Long Wavelength Laser MMF Links: 50MMF results

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Outline

- *Methodology*
- *Experimental Setup*
- *Results*
- *Theory*
- *Conclusions*

Methodology

Goals: *1) Prove Long wavelength laser & MMF form a robust Gb/s Ethernet link*

2) Theoretically investigate specification issues

by

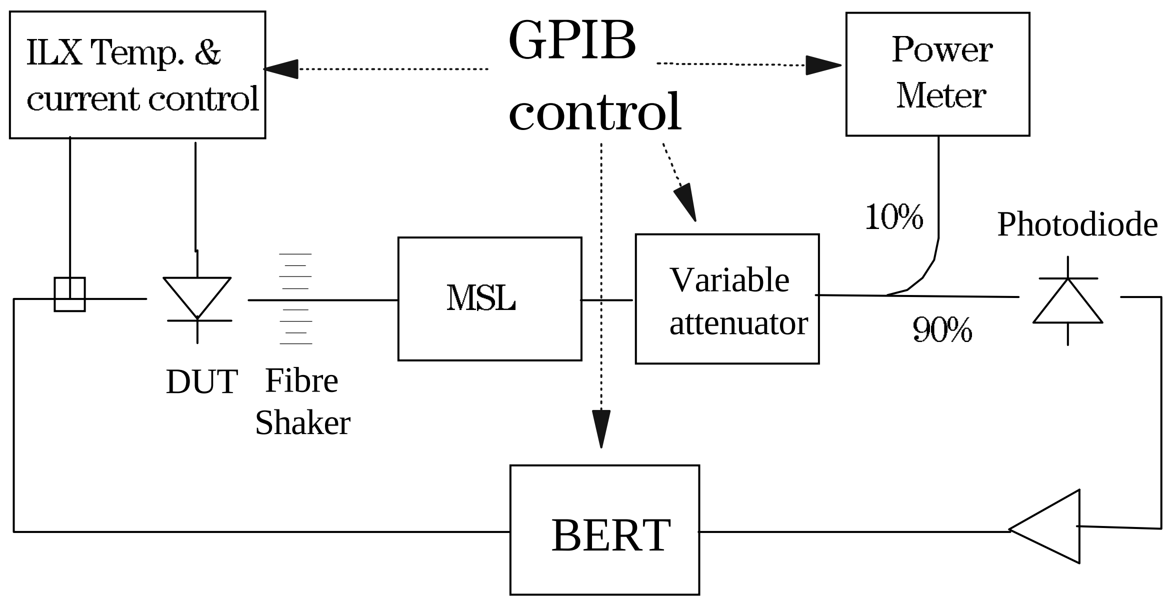
Worst case experimental testing:

- *50MMF*
- *Worst case lasers ~ 0.7 nm rms spectral width*
- *Many laser-MMF launch methods*
- *TIA FO 6.5 Draft Procedure*

Simulation:

- *MSL penalties & confirmation of experimental results*

Modal Noise BER Power Penalty Measurement Setup



- Shake fibre
- Ramp laser temperature
- Computer controlled

- Three 1 dB Points of MSL

or

- Single 3 dB lumped axial offset loss

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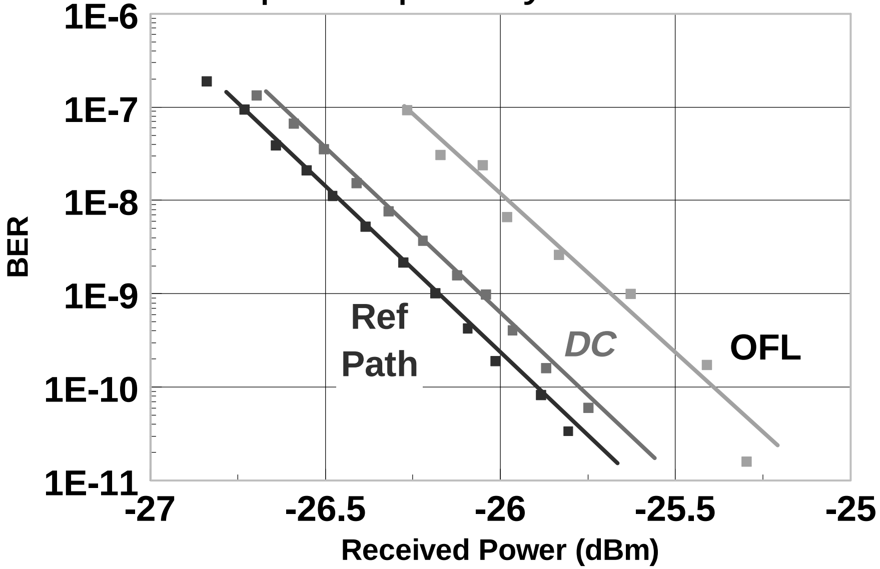
Results: *Measured modal noise penalties, 1300nm, 50MMF*

Typical modal noise power penalty curves



- ***Near worst case lasers***

  ~ 0.7 nm RMS spectral width

- ***Three points of MSL (1 dB each)***

  - axial and longitudinal offset connectors

  - 1st MSL point 12 m from laser launch

Laser Launch	Penalties @ 10^-10 BER minimum	average	maximum
OFL	0.4 dB	0.5 dB	***0.6 dB***
Connected Directly to Transceiver	0.2 dB	0.15 dB	***0.25 dB***

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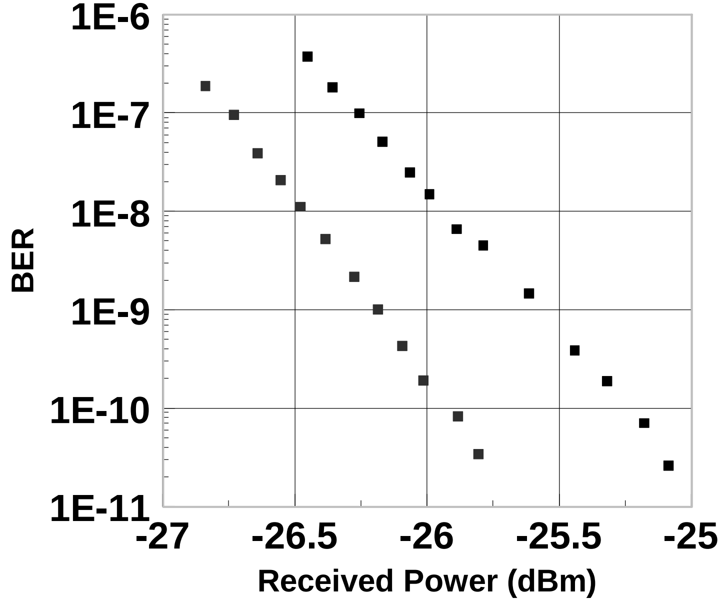
Results: *Measured modal noise penalties, 1300nm, 50MMF, 3 dB lumped MSL*

Example modal noise power penalty curve



- ***Near worst case lasers***

  ~ 0.7 nm RMS spectral width

- ***Single 3 dB point of MSL***

  - axial offset connector

  - 12 m from laser launch

Laser Launch	Penalties @ 10^-10 BER		
	minimum	average	**maximum**
Connected Directly to Transceiver	0.4 dB	0.8 dB	***1.2 dB***

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Results: *Measured modal noise penalties, 1300nm, 50MMF versus launch category*

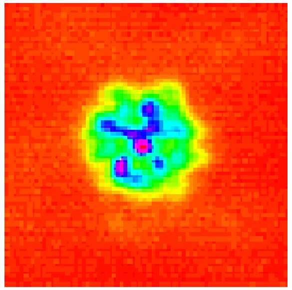
Launch Category	**Modal Noise Penalty (dB)**
1 *(overfilled)*	***0.42***
2	***0.37***
3	***0.37***
4	***0.2***
5 (very underfilled)	***0.15***

Three points of MSL (1 dB each)

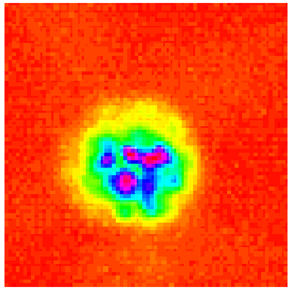
- axial and longitudinal offset connectors

- 12 m from laser launch

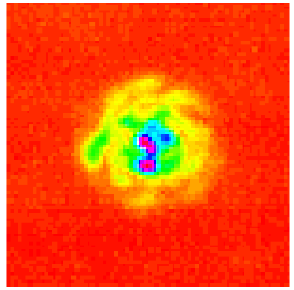
Pictures of the Categories of launch*



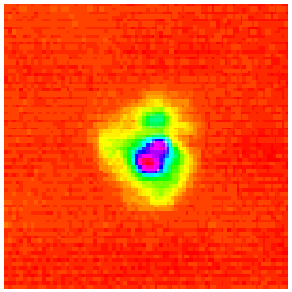
Category 1
Overfilled



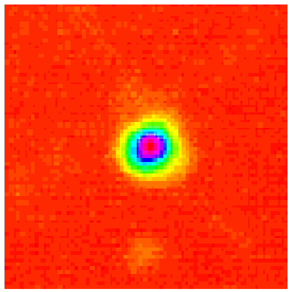
Category 2



Category 3



Category 4



Category 5
Very Underfilled

1300nm
50MMF

*The categories of launch are defined by EIA/TIA OFSTP-14A

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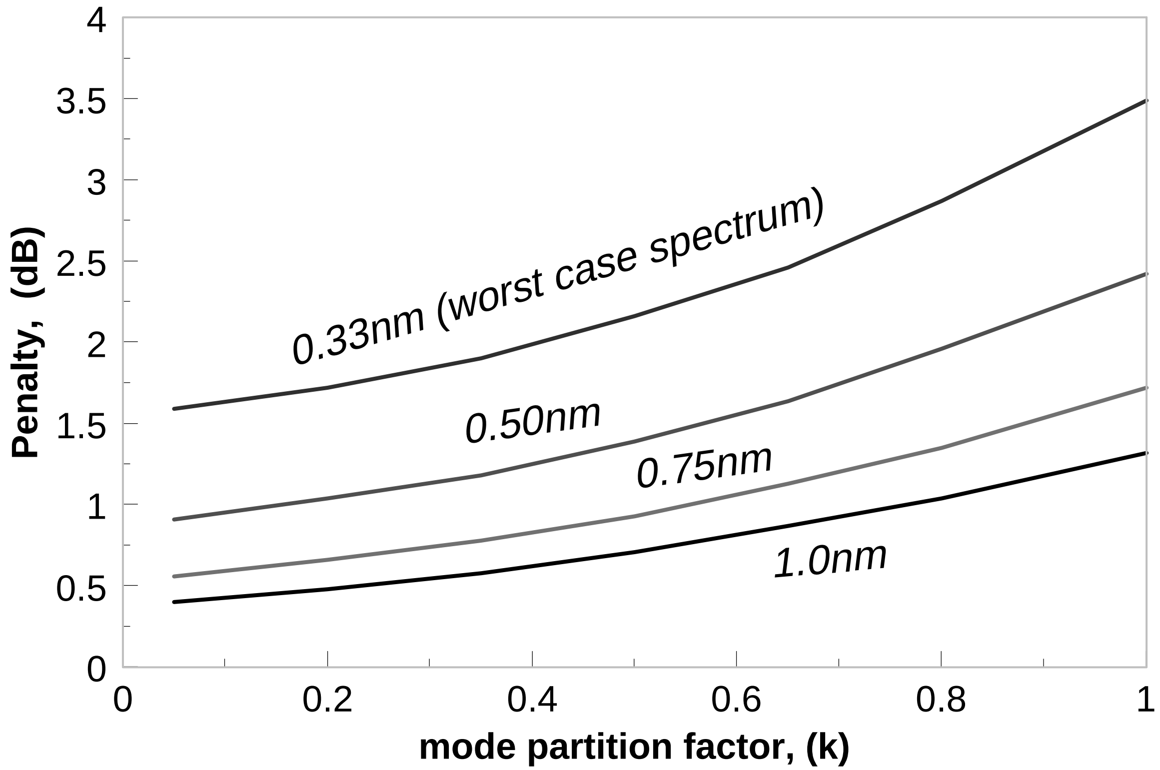
Theory: *Modal Noise Penalty, OFL, 1300nm, 50MMF*



Calculated assuming:

- three 1dB points of MSL separated by 4m, 1st point located 12m from laser
- 0.65nm mode spacing
- Theoretical MSL Penalty versus k and RMS spectral width
- 10^-12 BER

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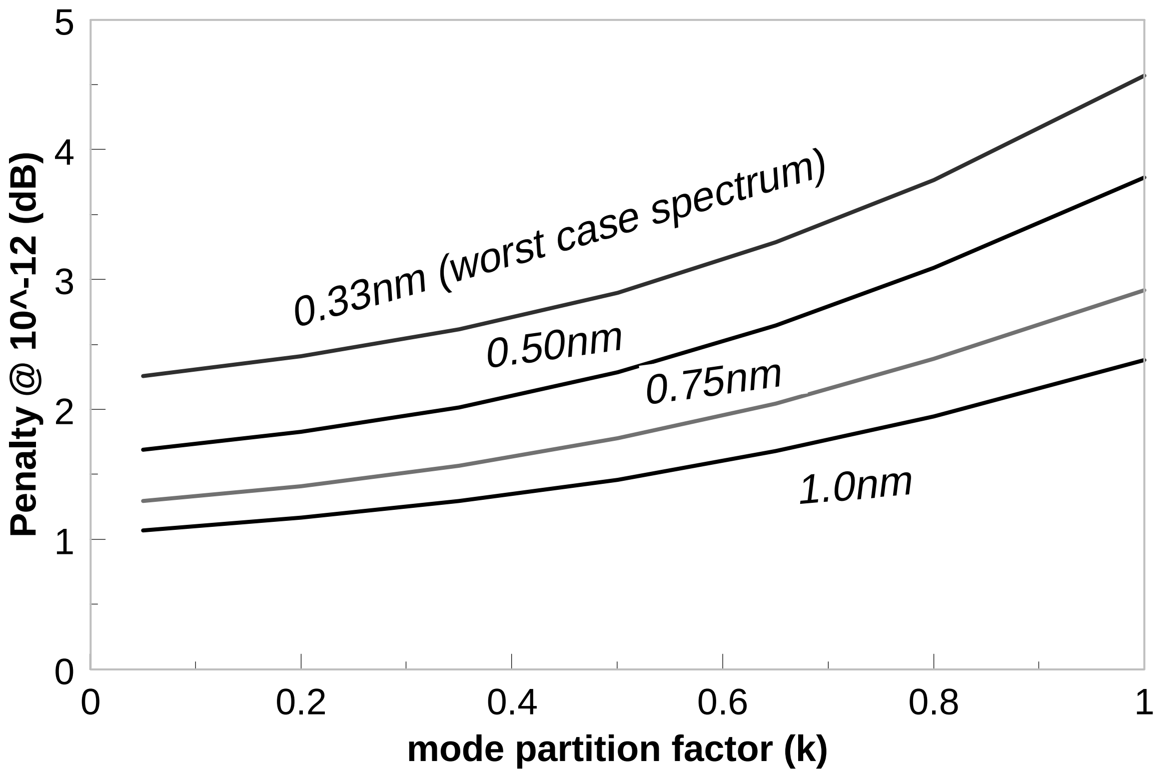
Theory: *Modal Noise Penalty, OFL, 1300nm, 50MMF*



Calculated assuming:

- three 1dB points of MSL separated by 4m, ***located to maximise the penalty***
- 0.65nm mode spacing
- Theoretical MSL Penalty versus k and RMS spectral width
- 10^-12 BER

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Mode Coupling Theory Of Modal Noise

Modal noise penalty measurements indicate :

- Smallest penalties with direct launch from laser transceivers (SW or LW)
- Smaller loss at MSL connectors than OFL measurement would imply
- OFL not achieved with laser transceivers
  - ➡ *especially true for 62MMF*

Mode Coupling Theory Of Modal Noise

- Modes of infinite square-law medium approximate modes of near parabolic MMF
- Let [C] be mode coupling matrix of the connector joining two fibers
- Then the transmission matrix [F] for the joint is defined by:

$$[F] = [C][C]^T$$

- Elements of [F] can be used to calculate coupling and modal noise characteristics of the fiber joint

Mode Coupling Theory Of Modal Noise: Coherent Source

Average power coupling:

$$\langle\eta\rangle = \frac{\sum_{v=1}^{N} F_{vv} W_v}{\sum_{v=1}^{N} W_v}$$

Standard deviation of η:

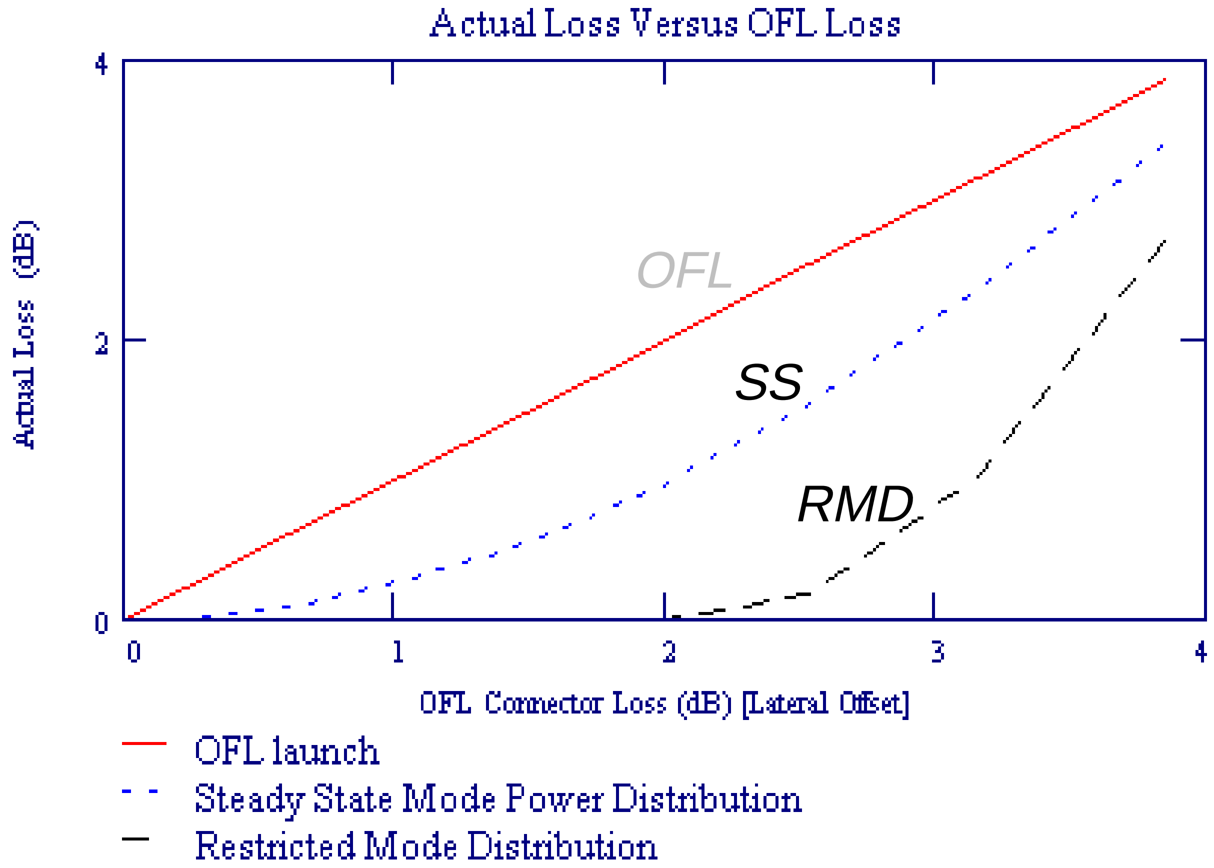
$$\sigma(\eta) = \frac{\left[\sum_{\substack{v=1 \\ v \text{ not } x}}^{N} \sum_{x=1}^{N} W_v W_x \left(F_{vx} \right)^2 \right]^{0.5}}{\sum_{v=1}^{N} W_v}$$

Low frequency SNR:

$$\text{dc-SNR} = \left(\frac{\langle\eta\rangle}{\sigma(\eta)} \right)^2$$

W_v is the mode power weighting for mode v

*Mode Coupling Theory Of Modal Noise: Coherent Source, **Coupling Loss***



Underfilled fibers exhibit less loss at connectors

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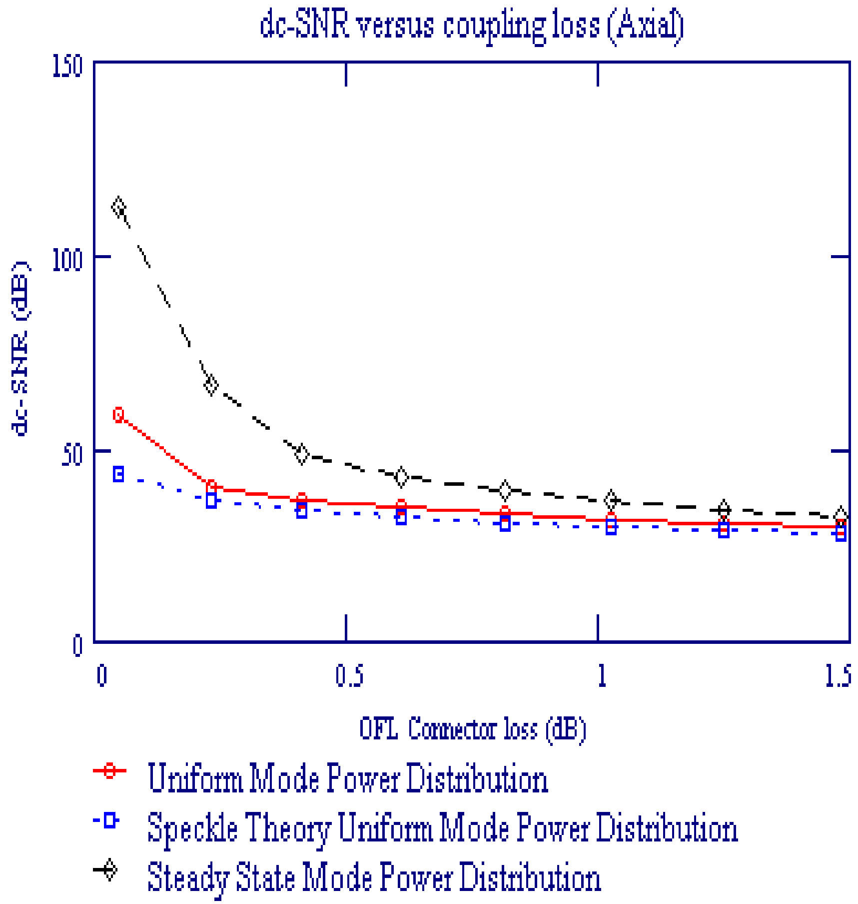
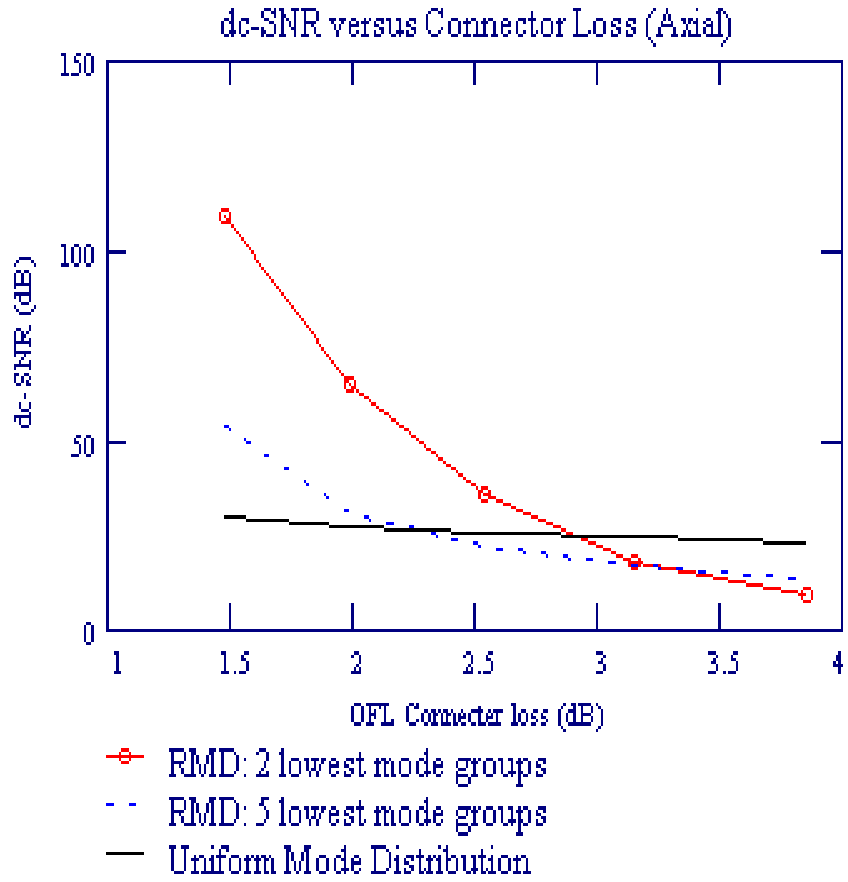
Mode Coupling Theory Of Modal Noise: ***Coherent Source, dc-SNR, single connector***





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Mode Coupling Theory Of Modal Noise: ***Coherent Source, dc-SNR***

We have used Mode Coupling Theory to show:

- **For single OFL connector loss up to ~ 2 d**B:
  - *RML has higher dc-SNR compared to Uniform Mode Power distribution (OFL)*
  - ***RML has smaller BER penalty compared to OFL***
- **For larger (> 2 dB) OFL connector loss at a single point:**
  - *RML dc-SNR less than OFL dc-SNR*
  - ***RML has larger BER penalty compared to OFL***

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Conclusions

Long wavelength lasers & MMF form robust Gb/s Ethernet links

- ***Transceivers can be qualified with Modal Noise Test Procedure***
- ***62MMF:*** *Theoretical worst case modal noise power penalty < 1 dB*
- ***50MMF:*** *Theoretical worst case modal noise power penalty < 2 dB*
  - ➡ *penalty may be reduced by increasing laser spectral width*
  - ➡ *HP allocates 1.5 dB penalty for modal noise*
- ***Experimental penalties less than predicted by worst case speckle theory***
- ***Mode coupling theory:*** *proved RML dramatically reduces modal noise penalties for single points of MSL < 2 dB*

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References:

1. Klaus Petermann, "Nonlinear Distortion and Noise in Optical Communication Systems due to Fiber Connectors",
   IEEE Journal of Quantum Electronics, Vol. QE-16, N0. 7, July 1980, pp761-770

2. Robert Olshansky and Donald B. Keck, "Pulse broadening in graded-index optical fibers", Applied Optics, Vol. 15, No. 2, February 1976, pp483-491.

3. T.H. Wood, " Actual modal power distributions in multimode optical fibers and their effect on modal noise", Optics Letters, Vol. 9, No. 3, 1984.

4. J. Saijonma and S. J. Halme, "Reduction of modal noise by reduced spot excitation", Applied Optics, Vol. 20, No. 24, 1981, pp3402-4306.

5. Santanu Das, Colin G. Englefield, and Paul A. Goud, " Modal noise and distortion caused by a longitudinal gap between two multimode fibers", Applied Optics , Vol. 23, No. 7, April 1984, pp1110-1115.

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