Long duration PMD measurement results for aerial fibre and their implications for 40 Gbit/s systems

CEF Workshop

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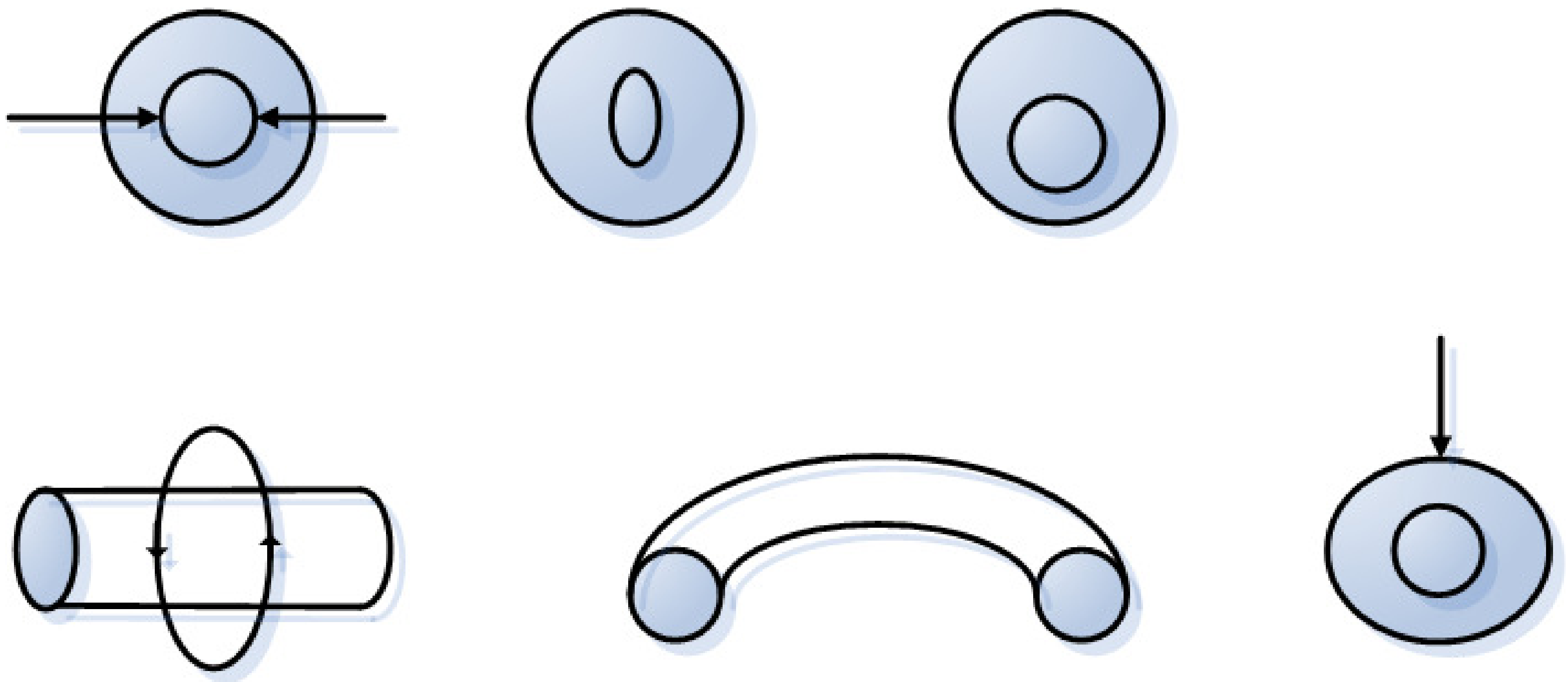
Agenda

- Introduction to PMD
- What the standards say for PMD
- The problem of PMD for 40G and 100G
- Limiting PMD
- PMD and Aerial fibre
- Conclusions

No. 1 Introduction to PMD - Bi-refringence

Core stress　Elliptical fiber　Cladding eccentricity

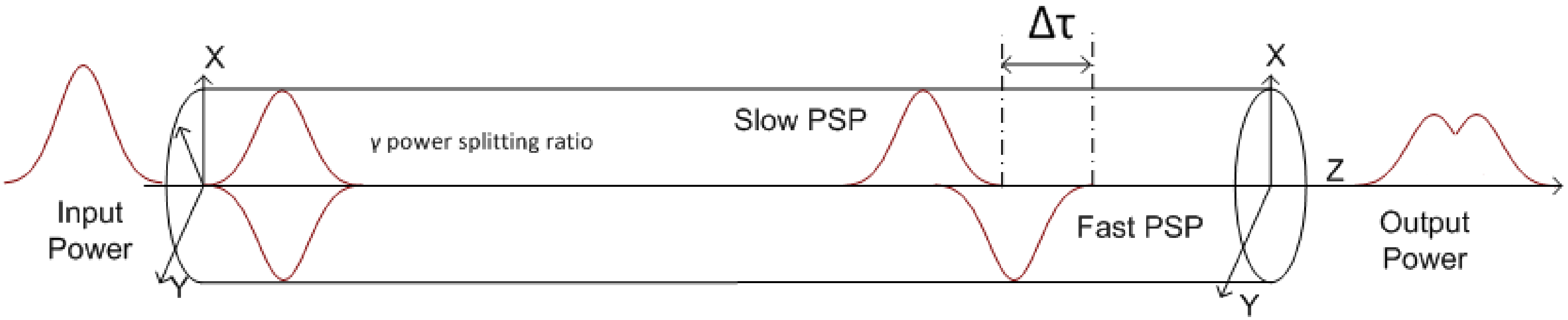


Fiber twist　Fiber bend　External fiber stress

Why PMD Occurs?

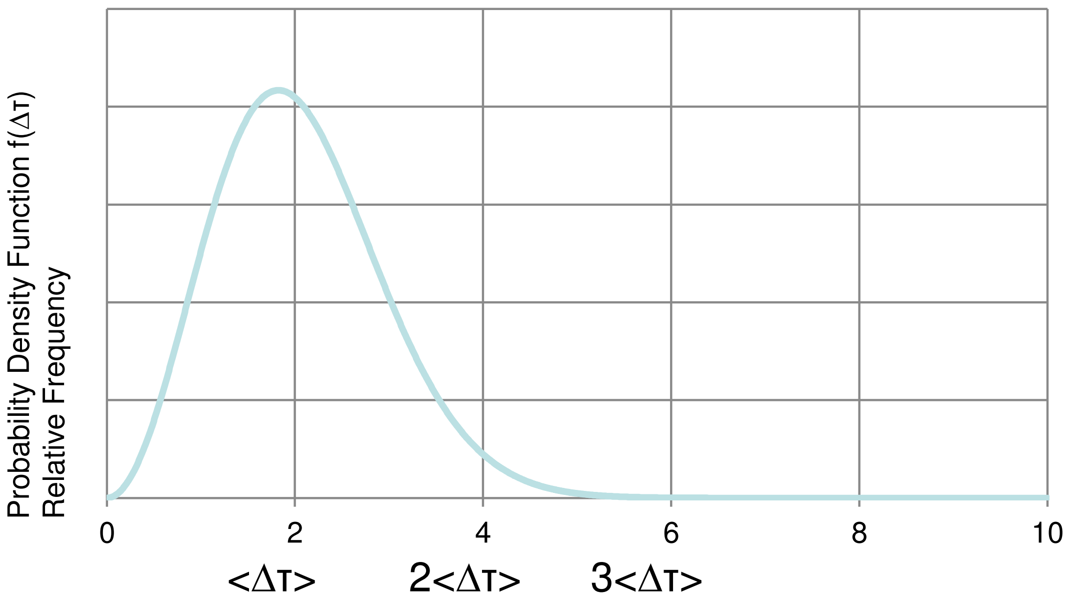
- Manufacturing defects
  - Fiber core is not perfectly circular along its overall length
  - Fiber core is not perfectly concentric with the cladding.
  - Fiber twisted or bent along its span
  - Fiber stress/tension
- Environmental/Human
  - Temperature
  - Human interaction at patch panels, PoPs, street cabinets, etc
  - Wind (aerial fiber)
  - Vibrations (trains)

Differential Group Delay (Δτ)



- Asymmetry in the refractive index causes a delay between the Principal states of polarization (PSP) DGD.
- DGD causes an optical pulse to spread in the time domain. Can lead to Inter symbol interference.
- DGD varies randomly with wavelength and time
- PMD (ps) – average or RMS of the DGD across a certain wavelength range.
- PMD is a statistical Attribute.

Statistical DGD Distribution



$$pdf(\Delta\tau) = 32\frac{\Delta\tau^2}{\pi^2 < \Delta\tau >^3}\exp\left(-\frac{4\Delta\tau^2}{\pi < \Delta\tau >^2}\right)$$

Δτ instantaneous DGD

< Δτ> Mean DGD across a certain wavelength range

The time averaged differential time delay between the two orthogonal SOPs on a link is known to obey the following relationship: Δτ = < Δτ> x √L

Above is an example with PMD = Mean DGD of 2ps and DGDmax = 6ps – Typical 40Gbit/s transponder.

The ratio between DGDmax and PMD is referred to as the safety factor S.
For an outage probability of 4.2x10-5 S factor is 3 Δτ(max) = S x <Δτ>

Integrating the pdf from Δτ to ∞ gives the probability P(Δτ≥ Mean DGD)

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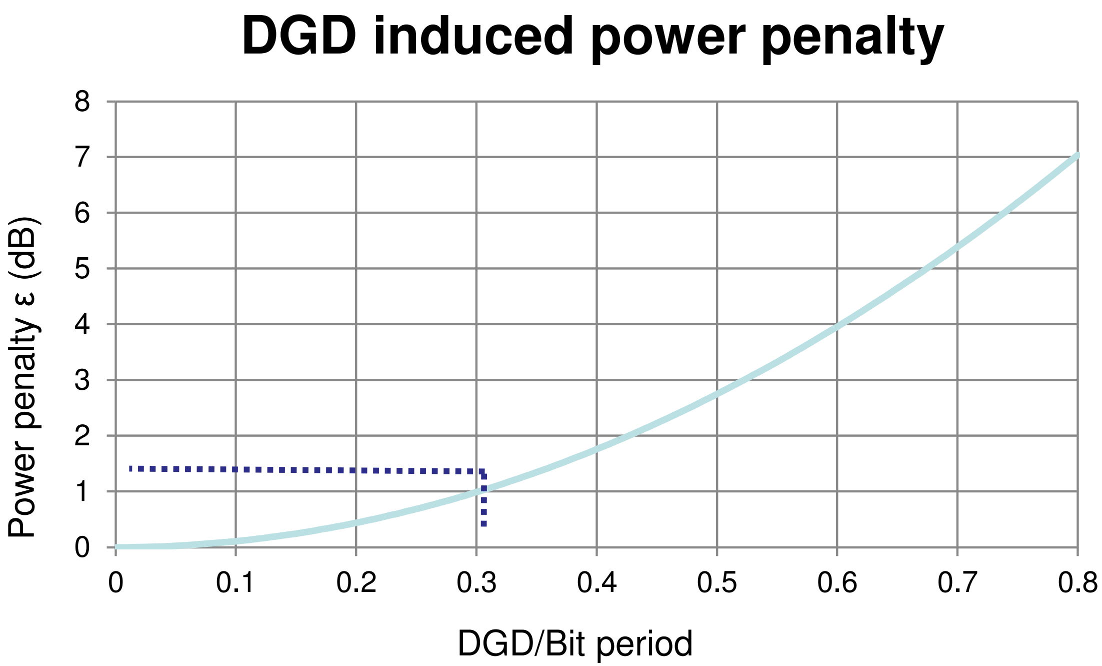
DGD Power Penalty



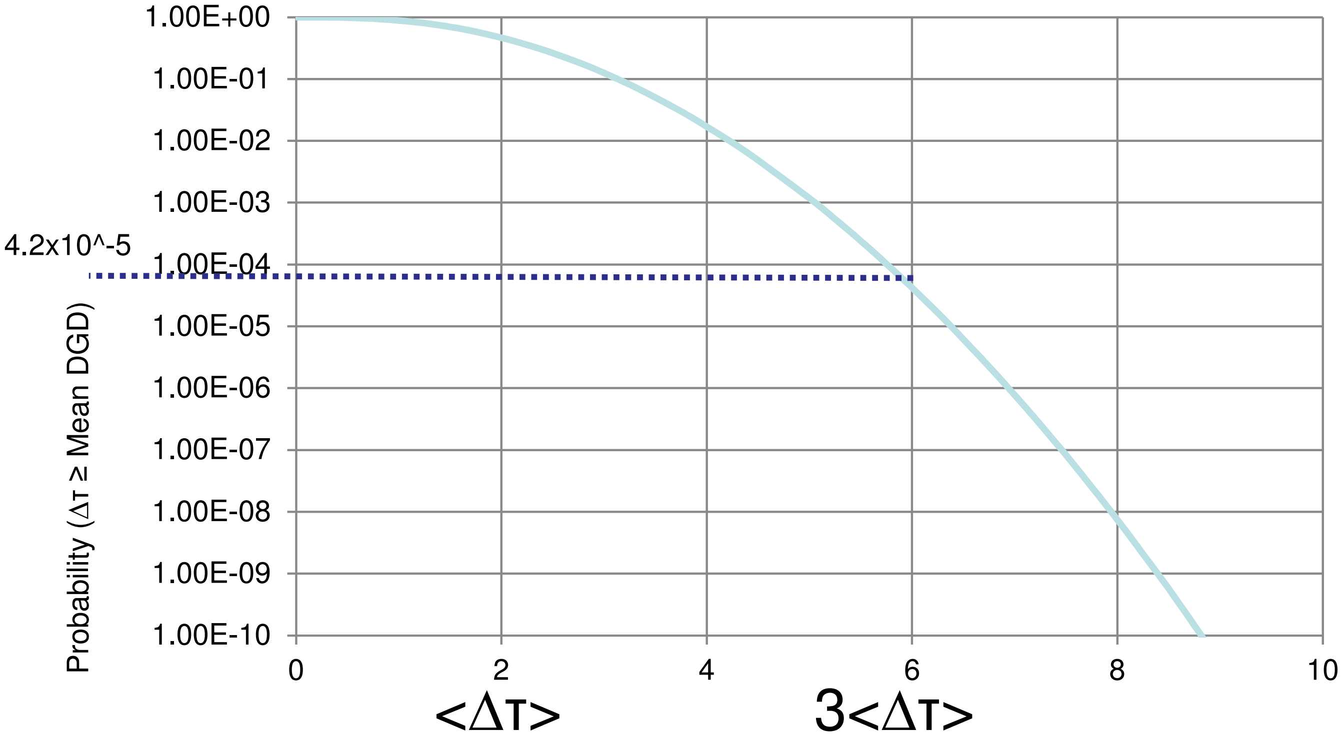
$$\epsilon = 2A\left(\frac{\Delta\tau}{T}\right)^2 \gamma(1-\gamma)$$

A factor relating to temporal pulse shape
γ power splitting ratio (0-1)
T Bit Period

For a 1db penalty due to PMD(NRZ up to 40Gbit/s) the DGDmax/Bit period is set at 30% – recommendation G.sup 39 + G.691
Example above is for A = 22 (rasied cosine) and γ = 0.5(worst case)

ITU (G.691) specifies a DGDmax of 30% of the bit period Tb. But PMD = 1/3DGDmax for an S of 4.2x10-5. Hence the mean DGD (ie PMD) must be < 1/10 Tb.
G.691 also specifies the Max DGD is defined to be the value of DGD that the system must tolerate with a maximum sensitvity of 1dB

Outage Probability



$$P(\Delta\tau \geq \Delta\tau_1) = \int_{\Delta\tau_1}^{\infty} f(\Delta\tau)\, d(\Delta\tau)$$

It is assumed that the system is designed with a power budget that allows a certain receive sensitivity penalty when the differential group delay exceeds a design value, *DGDmaxTot. If this* were to happen at a time when all other design variables are at the design limit, *PMD could* induce impairment for the period of time while *DGD > DGDmax tot.*

Probability of exceeding DGDmax

Ratio of Max to Mean	Probability of exceeding Maximum	Time > Max per year
3.0	4.2E-5	22 minutes
3.5	7.7E-7	24 seconds
3.775	6.5E-08	2.1 seconds
4.0	7.4E-09	0.23 seconds

- Interpret as potential unavailability
- Penalty, based on DGDmax, is allocated to system design
- If DGD<DGDmax, system is ok for that design
- If DGD>DGDmax, system could go down if everything else is at a limit
- Minutes/year/circuit = 2(fibers)*minutes in year(365.25x24x60)*Probability

Calculation of system max DGD (Δτ)

$$\Delta\tau\,(total) = \left[\Delta\tau^2_{\max F} + S^2 \sum_i PMD^2_{Ci}\right]^{1/2}$$

$$P(\Delta\tau_{total} > \Delta\tau_{\max\_total}) \leq P_{fiber} + P_{components}$$

- Δτ (total) is the maximum link DGD (ps)
- S is the Maxwell adjustment factor

- Requirement : Design a l with link length 400Km, DGDmax ≤ 30ps and a max probability of outage Total ≤ 1.3E-7.

- Given: DGDmax (fiber) = 25ps Probability of outage ≤ 6.5E-8
- 6 Random optical components (eg DCF) each of 1.5ps.
- Determine the PMD specification for each of the 6 deterministic elements (eg EDFA)
- To meet the overall probability requirement of ≤ 1.3E-7, the Probability for the components must be 6.5E-8. ie 6.5E-8+6.5E-8 = 1.3E-7
- The value of S is therefore 3.78 for 6.5E-8.
- PMD of each of the 6 deterministic elements is 0.98ps each.

$$\Delta\tau^2_{total} - \Delta\tau^2_{\max F} - S^2 \sum_i PMD^2_{Ri} = S^2 \sum_i PMD^2_{Di}$$

$$\left[\frac{30^2 - 25^2 - S^2(6x1.5)}{S^2 x\, 6}\right]^{1/2} = 0.98ps$$

Source Annex c – IEC TR61282-3

What the standards say for PMD

When calculating the PMD of a fiber link, the historical approach has been to assume that all fibers have the max PMD. IEC 61282-3 introduced a standard way based on the actual distribution of PMD comprising the link. IEC 61282-3. Defines a Link design value based on M 20 cables and Q = 0.01%(1E-4).

ITU specs specify PMD coefficient (PMDq) which is the link design value from IEC 61282-3.

G652 A/C PMDq = 0.5ps/√Km
G.652 B/D PMDq = 0.2ps/√Km
New fiber today has typically low PMD <0.05ps/√Km

G.691 specifies the max DGD to be a value the system must tolerate with a max sensitivity degradation of 1dB.
G.691 also allows for a DGD of 0.3T, where T is the bit duration.
Hence $\Delta\tau$ = PMDcoef √Km <0.1T

Survey of Fiber PMD values

- Old fibers (before 2000) >0.5ps/√Km
- New fibers can have 0.05ps/√km
- Typical post 2002 0.1ps/√Km

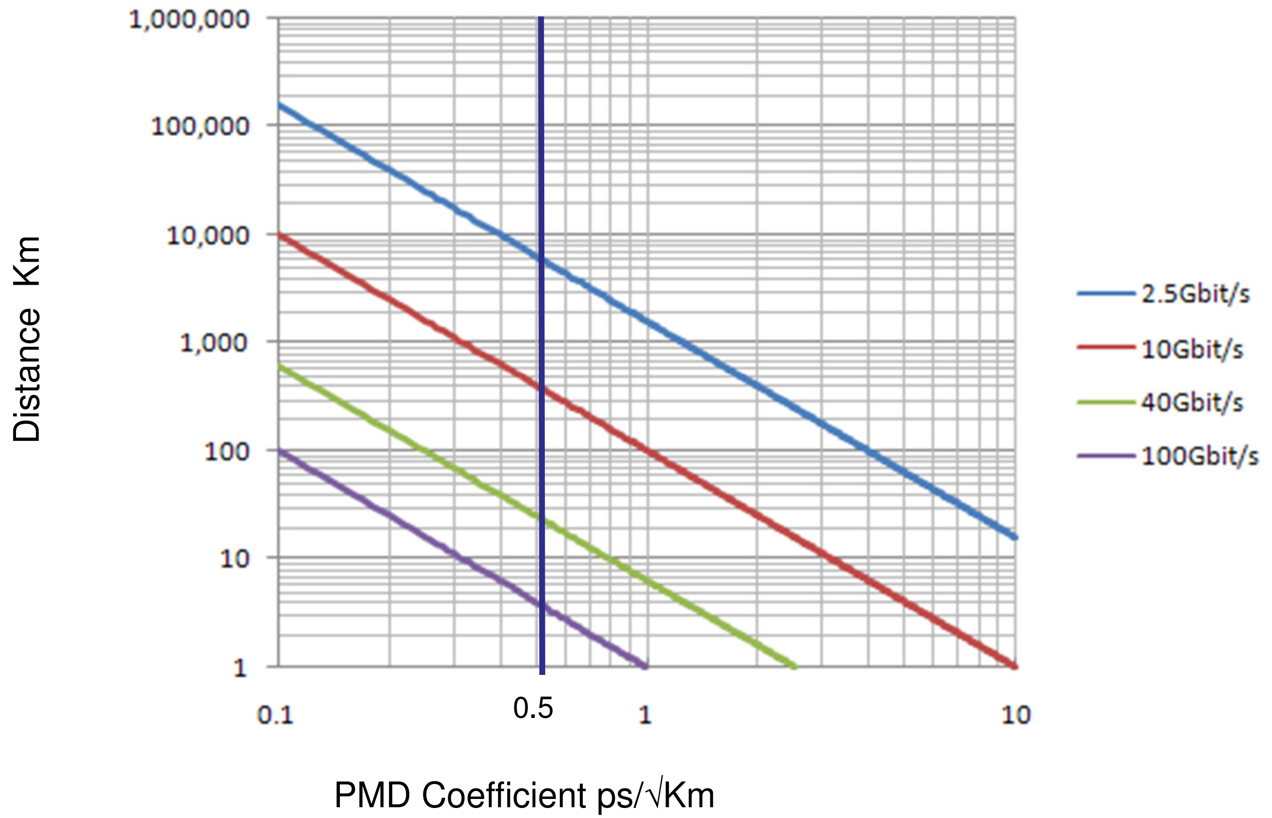
- DT Stats – Less than 50% of fibers usable for 40 Gb/s (Long Haul), 72% suitable for metro 400Km.
- Brazil of 2140 cable installed 1997-2002 – 19% had PMDcoef >0.5ps/√Km – not suitable according to ITU for 10Gbit/s
- Portugal PMD testing 4150 fibers tested(installed 2000-2005) Only 4% >0.5ps/√Km. Pre 2000(610 fibers) 24% > 0.5ps/√Km
- UK PMD tests (2266 fibers) 15% > 0.5ps/√Km

- PMD data Uk & Portugal OFC/NFOEC March 26th 2007 Richard Ednay & Modesto Morais
- Polarization Mode Dispersion of Installed fibers, Misha Brodsky 2006
- PMD as Bottleneck Problem for the Introduction of 40Gbit/s and Future 100Gbit/s Ethernet into German WDM Backbone W. Weiershausen, D. reuer T-Systems, Deutsche Telekom

The problem!

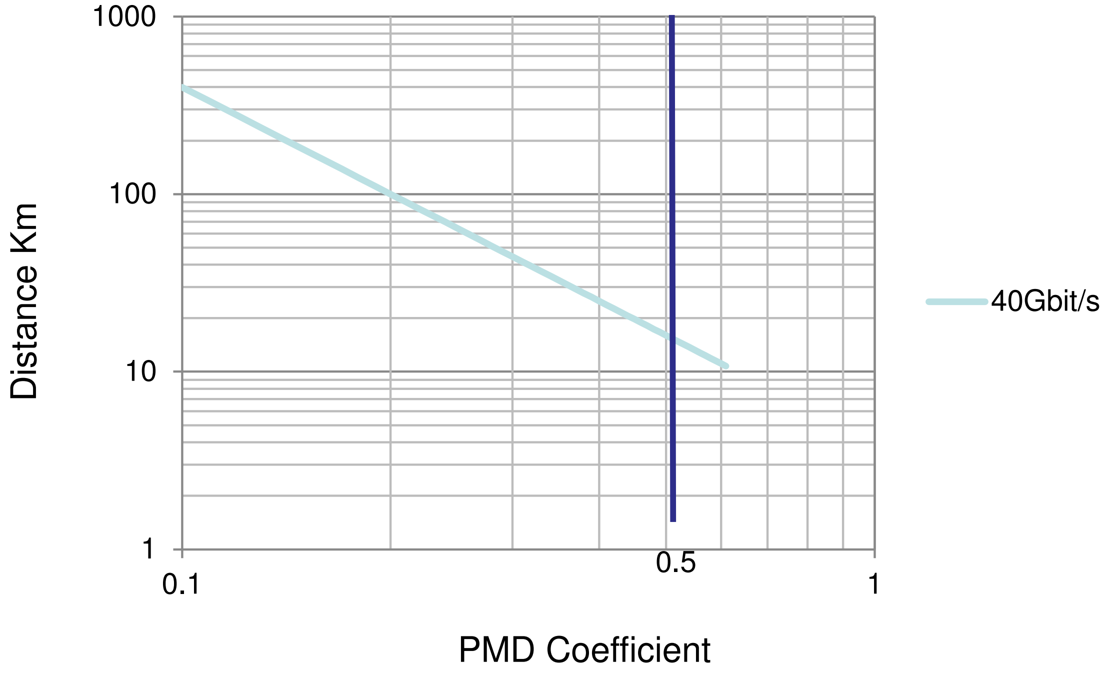
- Main challenge from a physical point of view to 40Gbit/s and 100Gbit/s is PMD
- Fibres that worked at 10Gbit/s may not work at all for 40Gbit/s and higher.
- ROADMs – passing through multiple nodes, different channels can go different routes. No OEO and different length paths.
- Timeslot decrease and the effects of PMD are increased proportionally

PMD Coefficient ps/√Km verses Distance Km



PMD considered Maxwellian, NRZ coding, 1db power penalty, BER>10-9. PMD =0.5ps/√Km, Max distance is 400Km at 10Gbit/s, 25Km at 40Gbit/s and 4Km at 100Gbit/s

Typical 40Gbit/s Transponder Versus Distance



Typical PMD(max) for 40Gbit/s transponder = 2ps. PMD coefficient =0.5ps/√Km, Max distance is 16Km
PMD(max) = 0.5x √16 = 2ps. PMD considered Maxwellian, NRZ coding, 1db power penalty

Typical transponder PMD values

- 40Gbit/s transponder - Ciena, Alcatel, Adva
- Maximum DGD 6ps, Maximum PMD 2ps – 2.5ps
- 10Gbit/s transponder
- Maximum DGD 30 ps, Maximum PMD 10 ps
- 2.5Gbit/s transponder
- Maximum DGD 120 ps, Maximum PMD 40 ps
- 1Gbit/s transponder,
- Maximum DGD 240 ps, Maximum PMD 80ps

- All for an outage probability of 4x10-5 and 1dB penalty due to PMD.

- Components
- EDFA 0.25ps
- DCF 0.5ps for 80Km and 10.7ps 160Km

- Nortel 100Gbit/s transponder using DPQSK – single wavelength at 50Ghz spacing, Mean PMD = 25ps, therefore DGD max = 75.

Limiting PMD

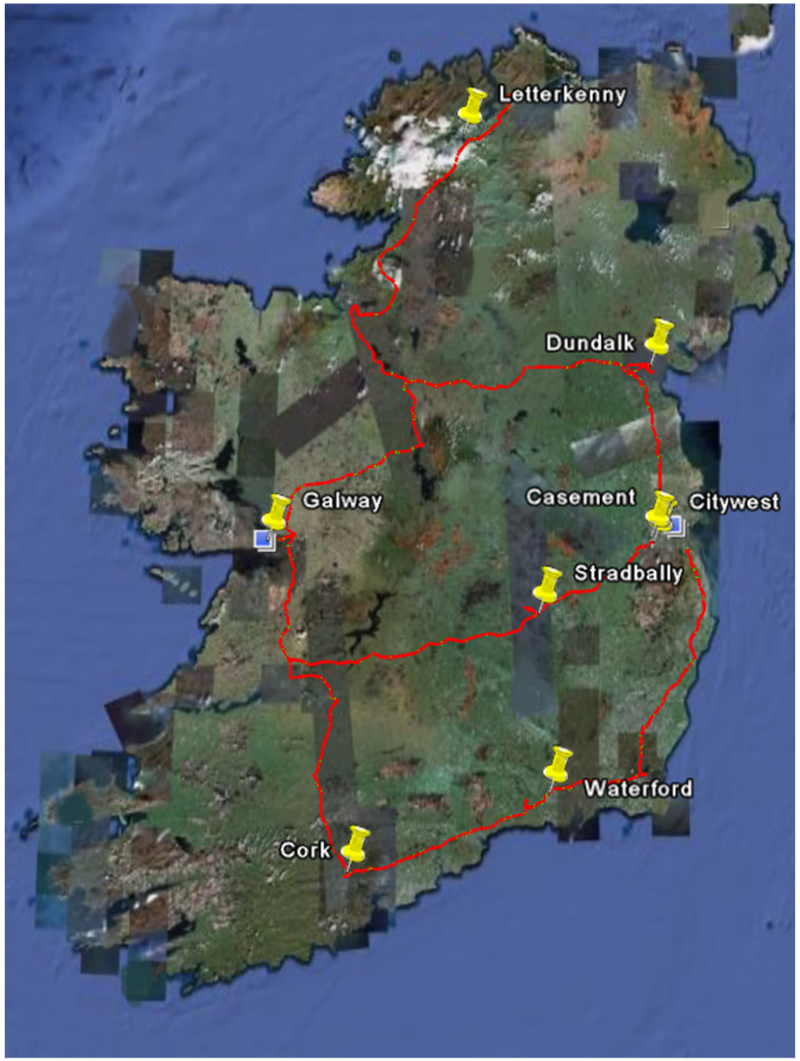
Options:

- •Compensation Techniques
  - •Optical compensation up to 8ps
  - •Electrical compensation 4ps
  - •More advanced modulation techniques up to 11ps
- •Deploy or lease new fiber
- •Deploy OEO regenerators
- •Stick with lower speed line rates and inverse multiplex
- •Replace high PMD sections of fiber with new fiber.
- •Long term replacing old fiber will have to happen

PMD and Aerial Fiber

- Aerial fibers are exposed to temperature, wind, and ice.
- Very little information available on PMD and aerial fiber.
- Most of the Aerial fiber and PMD research is based on OPGW aerial fiber and not on wrapped aerial fiber.
- For Submarine and buried fibre the SOPs vary slowly with time (hours or days). For aerial fibre the SOPs have been shown to vary with sub ms times.

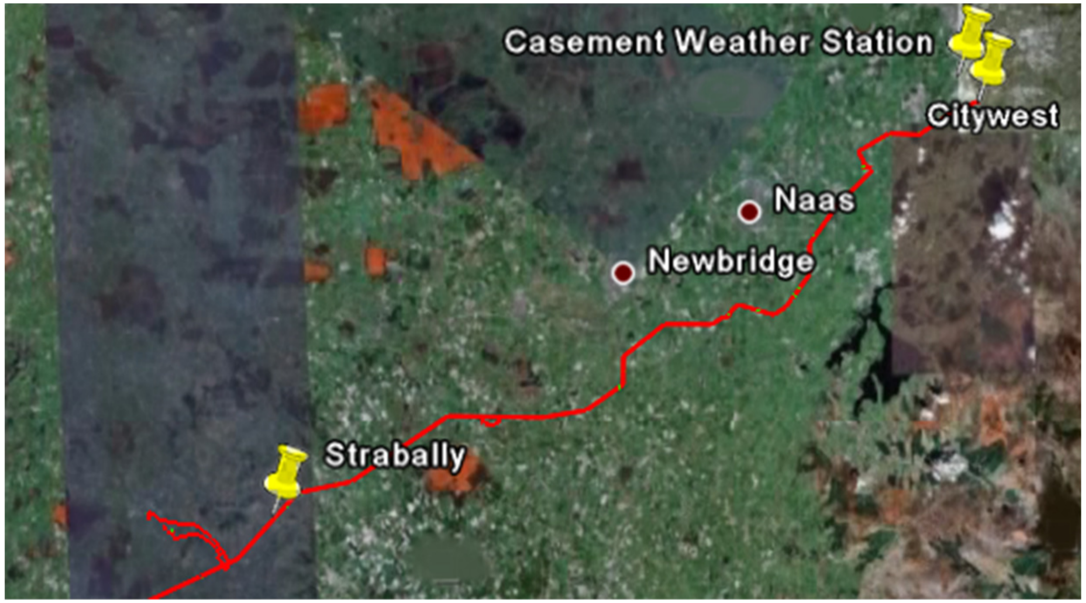
HEAnet Aerial Fiber



1300Km fiber wrapped on overhead power lines.
Combination of different Pylon infrastructure.
400Kv, 220KV and 110KV
Fiber is wrapped and not OPGW
Supplier AFL, and the fibre used was corning smf-28.

Fiber spec is G.652C – ITU spec for max PMDq for G.652C is 0.5ps/√Km
BUT our
Corning SMF-28 - max PMDq of 0.1ps/√Km

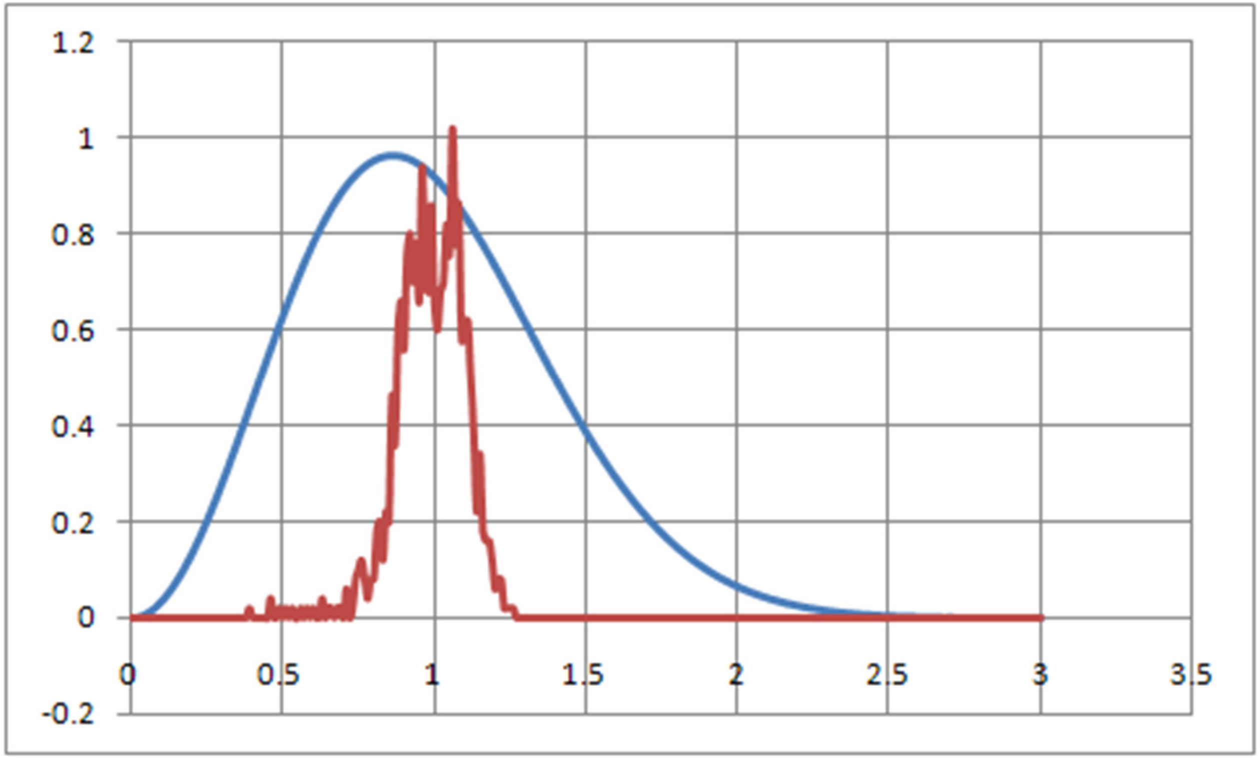
Test Section



Dublin Citywest to Stradbally
76.23Km long
Attentuation 15.6dB

Weather station – Casement Aerodrome
400Kv system Pylons

Results



1023 measurements over 3 weeks
MEAN DGD 0.974ps
PMDq = 0.111ps/√Km
Data sheet PMDq (Link design value 0.1ps/√Km

We were unable to identify diurnal(Day/night) changes in PMD, we expect this is because the PMD values were low. Other research has shown diurnal changes in PMD for aerial fiber but in fiber with higher PMD values

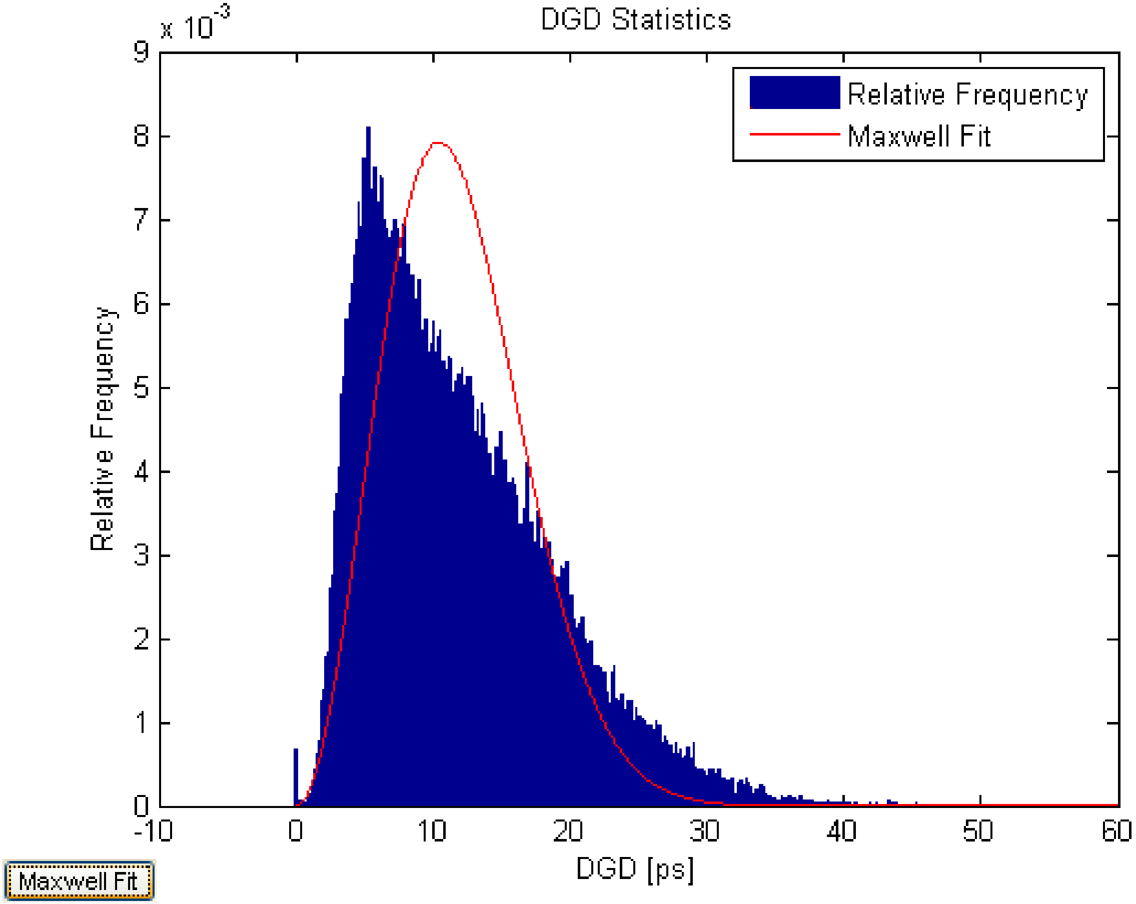
Conclusions & Future

- To measure PMD for aerial fibre you must measure for at least 24hours.
- It will also be beneficial to measure the fiber during a storm. Some tests have been based on a month in Winter and a month in Summer time(Nellen).
- Rate of change of SOP very important for aerial fiber. Could have an impact on the type of PMD compensation selected.(Waddy)
- Aerial fiber with good PMD characteristics can be consider the same as buried fiber from a PMD point of view.
- All or observations were were with wind speeds of less than 35Km/hour. Would like to test at much higher speeds ie Storms.
- Also plan to measure the rate of change of the SOPs in the future.

References

- Fast PMD and PDL measurements of Aerial Fiber David S.Waddy 2004
- Polarization effects in aerial fibers – David S.Waddy, Liang Chen, Xiaoyi Bao, 2005
- PMD Measurements on Undeployed and Deployed Aerial Optical Fibre Cables using the Interferometric Technique. Azwitamisi E. Mudau, Lorinda Wu, Timothy B. Gibbon, and Andrew W. R. Leitch 2007.
- PMD data Uk & Portugal OFC/NFOEC March 26th 2007 Richard Ednay & Modesto Morais
- Polarization Mode Dispersion of Installed fibers, Misha Brodsky 2006
- Long term monitoring of Polarization-Mode Dispersion of Aerial Optical Cables with Respect to Line Availability. Philipp M. Nellen 2004.
- ITU-T Recommendation G.650.2, Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable

August 2009 Using an Adaptif PMD tester


DGD Statistics
x 10^-3
Relative Frequency
Maxwell Fit
Relative Frequency
DGD [ps]
0
1
2
3
4
5
6
7
8
9
-10
0
10
20
30
40
50
60
Maxwell Fit

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