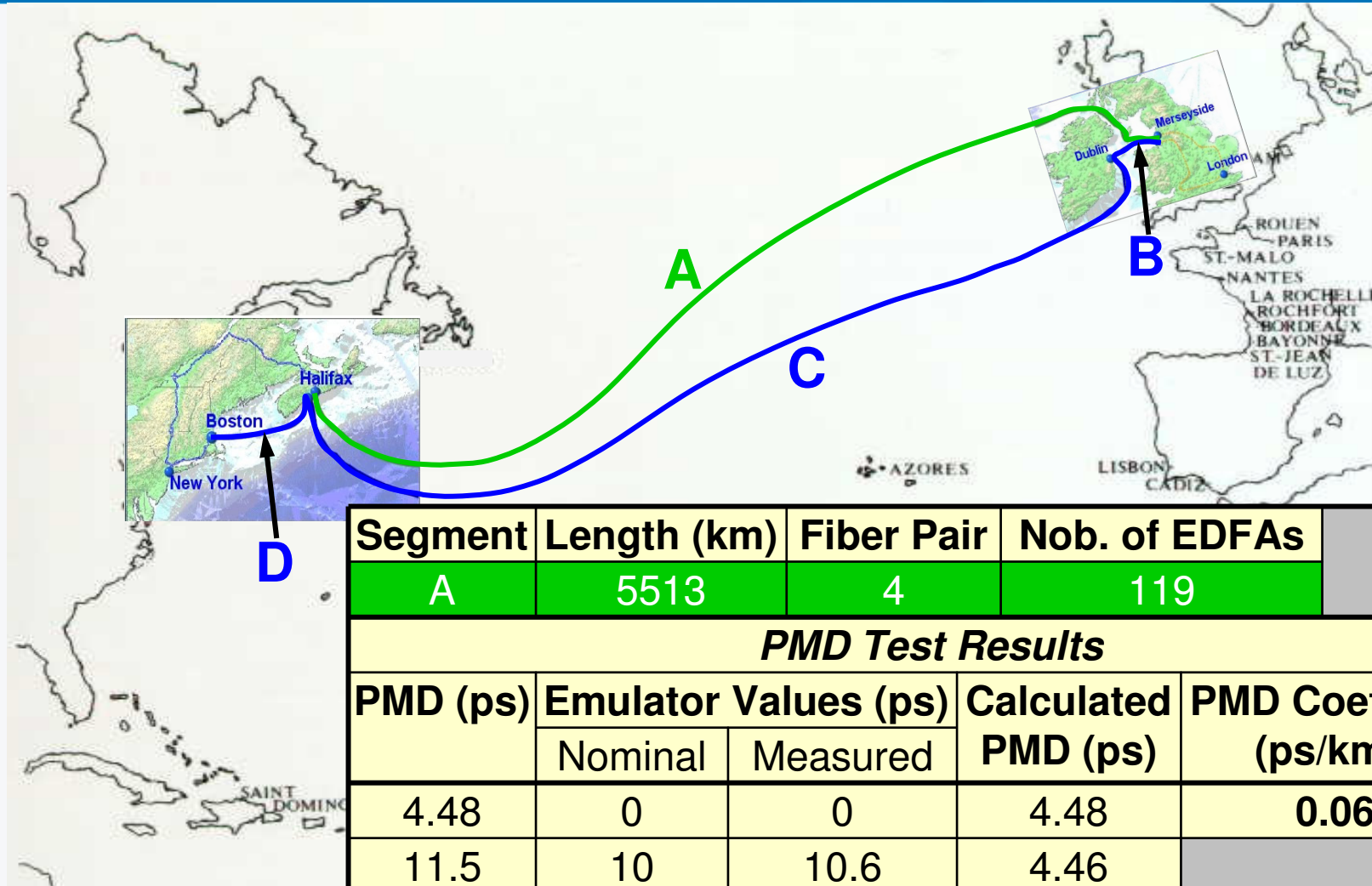
## NA – Canada/Province of Quebec/Terrestrial Network





# PMD Test Results

## Trans-Atlantic Submarine Network



Segment	Length (km)	Fiber Pair	Nob. of EDFAs	
A	5513	4	119	
<b>PMD Test Results</b>				
PMD (ps)	Emulator Values (ps)		Calculated PMD (ps)	PMD Coefficient (ps/km <sup>1/2</sup> )
	Nominal	Measured		
4.48	0	0	4.48	<b>0.060</b>
11.5	10	10.6	4.46	
7.3	5	5.8	4.43	

# PMD Test Results

## Africa/Terrestrial Network (1)

Readiness Cable	10 Gbit/s						40 Gbit/s					
	Section					Total	Section					Total
Length (m)	31216	51360	15056	50411	77135	225178	31216	51360	15056	50411	77135	225178
Fiber No.	PMD Coefficient (ps/km <sup>1/2</sup> )											
1	0.26	0.22	0.23	0.56		0.38	0.26	0.22	0.23	0.56		0.38
2	0.14	0.17	0.29	0.46		0.31	0.14	0.17	0.29	0.46		0.31
3	0.21	0.28	0.22	0.41	0.25	0.30	0.21	0.28	0.22	0.41	0.25	0.30
4	0.22	0.35	0.22	0.10	0.35	0.29	0.22	0.35	0.22	0.10	0.35	0.29
5	0.25	0.36	0.18	0.19	0.09	0.23	0.25	0.36	0.18	0.19	0.09	0.23
6	0.33	0.23	0.13	0.53	0.26	0.34	0.33	0.23	0.13	0.53	0.26	0.34
7	0.61	0.50	0.54	0.24	0.37	0.43	0.61	0.50	0.54	0.24	0.37	0.43
8	0.14	0.57	0.56	0.35	0.27	0.39	0.14	0.57	0.56	0.35	0.27	0.39
9	0.17	0.24	1.70	0.53	0.09	0.52	0.17	0.24	1.70	0.53	0.09	0.52
10	0.37	0.48	0.56	0.19	0.33	0.37	0.37	0.48	0.56	0.19	0.33	0.37
11	0.12	0.25	0.17	0.91	0.25	0.47	0.12	0.25	0.17	0.91	0.25	0.47
12	0.14	0.19	1.58	0.24	0.26	0.46	0.14	0.19	1.58	0.24	0.26	0.46

# PMD Test Results

## Africa/Terrestrial Network (2)

Readiness Cable	10 Gbit/s						40 Gbit/s					
	Section					Total	Section					Total
Length (m)	31216	51360	15056	50411	77135	225178	31216	51360	15056	50411	77135	225178
Fiber No.	PMD Coefficient (ps/km <sup>1/2</sup> )											
13	0.33	0.42	2.19	0.65	0.37	0.72	0.33	0.42	2.19	0.65	0.37	0.72
14	0.42	0.21	0.29	0.62	0.30	0.40	0.42	0.21	0.29	0.62	0.30	0.40
15	0.16	0.21	0.65	0.17	0.76	0.49	0.16	0.21	0.65	0.17	0.76	0.49
16	0.44	0.53	1.22	0.67	0.64	0.66	0.44	0.53	1.22	0.67	0.64	0.66
17	0.38	0.17	0.21	0.32	0.36	0.31	0.38	0.17	0.21	0.32	0.36	0.31
18	0.24	0.34	0.95	0.28		0.42	0.24	0.34	0.95	0.28		0.42
19	0.09	0.10	0.44	0.41		0.29	0.09	0.10	0.44	0.41		0.29
20	0.19	0.48	0.43	0.28		0.36	0.19	0.48	0.43	0.28		0.36
21	0.20	0.41	0.88	0.72		0.57	0.20	0.41	0.88	0.72		0.57
22	1.16	0.14	0.97	0.91	0.13	0.67	1.16	0.14	0.97	0.91	0.13	0.67
23	1.41	0.77	0.59	1.16	0.65	0.94	1.41	0.77	0.59	1.16	0.65	0.94
24	0.36	0.11	1.91	0.77	0.35	0.66	0.36	0.11	1.91	0.77	0.35	0.66

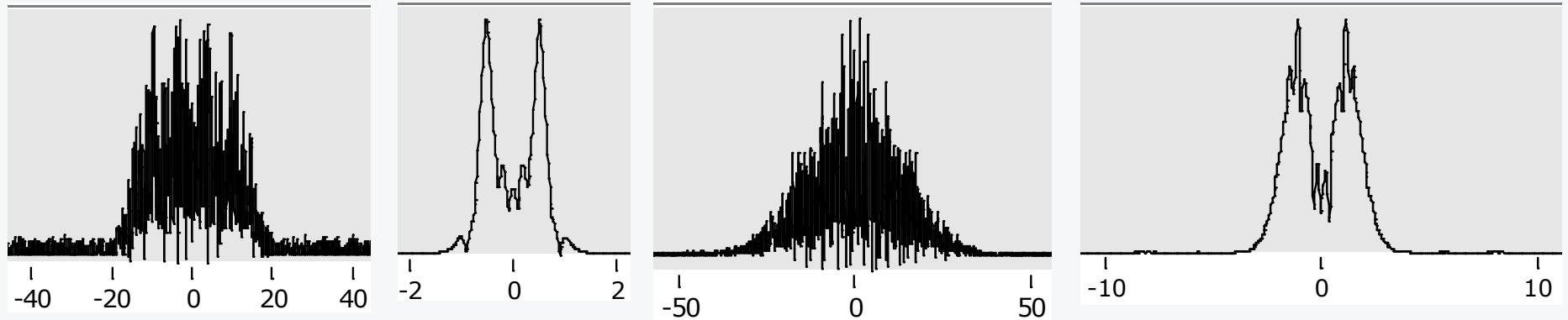
# PMD Test Results

## Africa/Terrestrial Network (1+2)

Readiness	10 Gbit/s						40 Gbit/s					
	Section					Total	Section					Total
Cable	31216	51360	15056	50411	77135	225178	31216	51360	15056	50411	77135	225178
Length (m)												
Fiber No.	PMD Coefficient (ps/km <sup>1/2</sup> )											
1	0.26	0.22	0.23	0.56		0.38	0.26	0.22	0.23	0.56		0.38
2	0.14	0.17	0.29	0.46		0.31	0.14	0.17	0.29	0.46		0.31
3	0.21	0.28	0.22	0.41	0.25	0.30	0.21	0.28	0.22	0.41	0.25	0.30
4	0.22	0.35	0.22	0.10	0.35	0.29	0.22	0.35	0.22	0.10	0.35	0.29
5	0.25	0.36	0.18	0.19	0.09	0.23	0.25	0.36	0.18	0.19	0.09	0.23
6	0.33	0.23	0.13	0.53	0.26	0.34	0.33	0.23	0.13	0.53	0.26	0.34
7	0.61	0.50	0.54	0.24	0.37	0.43	0.61	0.50	0.54	0.24	0.37	0.43
8	0.14	0.57	0.56	0.35	0.27	0.39	0.14	0.57	0.56	0.35	0.27	0.39
9	0.17	0.24	1.70	0.53	0.09	0.52	0.17	0.24	1.70	0.53	0.09	0.52
10	0.37	0.48	0.56	0.19	0.33	0.37	0.37	0.48	0.56	0.19	0.33	0.37
11	0.12	0.25	0.17	0.91	0.25	0.47	0.12	0.25	0.17	0.91	0.25	0.47
12	0.14	0.19	1.58	0.24	0.26	0.46	0.14	0.19	1.58	0.24	0.26	0.46
13	0.33	0.42	2.19	0.65	0.37	0.72	0.33	0.42	2.19	0.65	0.37	0.72
14	0.42	0.21	0.29	0.62	0.30	0.40	0.42	0.21	0.29	0.62	0.30	0.40
15	0.16	0.21	0.65	0.17	0.76	0.49	0.16	0.21	0.65	0.17	0.76	0.49
16	0.44	0.53	1.22	0.67	0.64	0.66	0.44	0.53	1.22	0.67	0.64	0.66
17	0.38	0.17	0.21	0.32	0.36	0.31	0.38	0.17	0.21	0.32	0.36	0.31
18	0.24	0.34	0.95	0.28		0.42	0.24	0.34	0.95	0.28		0.42
19	0.09	0.10	0.44	0.41		0.29	0.09	0.10	0.44	0.41		0.29
20	0.19	0.48	0.43	0.28		0.36	0.19	0.48	0.43	0.28		0.36
21	0.20	0.41	0.88	0.72		0.57	0.20	0.41	0.88	0.72		0.57
22	1.16	0.14	0.97	0.91	0.13	0.67	1.16	0.14	0.97	0.91	0.13	0.67
23	1.41	0.77	0.59	1.16	0.65	0.94	1.41	0.77	0.59	1.16	0.65	0.94
24	0.36	0.11	1.91	0.77	0.35	0.66	0.36	0.11	1.91	0.77	0.35	0.66

# PMD Test Results

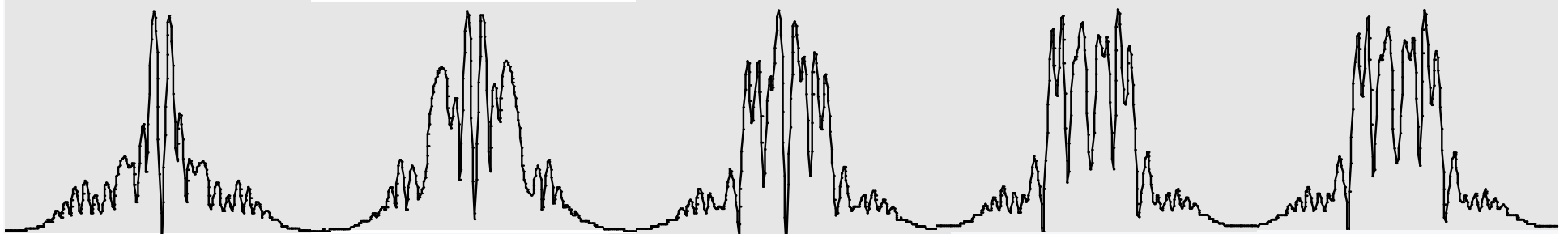
## NA – USA – Terrestrial Networks



Date	Location	Length (km)	PMD		Gaussian Compliance Factor	Readiness	
			Value (ps)	Coefficient (ps/km <sup>1/2</sup> )		10G	40G
2006	East Coast	53.325	9.715	1.33	0.79		
2004	Northern Central	1	0.604	0.605	0.752		
2006	Middle West	27.270	11.841	2.27	0.987		
2007	West	80	1.512	0.169	0.838		

# PMD Test Results

## Europe – UK – Terrestrial Network (2005)

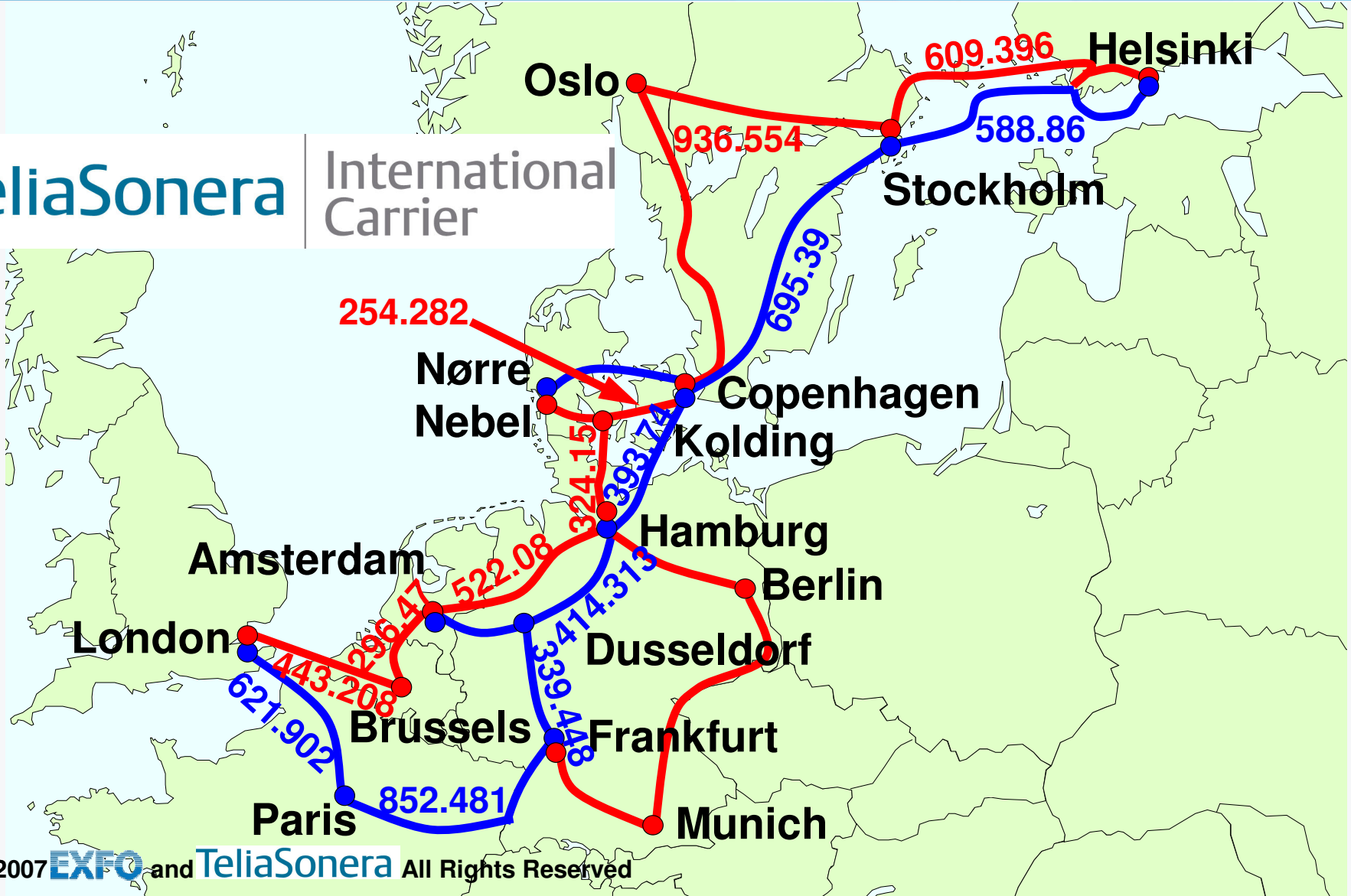


Length (km)	PMD		Gaussian Compliance Factor	Readiness	
	Value (ps)	Coefficient (ps/km <sup>1/2</sup> )		10G	40G
55	0.360	0.049	1.19	Green	Green
	0.396	0.053	1.00	Green	Green
	0.352	0.048	1.10	Green	Green
	0.363	0.049	1.07	Green	Green
	0.364	0.049	1.06	Green	Green

**The Viking Network  
European Core Fibre Routes**

**TeliaSonera**

International  
Carrier







Tests @ 1550nm		Attenuation (dB/km)	PMD Coefficient ps/√km	Readiness	
From	To			10G	40G
London	Brussels	0.214	0.016		
Brussels	Amsterdam	0.217	0.014		
Amsterdam	Hamburg	0.218	0.019		
Hamburg	Kolding	0.207	0.040		
Kolding	Copenhagen	0.212	0.056		
Copenhagen	Stockholm	0.211	0.025		
Stockholm	Helsinki	0.208	0.018		
London	Paris	0.210	0.013		
Paris	Frankfurt	0.210	0.044		
Frankfurt	Dusseldorf	0.211	0.072		
Dusseldorf	Hamburg	0.200	0.018		
Hamburg	Copenhagen	0.210	0.051		
Copenhagen	Stockholm	0.205	0.027		
Stockholm	Helsinki	0.212	0.036		

## Summary and Conclusion

- PMD in the field is created by *random/distributed stresses (stochastic)*
- PMD =  $DGD_{mean}$  or  $DGD_{rms}$ ; both definitions are internationally approved
- $DGD_{mean}$  = characteristic of *Maxwell Distribution*/useful predictor of  $DGD_{max}$
- $DGD_{rms}$  = practical predictor of pulse broadening

## Summary and Conclusion

- *Maxwell Assumption* = **valid/applicable** ►
  - GINTY cross-correlation interferogram = **Gaussian**
  - Polarization mode coupling = **ideally random**
- *Maxwell Assumption* = **invalid/non-applicable**
  - GINTY cross-correlation interferogram **≠ Gaussian**
  - Polarization mode coupling = **semi-random**
  - **Solution** = use  **$DGD_{rms}$  from GINTY** and still **apply the Maxwell Adjustment Factor  $S$  and PDF**

## Summary and Conclusion

- ***PMD<sub>Q</sub> Coefficient***
  - Specification for *long* cabled fibers (> 40km)
  - Depends on the fiber type only
- ***DGD<sub>max</sub>***
  - System/Link Specification; related to QoS
  - For link made of cabled fibers only
  - For link made of cabled fibers and components and sub-systems

## Summary and Conclusion

- *Link  $DGD_{max}$  specifications* are available for STM-4/16/64/256 for various link distances
- *For short links,  $DGD_{max}$*  is a specification for both fiber and link
- Case studies have been shown for various locations in the world





Thank you!

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## $DGD_{mean}$ and $DGD_{rms}$ Two Standardized Accepted Definitions

- IEC 60793-1-48: **Optical fibres** – Part 1-48: Measurement methods and test procedures – Polarization mode dispersion
- IEC 61280-4-4: Fibre optic communication subsystem test procedures – Part 4-4: **Cable plants and links** – Polarization mode dispersion measurement for installed links
- IEC 61282-9 TR: Fibre optic communication system design guides – Part 9: **Guidance** on polarization mode dispersion measurements and theory
- IEC 61290-11-1/2 : **Optical amplifiers** – Test methods – Part 11-1/2: Polarization mode dispersion parameter
- IEC 61300-3-32: Basic test and measurement procedures – Part 3-32: Examinations and measurements – Polarisation mode dispersion measurement for **passive optical components**
- ITU-T Recommendation G.650.2, Definitions and test methods for statistical and non-linear related attributes of **single-mode fibre and cable**
- TIA-455-113/122A/124A, FOTP, Polarization-Mode Dispersion Measurement for **Single-Mode Optical Fibers** Rights Reserved