1.25 GBd, 550 m Links on Installed 62 MMF for IEEE 802.3: *Leveraging Existing Long Wavelength Specifications.*

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Outline

- **Need for 62 MMF support in building backbone, 550 m links**
- **Bandwidth of 62 MMF at 1300 nm**
  - *Over Filled Launch (OFL) bandwidth*
  - *Restricted Mode Fill bandwidth*
- **Modal Noise allocations**
  - *Modal Noise in MMF systems*
  - *Review of 850 nm allocation calculation*
  - *Calculation of 1300 nm allocations by same method*
- **Longer MMF links in the future (TIA FO 2-2)?**
- **Conclusions**

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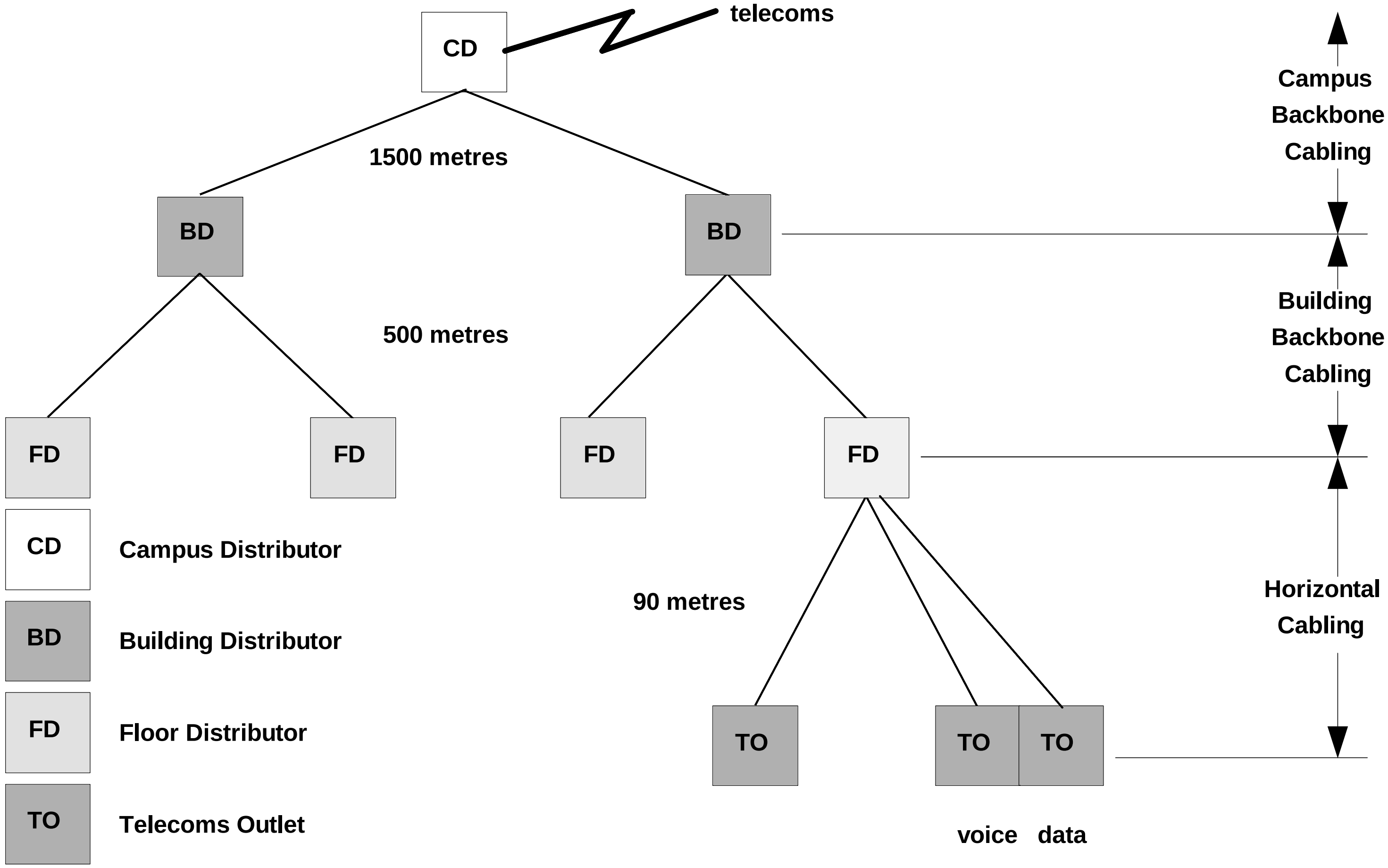
ISO 11801 Cable Model



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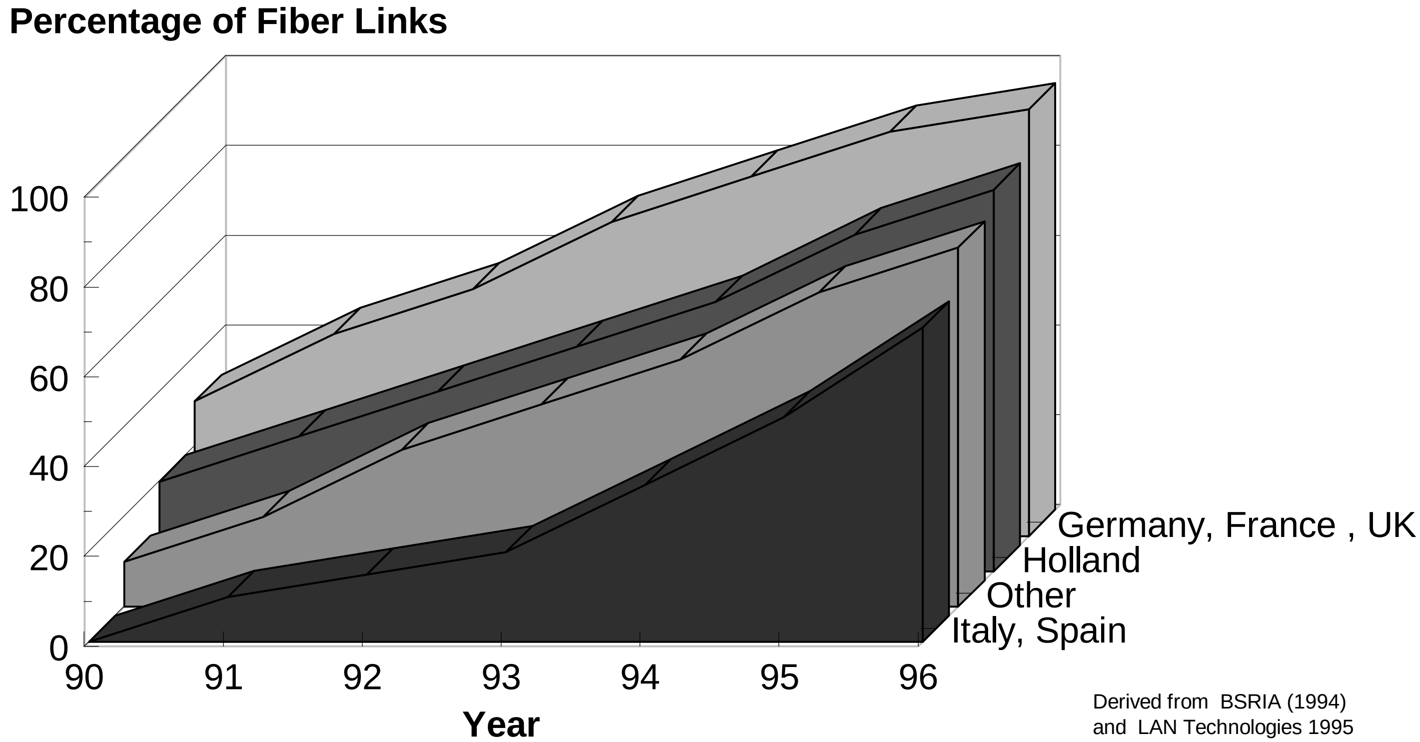
European Penetration of Fiber in the Building Backbone

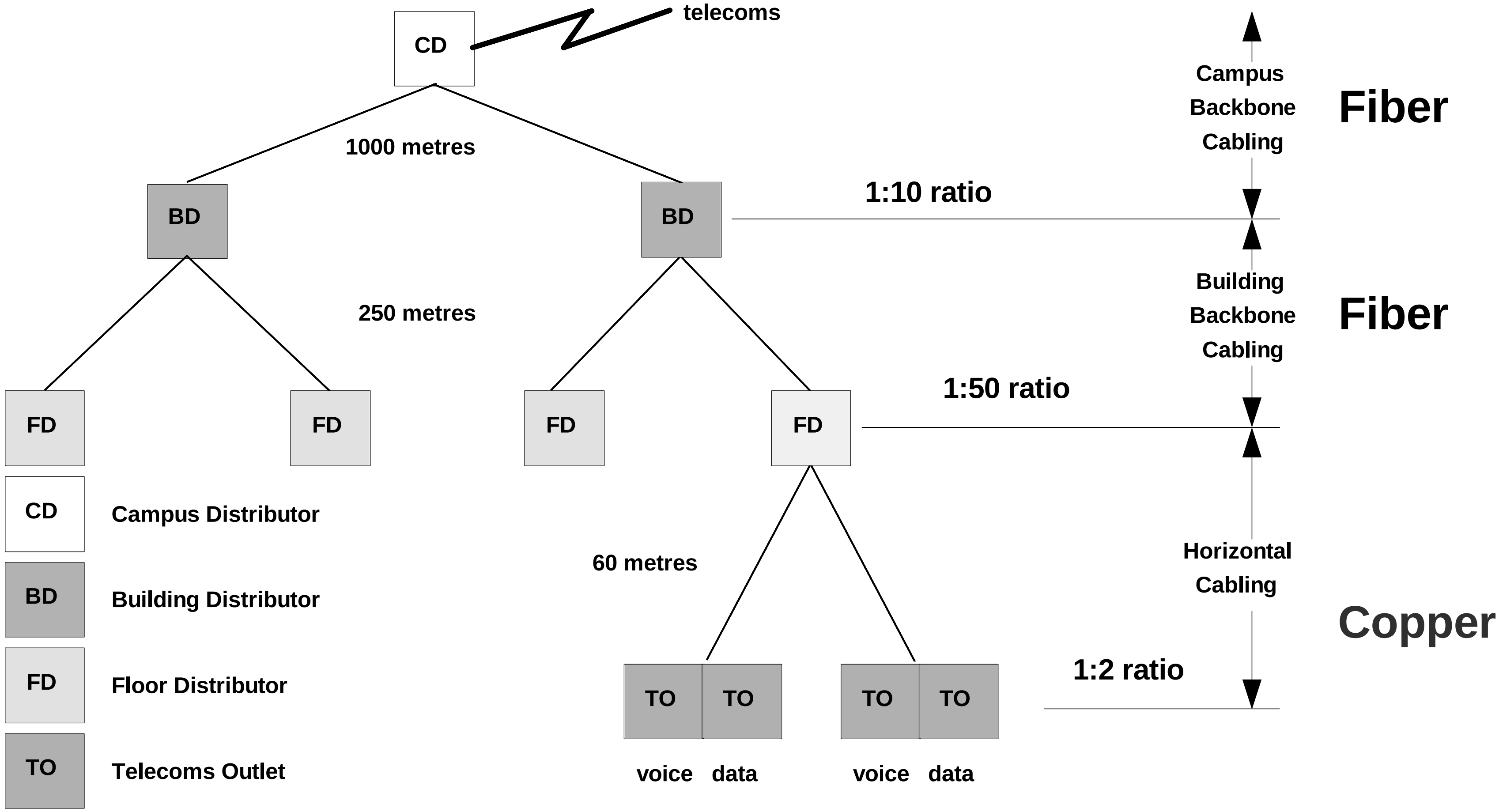


Derived from BSRIA (1994) and LAN Technologies 1995

- *Majority of cables are 62.5/125 MMF*
- *Small and decreasing historical base of 50/125 MMF*

European Cable Data

(Average Values)



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Source: LAN Technology (1995) European Mkt Research
Presented to IEEE 802. November 1995.

Optical Fiber LAN Standards

Standard	***Data Rate***	***Distance***	***Optical Fibre***	***Connector***
IEEE 802.3 FOIRL	10 Mbit/s	2 km	***62.5/125 MM***	SMA
IEEE 802.3 10Base-F	10 Mbit/s	2 km	***62.5/125 MM***	ST
IEEE 802.3 100Base-FX	100 Mbit/s	200 m	***62.5/125 MM***	**SC**
IEEE 802.5J Optical Attach	16 Mbit/s	2 km	***62.5/125 MM***	**SC**
IEEE 802.12 VGAnyLAN	100 Mbit/s	2 km	***62.5/125 MM***	**SC**
ANSI X3T12 FDDI	100 Mbit/s	2 km	***62.5/125 MM*** 8/125 SM	FD FD
ANSI X3T11 Fibre Channel*	106 Mbit/s **>106 Mbit/s**	2 km **2 km**	***62.5/125 MM, 50/125 MM*** **8/125 SM**	**SC**
ATM Forum 155Mbit/s LAN*	155 Mbit/s **622 Mbit/s**	2 km **2 km**	***62.5/125 MM*** **8/125 SM**	**SC**

** Shorter distances specified for data rates > 106 or 155 Mbit/s using 62 MMF*

Note: Data rates not baud rates are stated

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Summary Fibre Cable Data

- *ISO 11801 cable model and link lengths*
  - *90 m, Horizontal (+ 10 m for patchcords)*
  - *500 m, Building Backbone (+ 50 m for patchcords)*
  - *1.5 km, Campus Backbone (+ 50 m for patchcords)*
- *62.5 MMF dominant in building backbone*
- *Small population of SMF links*
- *300 m, extended horizontal (home run) links important for future installations*

Bandwidth of 62 MMF at 1300 nm

ISO/IEC 11801 Cable transmission performance parameters

Wavelength	*Maximum Attenuation*	*Minimum modal Bandwidth*
0.85 um	3.5 dB/km	200 MHz.km
1.3 um	1 dB/km	500 MHz.km

- *Modal Bandwidth is the critical link length limitation*
  - Worst Case 62 MMF OFL specification is 500 MHz.km at 1300 nm: ***1.25 GBd, 550m, 62 MMF links easily achieved with OFL***

- *Higher Bandwidth with Restricted Mode fill (TIA FO 2-2)?*
  - Initial data presented to FO 2-2 indicates a ***doubling of worst case Bandwidth might be possible*** in both wavelength windows

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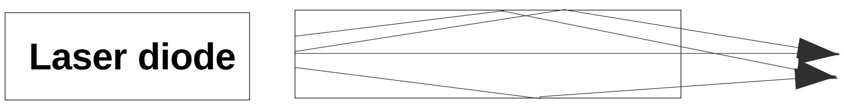
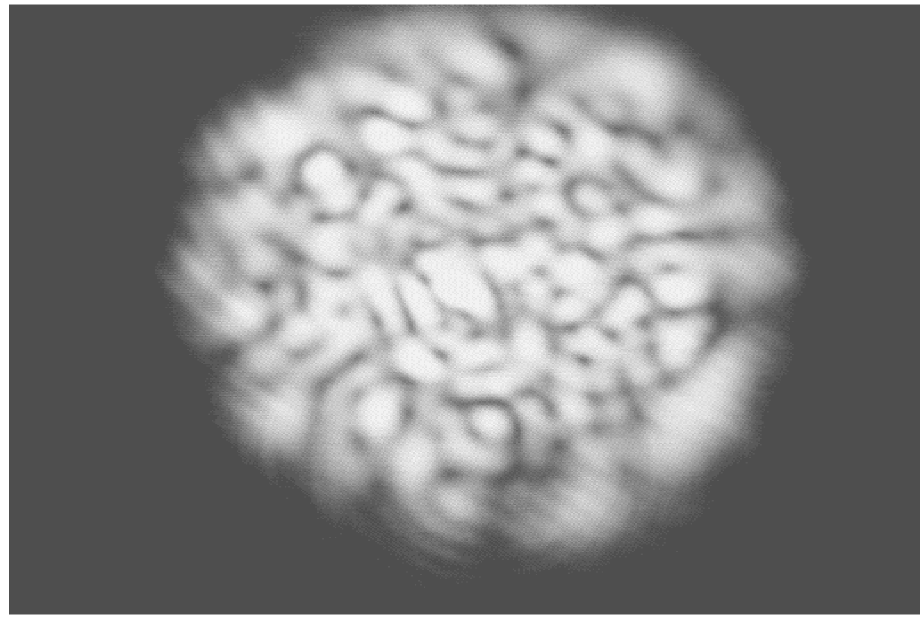
Modal Noise: Causes 1

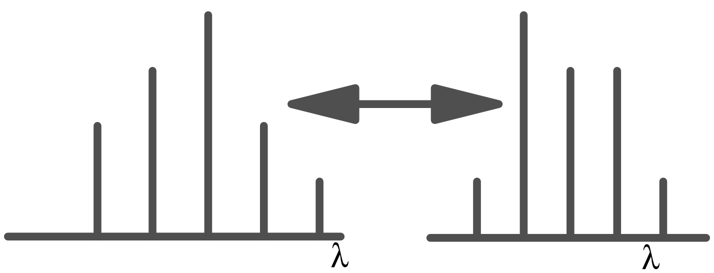
- Spatial modes ***propagating*** in a multimode fiber ***interfere*** and create ***speckle pattern***:

Multimode fibre



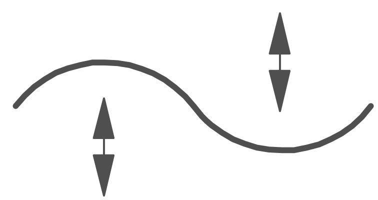


- ***Speckle pattern*** at fibre end ***changes with time***



High frequency effects (laser mode partitioning)

Low frequency effects:
vibrations
temperature changes



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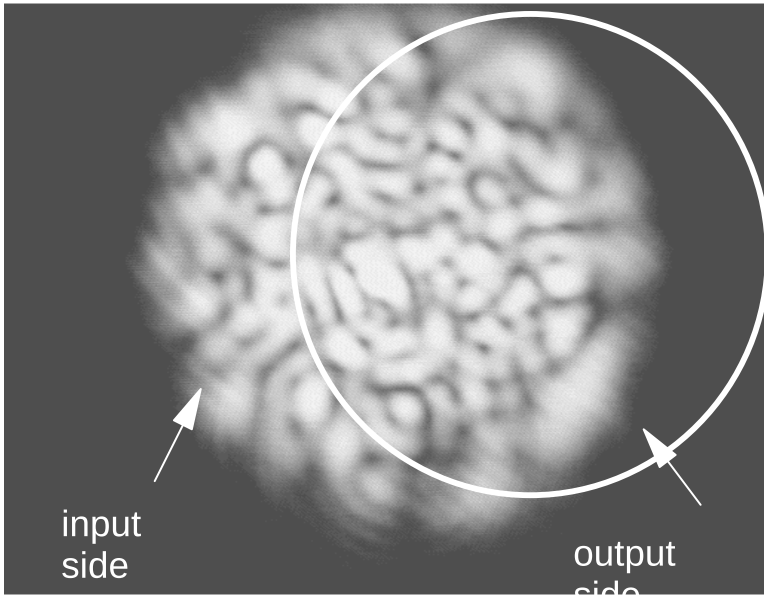
Modal Noise: Causes 2

- Imperfect connectors, splices create ***mode selective loss (MSL)***



With the changing speckle pattern, the amount of power lost in the mode selective element varies, creating ***amplitude noise*** at the receiver.

The amount of modal noise depends on:

1. *Coherence of the light source*
2. *Fiber bandwidth*
3. *Amount of the mode selective loss*

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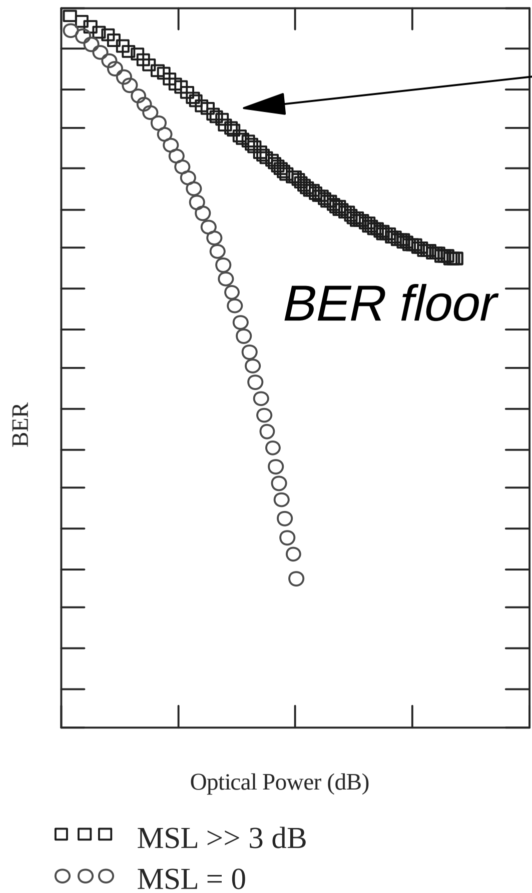
Modal Noise: *Consequences (exaggerated)*



power penalty

Approximate SNR for single point MSL:

$$\textbf{SNR} \sim \frac{1}{\sqrt{\frac{V^2 \cdot (1 - \eta)}{\eta \cdot N \cdot Neff} \cdot \left[1 + \left(1 - \frac{1}{Neff} \right) \cdot k^2 \right]}}$$

V, the laser visibility at point of MSL
n, MSL
N, number of fibre modes
Neff, effective number of laser modes
k, laser mode partitioning factor

- ***In real systems MSL is distributed:***
  - ➡ ***Must not use expression above to calculate link penalties***

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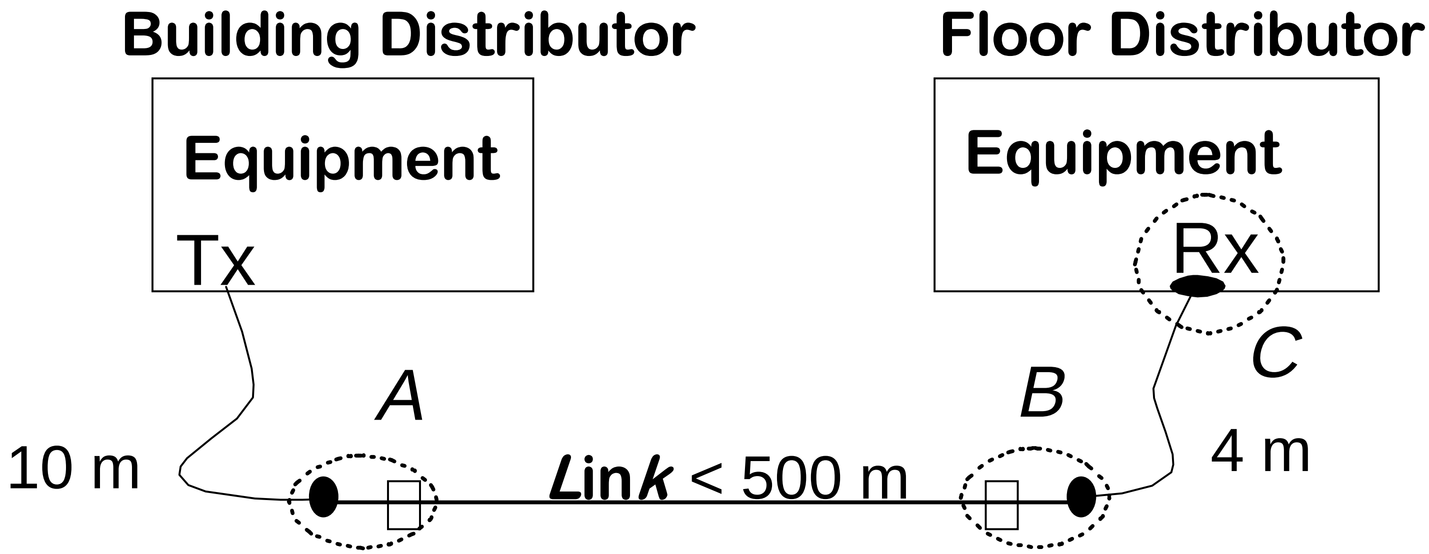
Standards With MSL Allocations

- **ATM Forum**
  - *short wavelength lasers, 1 dB max., penalty, 10^-10 BER*
- **Fibre Channel**
  - *short wavelength lasers, 1 dB max., penalty, 10^-12 BER*
- **Serial HIPPI**
  - *short and long wavelength lasers, 1 dB max., penalty, 10^-12 BER*

ISO/IEC 11801: *Worst Case MSL Model*



- ***Worst case connector loss (0.75 dB) and splice loss (0.3 dB) lumped together:***
  - *MSL of A = 1.05 dB*
  - *MSL of B = 1.05 dB*
  - *MSL of C = 0.75 dB*
  - *Short patch cords produce highest level of modal noise*
- ***MSL*** *is* ***<u>distributed</u>*** *throughout the link*

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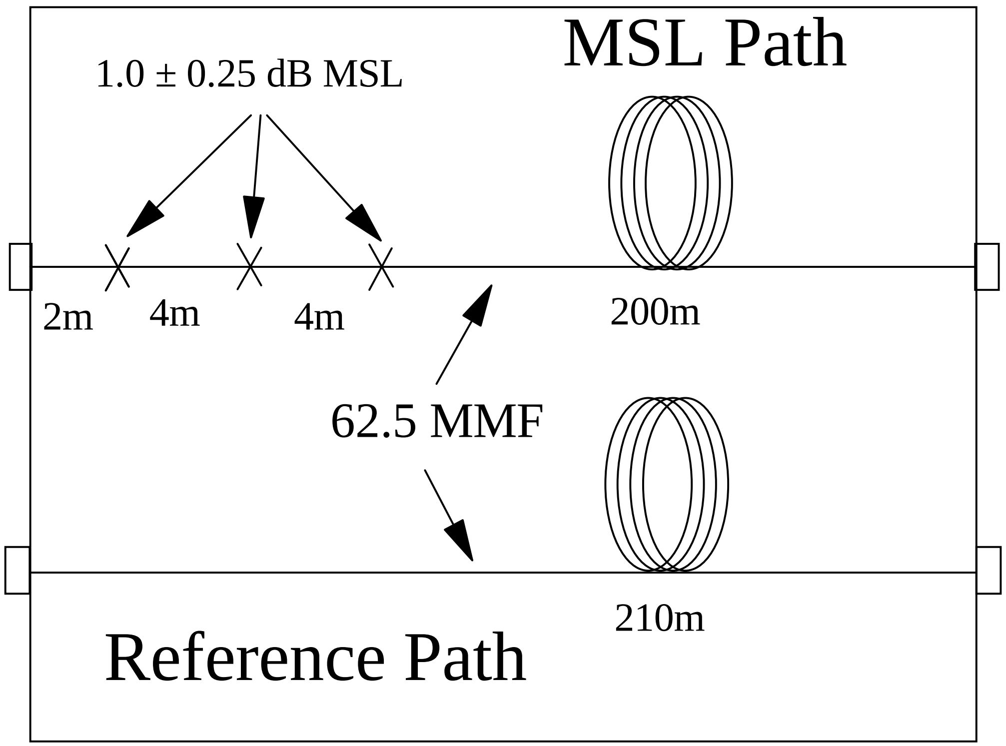
TIA FO 6.5 (MNTMG):

Modal Noise Test Procedure



MSL Test box

- **Worst case cable model agreed by simulation**
  - ➡ *MSL Test box*
  - ➡ *MSL fabrication*
  - ➡ *MSL calibration*
- **Measurement procedure maturing**
  - ➡ *Measurements agreed*
- **Round robin testing planned**

(MNTMG, Modal Noise Test Methodology Group an ad hoc Industry Group [IBM, Honeywell, Hewlett-Packard, Vixel Corp.]

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MNTMG: *Modal Noise Simulations*

- **Mathcad Implementation of model reported by Richard J. S. Bates, Daniel M. Kuchta, Kenneth P. Jackson,** *"Improved Multimode Fiber Link BER Calculations due to Modal Noise and Non Self-Pulsating Laser Diodes", Optical and Quantum Electronics, 1995.*

- **Calculates:**
  - *Laser visibility as function of fibre length*
  - *Power penalty for distributed MSL*

- **Worst Case Parameters:**
  - *k = 1*
  - *Few laser modes*

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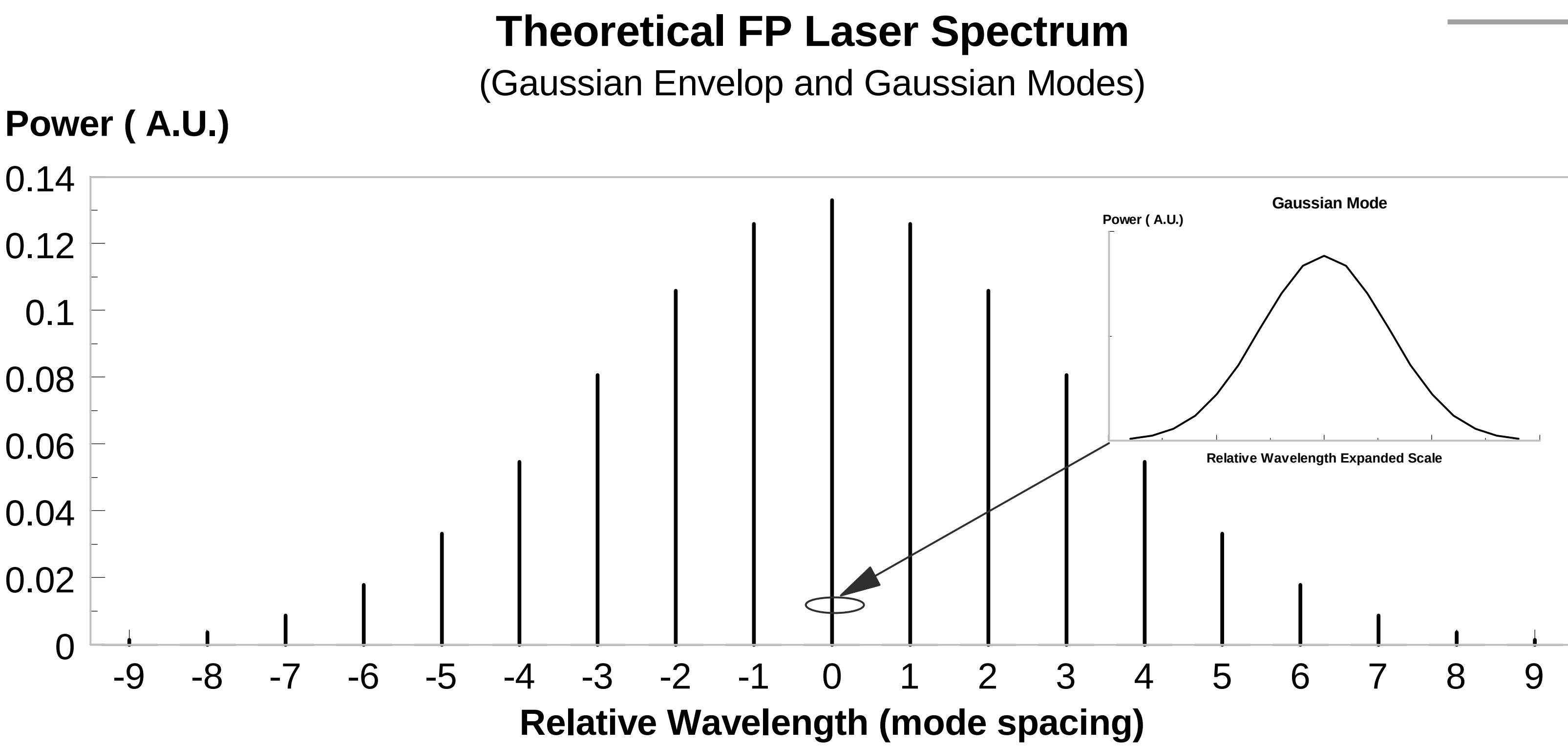
Laser Spectra: *Theoretical MSL Allocation*



- ***Parameters for modal noise model:***
  - *Centre wavelength, Mode spacing, RMS envelop width, RMS mode width,*
  - *Fibre bandwidth, Fibre core diameter, Fibre NA*

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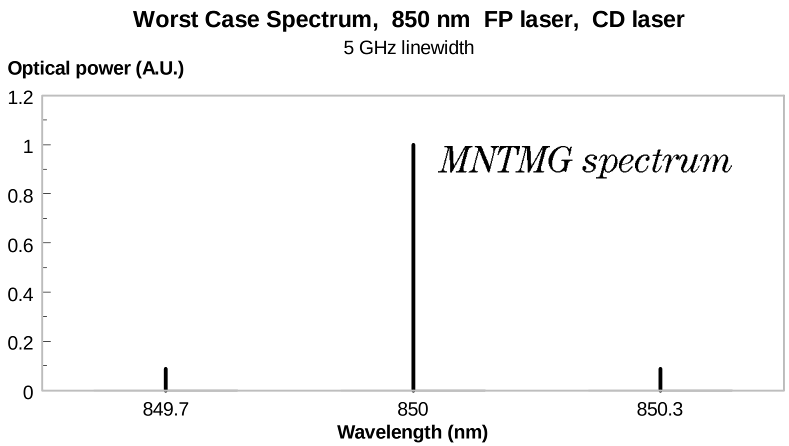
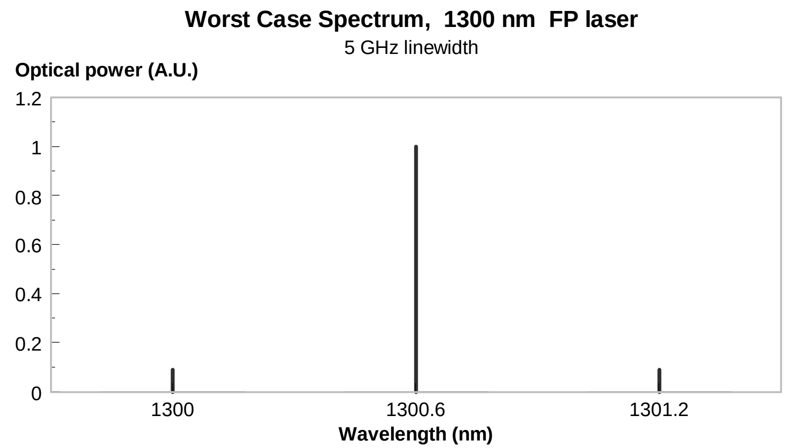
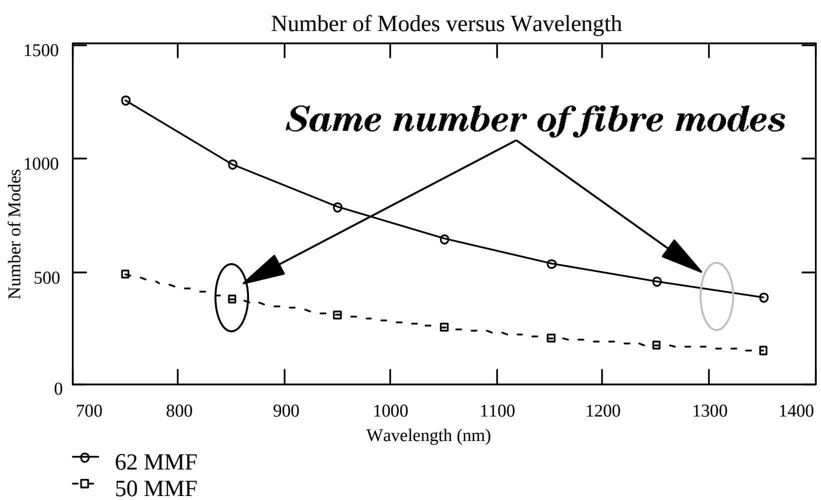
Laser Spectra: *Theoretical MSL Allocation (10^{-10} BER calculations)*







- ***Worst case lasers have similar coherence***
- ***Same number of fibre modes at :***
  850 nm in 50 MMF
  1300 nm in 62 MMF
- ***Expect similar power penalties for:***
  Short wavelength 50 MMF
  Long wavelength 62 MMF

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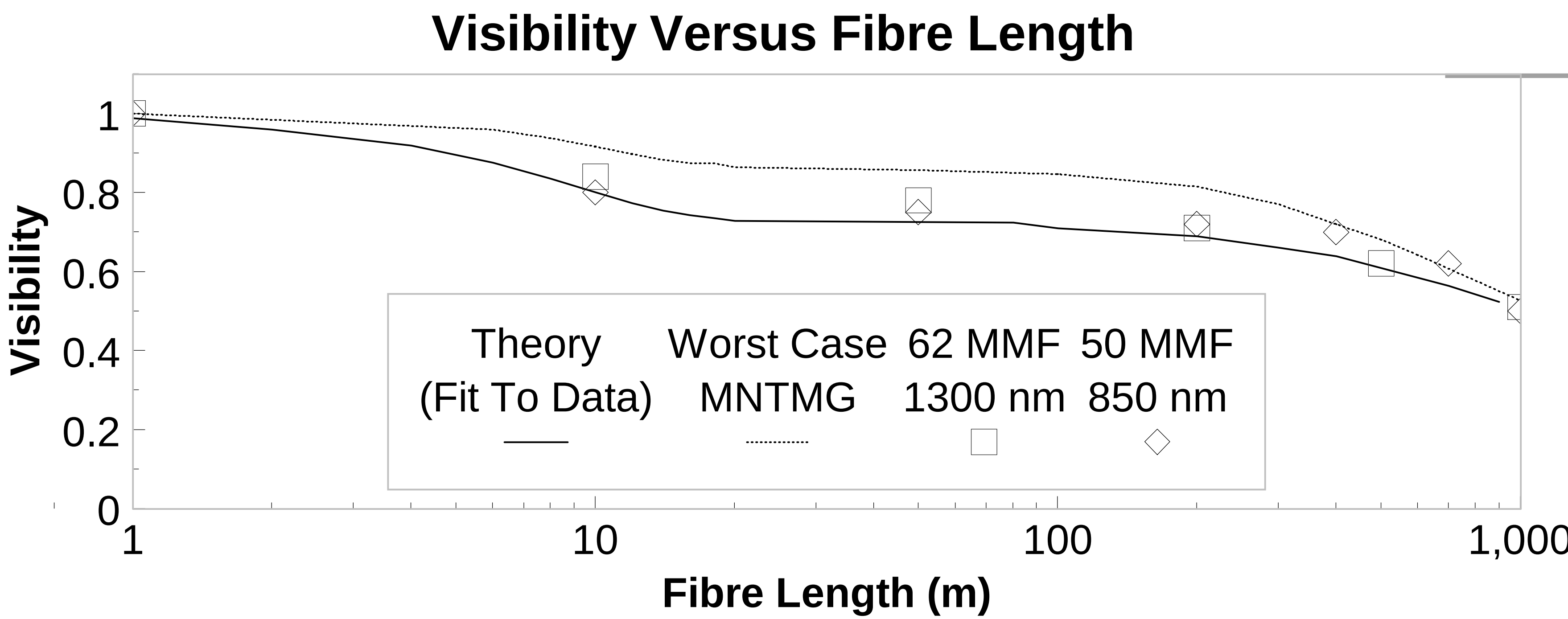
FP Lasers



- **Lasers chosen to have similar number of spectral lines**

  - Same visibility for SW and LW lasers as expected from theory
  - Both 50 MMF and 62 MMF had bandwidth of 1 GHz.km
  - Measured Laser linewidths ~ 1 to 2 GHz

- **Modal noise penalty measured to be << 1 dB for both lasers**

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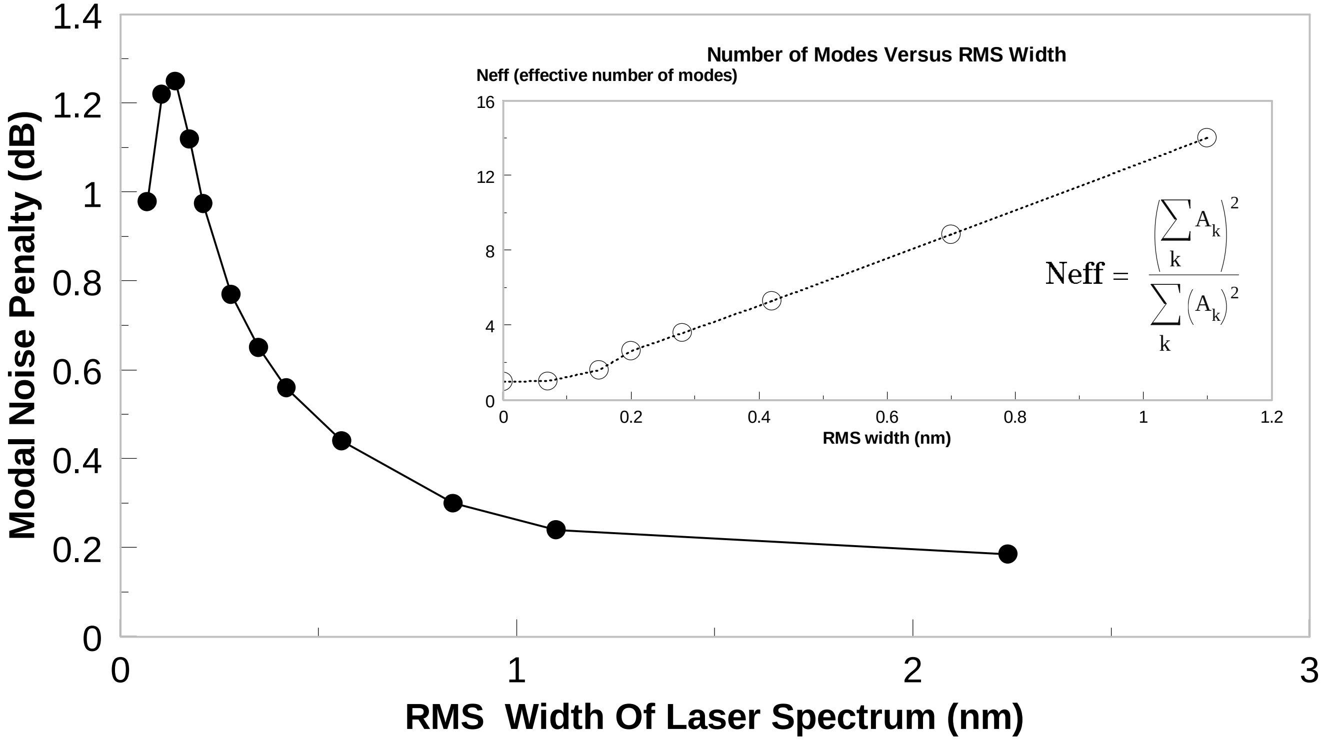
Short Wavelength Lasers: *MSL Allocation*

Modal Noise Penalty Versus RMS Width

(Theory, MNTMG Worst Case Model, 850 nm FP Laser, k=1, 50 MMF, 10^-10 BER)



(MNTMG, Modal Noise Test Methodology Group.
0.28 nm mode spacing assumed)

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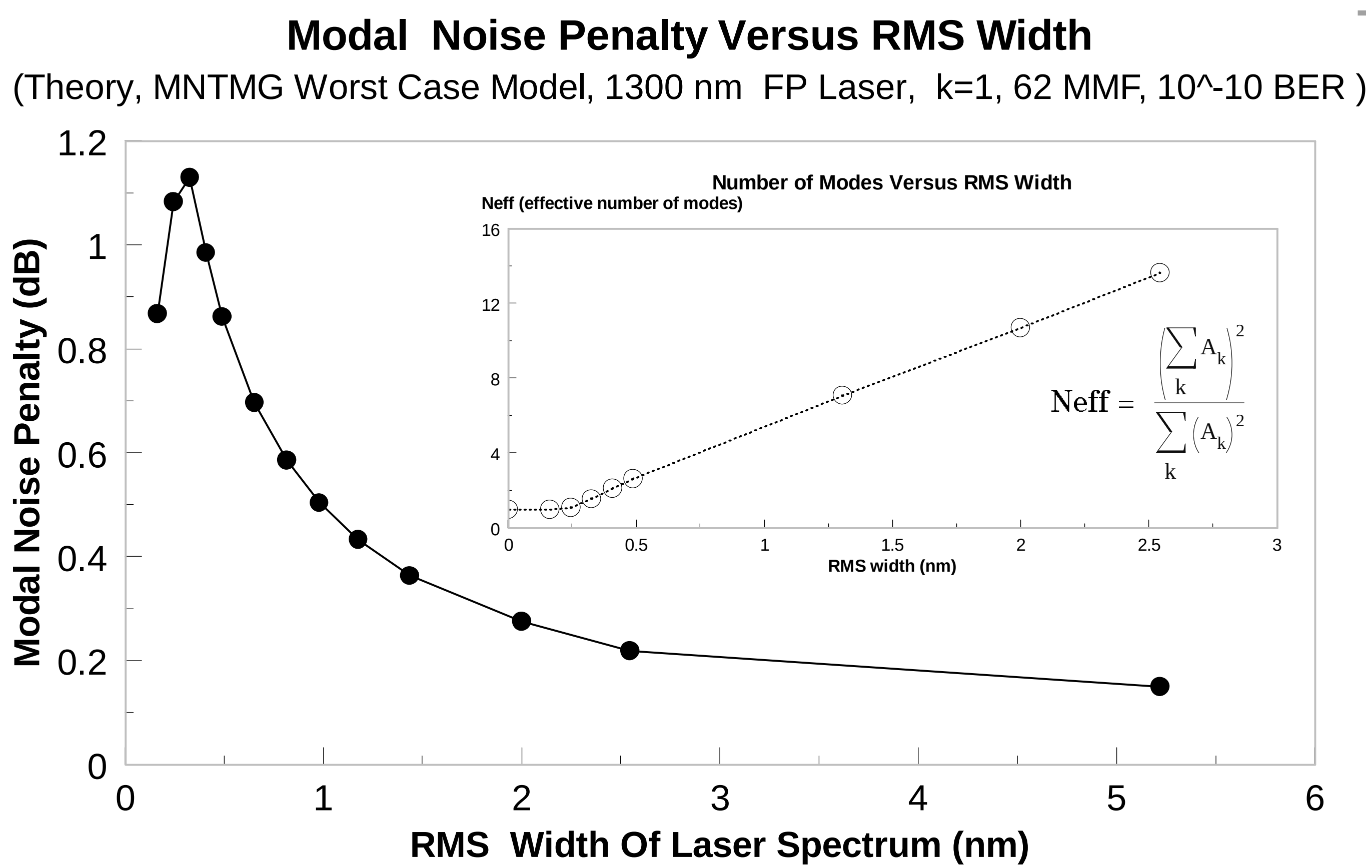
Long Wavelength Lasers: *MSL Allocation*



(MNTMG, Modal Noise Test Methodology Group. 0.65 nm mode spacing assumed.)

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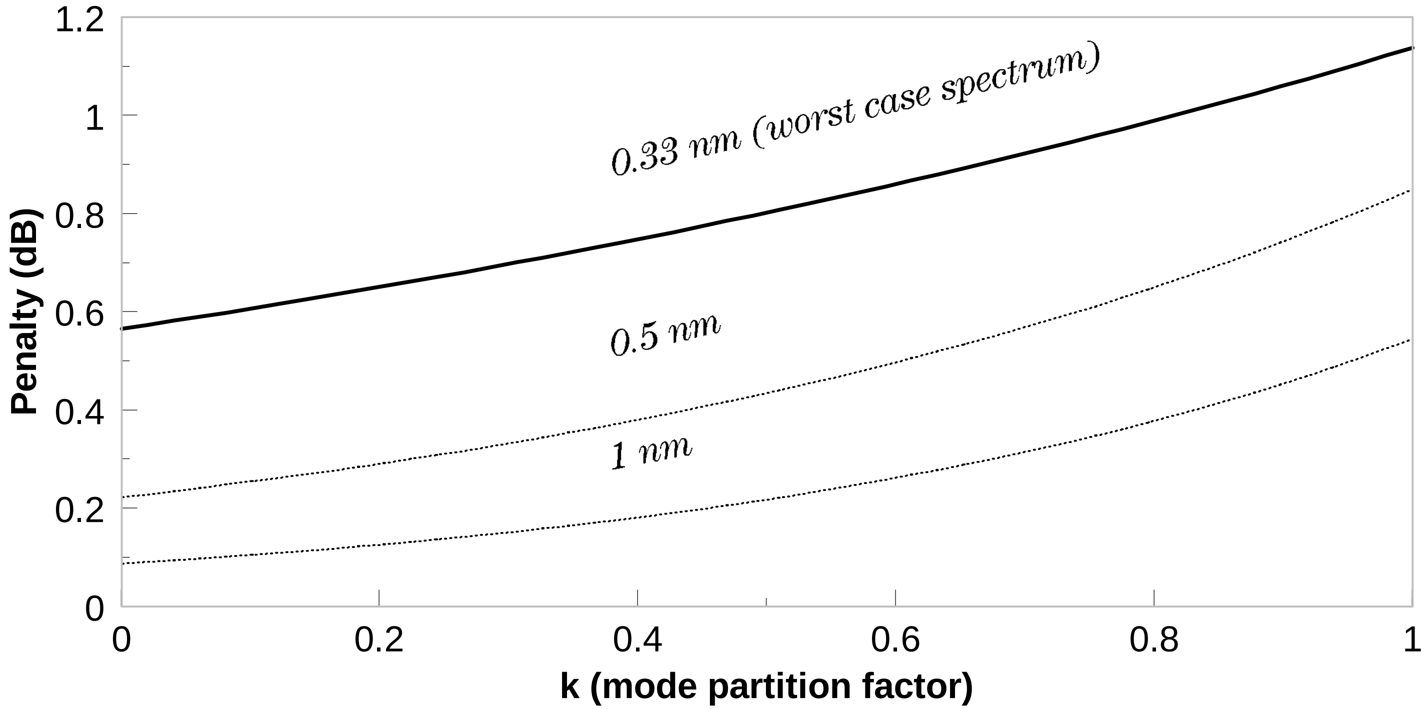
Long Wavelength Lasers: *MSL Allocation*

Theoretical MSL Penalty versus k and RMS Spectral Width

(1300 nm laser, MNTMG worst case model, 62 MMF, 10^-10 BER)



(MNTMG, Modal Noise Test Methodology Group.
0.65 nm mode spacing assumed)

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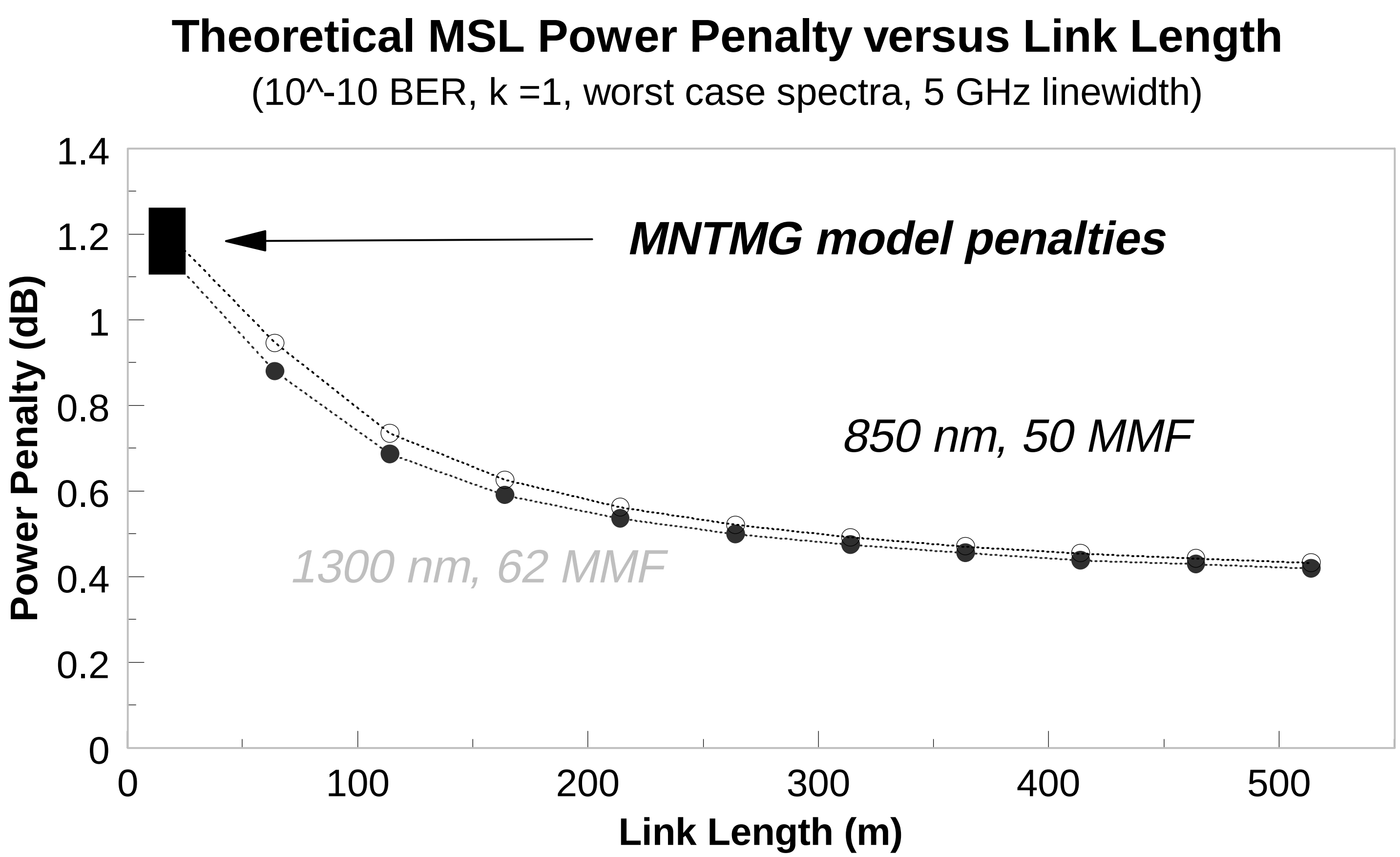
ISO/IEC 11801: *Worst Case MSL Model, Power Penalties*



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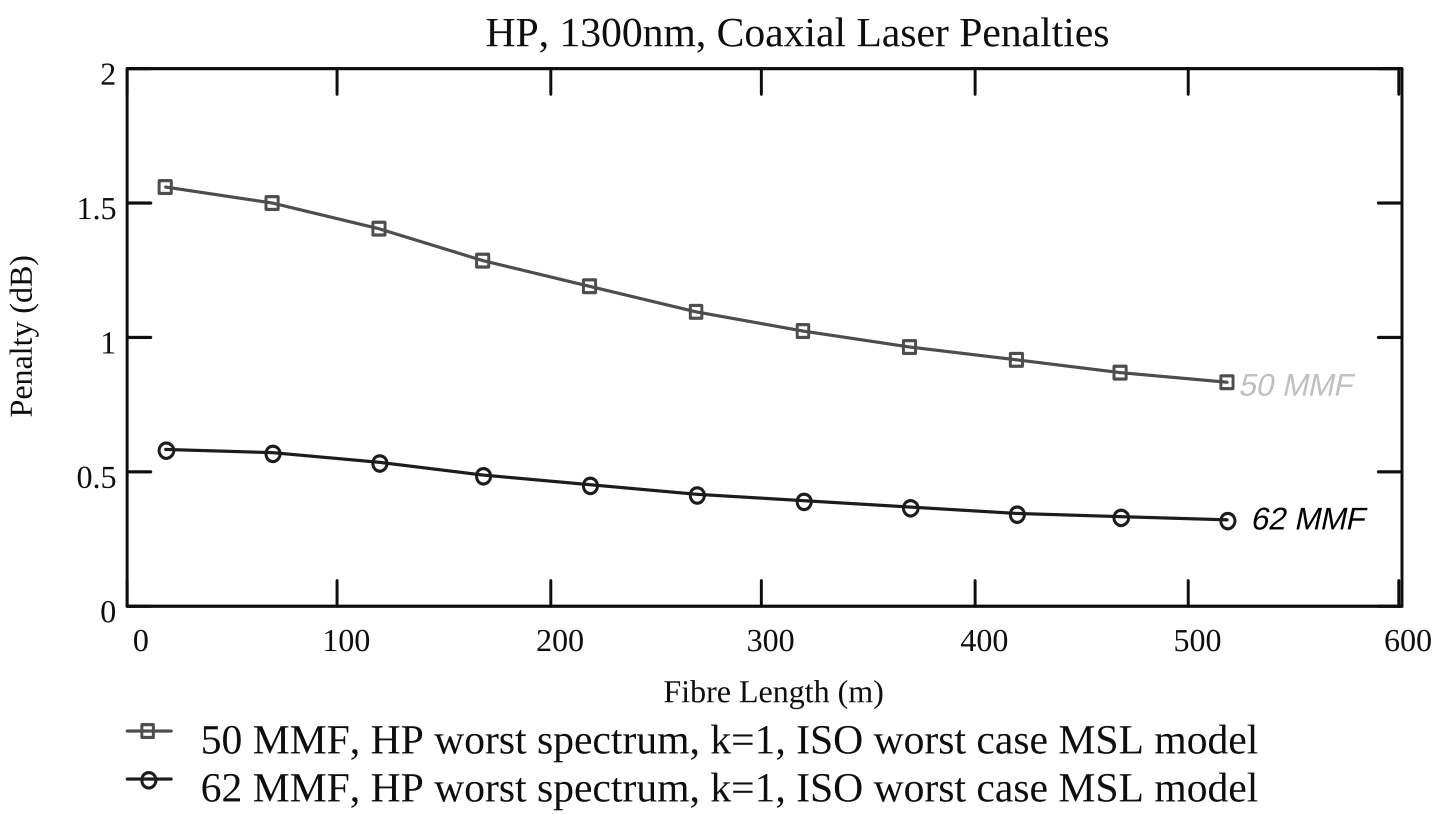
ISO/IEC 11801: *Worst Case MSL Model, Worst Case HP Laser Spectra*



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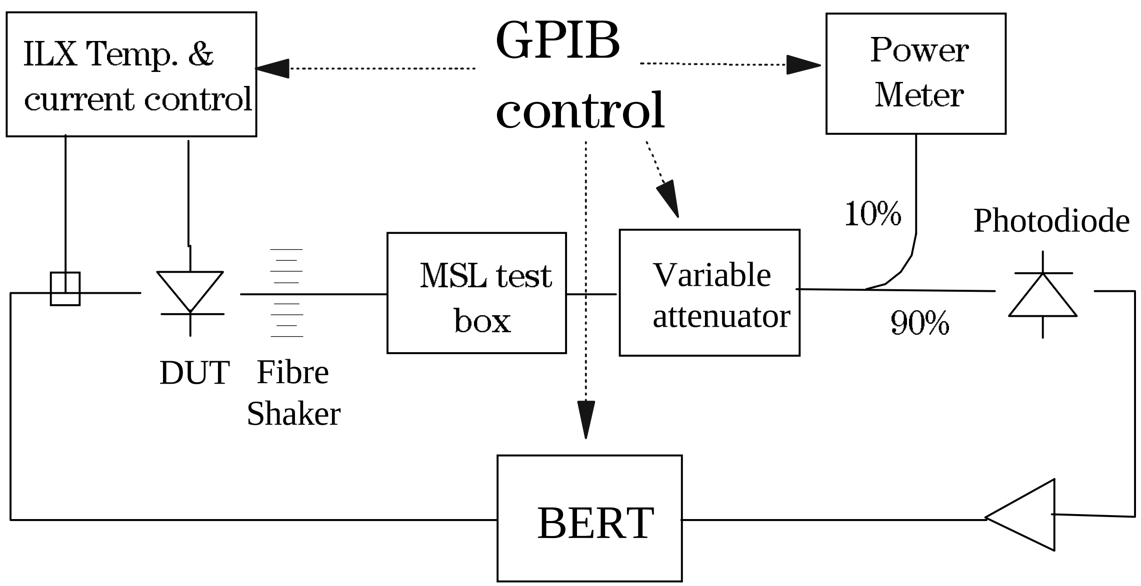
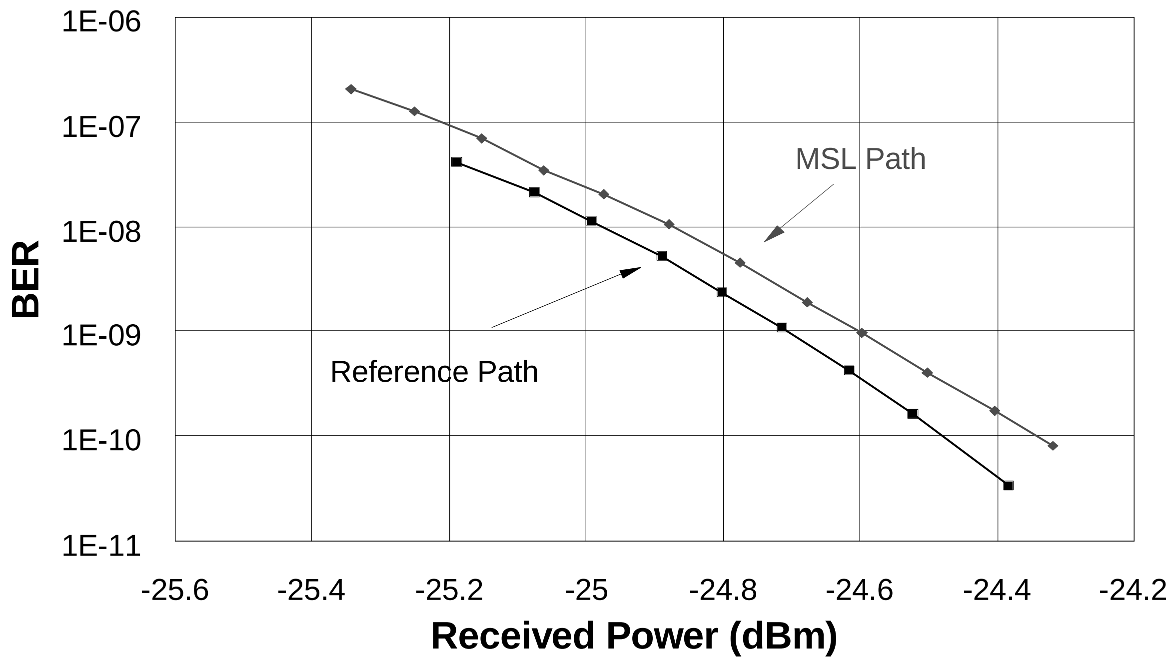
Modal Noise Test Setup



- Shake fibre
- Ramp laser temperature

Computer controlled modal noise power penalty measurement setup.

Measured Modal Noise Penalties: *62 MMF, 1300nm*



- *HP has concentrated experimental testing on lasers in worst case tail (for modal noise) of manufactured distribution of its 1300 nm, coaxial lasers*

- *Penalties << 1 dB for these lasers on 62 MMF*
  - *Model is worst case*
  - *k << 1*

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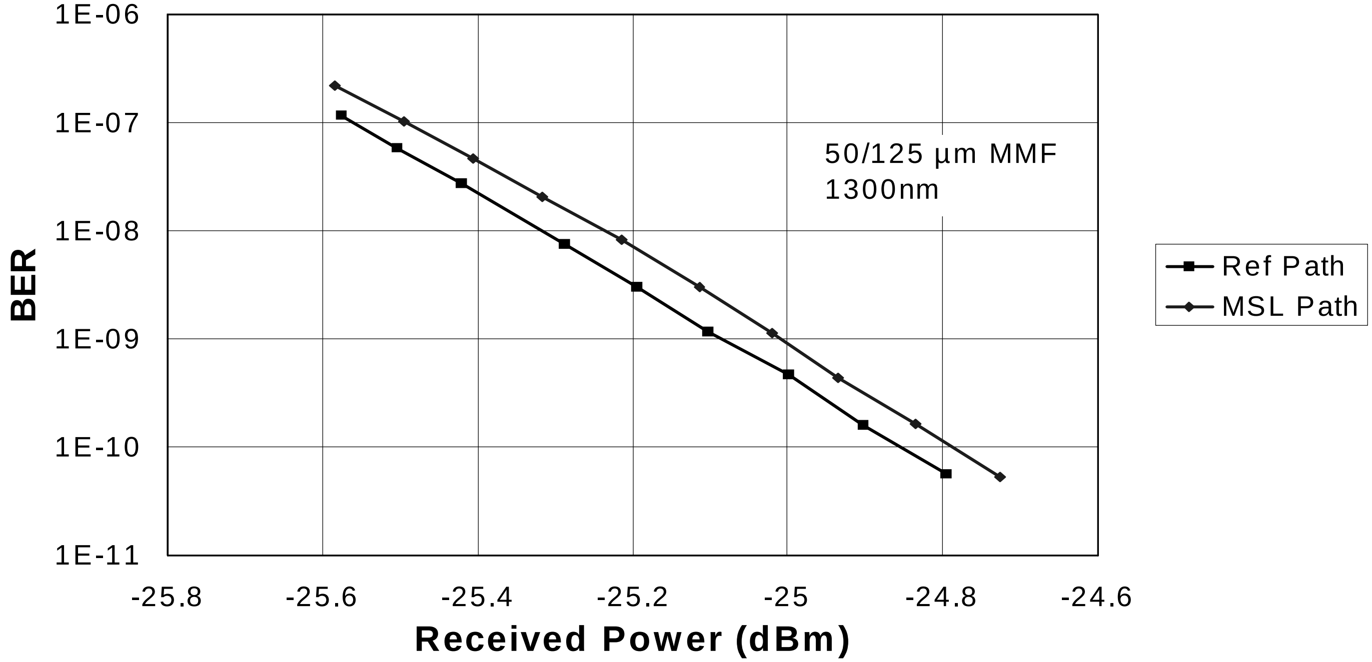
Measured Modal Noise Penalties: *50 MMF, 1300nm*



- *Penalties < 1 dB for worst case HP, 1300 nm, coaxial lasers <u>even</u> on 50 MMF*
  - ➡ *Model is worst case*
  - ➡ *k << 1*

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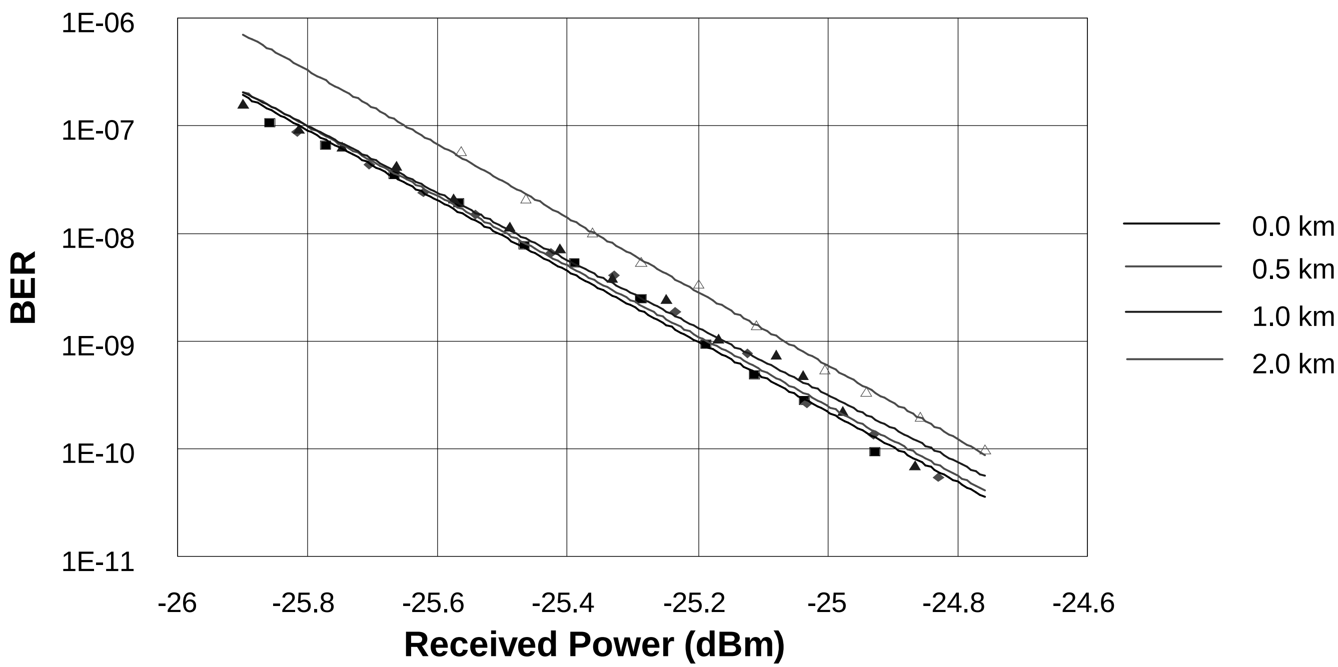
Extending 62 MMF Links: *Initial Results*

Power penalties as function of length



- *OFL fibre bandwidth 638 MHz.km*
- *1300 nm Laser, Restricted mode fill launch*
- *1250 Mb/s 2^7-1 PRBS*

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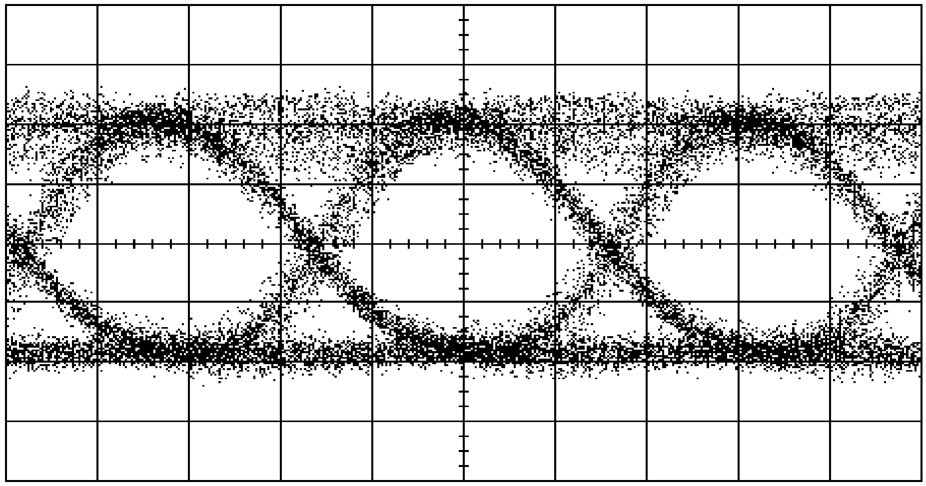
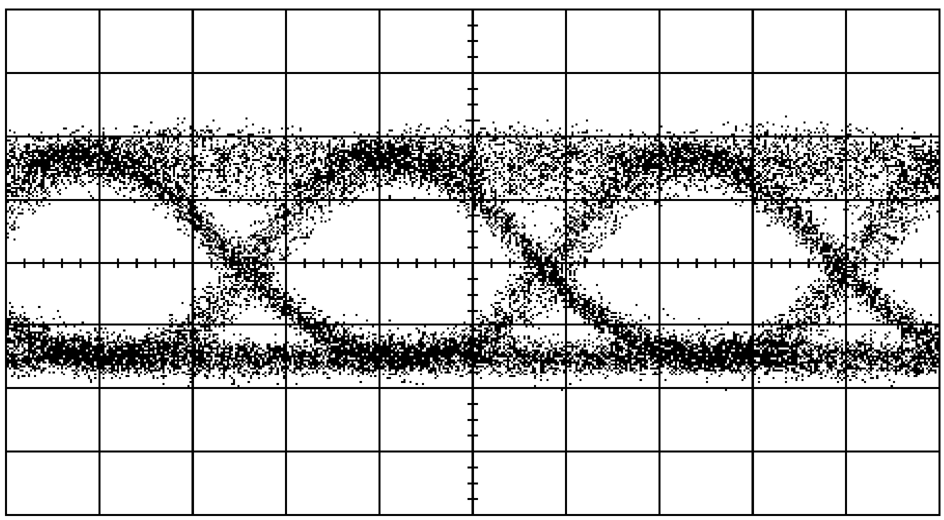
Extending 62 MMF Links: *Initial Results*

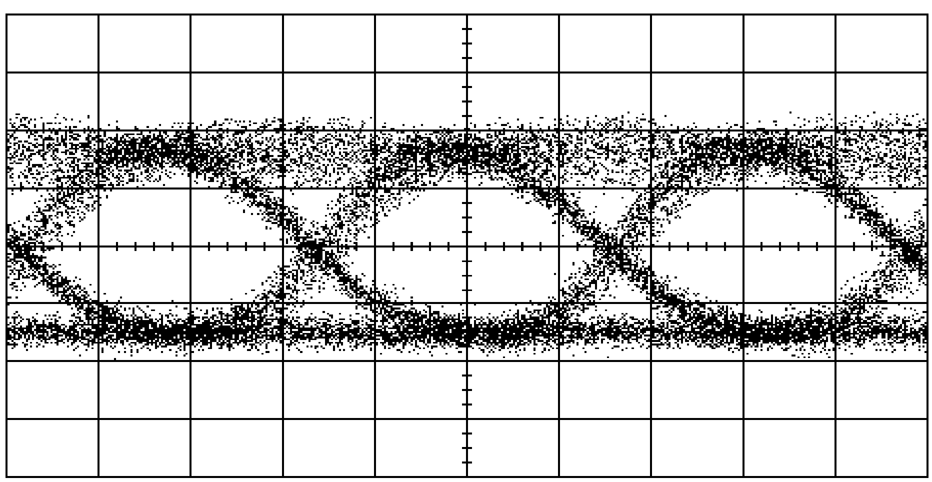
0 km



1 km



2 km



Summary

- **Shown need for 62 MMF support in building backbone, 550 m links**

- **Modal Noise allocations**
  - *Worst case lasers and connectors in theory and experiment*
  - *Equal number of modes at 850 nm in 50 MMF as at 1300 nm in 62 MMF*
    - ***Same MSL allocation, 1 dB maximum for 62 MMF***
  - *1300 nm lasers with RMS width > 0.7 nm can support 50 MMF*
    - ***MSL allocation 1.5 dB, maximum for 50 MMF***
  - *Measured penalties much less than MSL allocations for both fibre types*
    - ***Test methods TIA FO 6.5 initial draft***

- **2 km, 1300 nm, 62 MMF with restricted launch ?**
  - *Very promising results*
  - *Restricted launch can greatly increase MMF bandwidth*
    - ***Test methods TIA FO 2-2, significant work needed***

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