Improvements to Modal Noise Penalty Calculations

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Outline

- Modal Noise (MN) penalty calculation changes
- Calculation of MN penalty for various launch classes
  - Comparison of Overfilled launch (OFL) with Single Mode Fiber (SMF) Launch
  - Comparison of OFL with Multimode Fiber (MMF) Launch
- Conclusions/Recommendations

Why do we need changes to the theory?

- Theory developed in the mid 80s to 90s
- Fundamental assumptions are not completely valid for today's links
  - Original calculations assumed overfilled launch conditions – not valid for center, offset or restricted launch
  - Fiber transfer function assumed to be Gaussian
  - Noise bandwidth and receiver filtering needs to be taken into account
    - Modal noise bandwidth is at least equal to the signal bandwidth, may be much higher (or much lower)

Prior work: references for MN penalty calculations

1. R. J. S. Bates, D. M. Kuchta and K. Jackson – Improved multimode fibre link BER calculations due to modal noise and non-self-pulsating lasers (Optical and Quantum Electronics, vol. 27, (1995) pp. 203-224)
   - Contains complete set of equations to evaluate the MN penalty

   "Low frequency" (Gaussian) and "high frequency" (Double Exponential) noise probability density functions

   - Basis for the work by the Gigabit Ethernet MN group and our simulations
2. T. Kanada – Evaluation of Modal Noise in Multimode Fiber Optic Systems (IEEE JLT, vol. 2, 1984, pp. 11-18).
   - Modal Noise Bandwidth Calculated
3. K. Peterman – Non-linear Distortions and Noise in Optical Communication Systems due to Fiber Connectors (IEEE JQE, vol.16, July 1980 (pp. 761-770)
   - Take into account actual MPDs, connector effects, improve variance calculations
4. R. Dandliker – How Modal Noise in Multimode Fibers Depends on Source Spectrum and Fiber Dispersion (IEEE JLT, vol. 3, 1985 (pp.7-12)
   - Speckle contrast at output of long fibers

Changes to Standard Approach

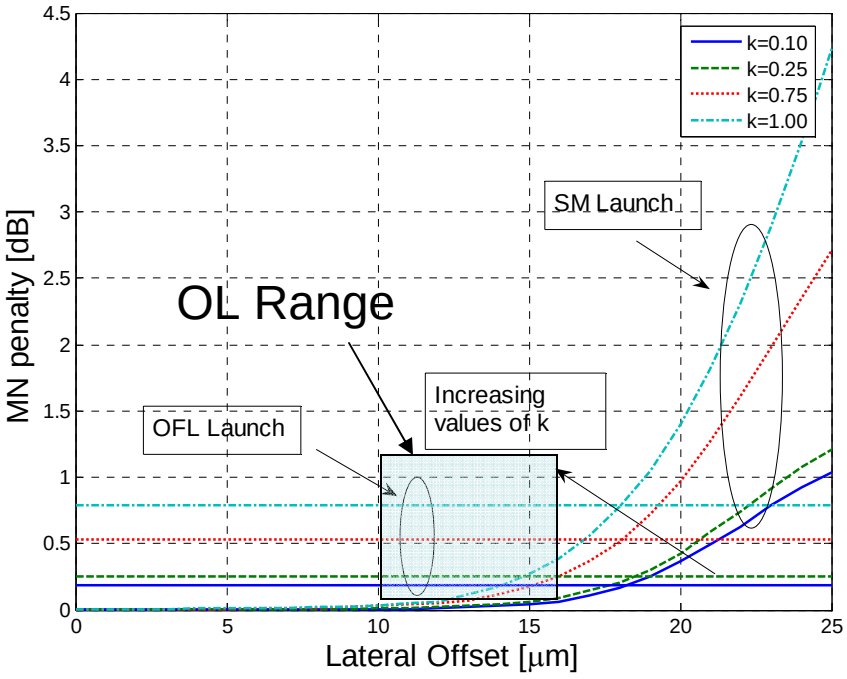
- Calculation of the “low frequency” modal noise std deviation in [1], eq. 4 modified not to use approximations
  - Calculations of the “high frequency” modal noise std. dev. also affected
- Take into account actual fiber TF
  - observed impact of launch conditions and fiber delay times on modal noise penalty
- Take into account the modal noise filtering in the receiver (if the bandwidth larger than the receiver bandwidth)
  - First calculations without correction – uncertainty in parameters, results will be worst case

Link Configuration

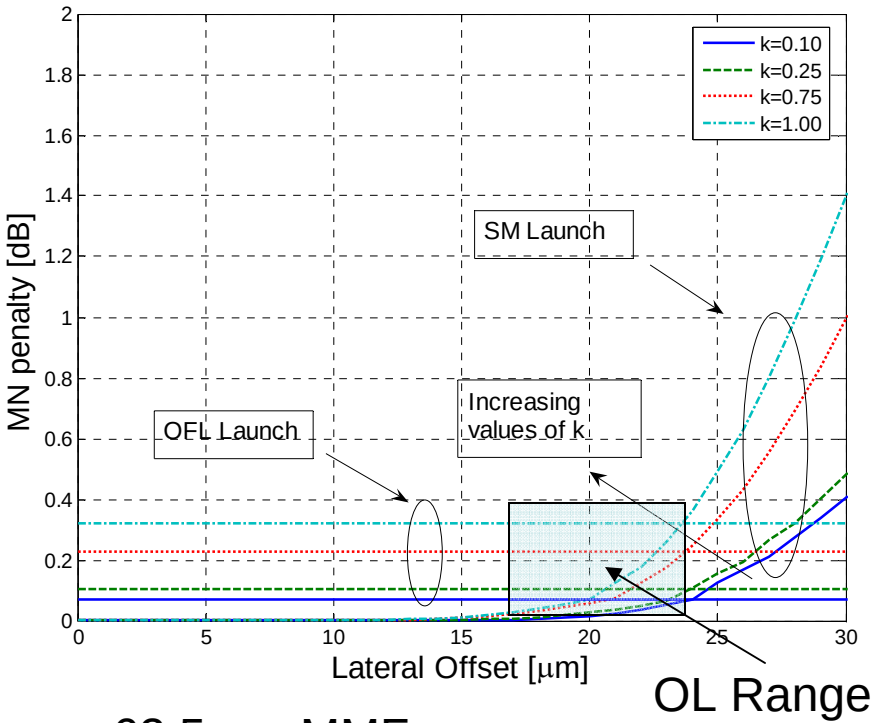
- Uses Worst Case MN Link agreed by the group
  - 2 connectors with 7 μm offset separated by 10m fiber, one with 4 μm offset after 220m
- High Coherence Laser Diode with α=0.98 and β=0.47 (Fabry-Perot)
- Fiber bandwidth 500 MHz·km
- First set of slides without correction for receiver bandwidth, assumes Gaussian fiber TF
- Second set takes into account actual fiber TF, and uses MMF launch
- Mode Partition Noise factor k is parameter

Comparison of MN Penalties for OFL Launch and SMF Offset Launch

- OFL conservative for smaller offsets, optimistic for larger offsets
- Penalties much smaller for 62.5 μm MMF, particularly for large offsets



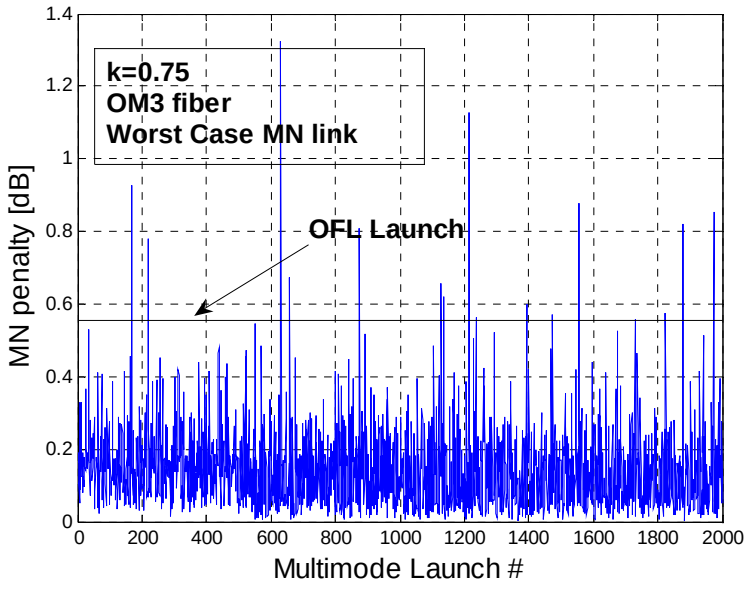
50 μm MMF

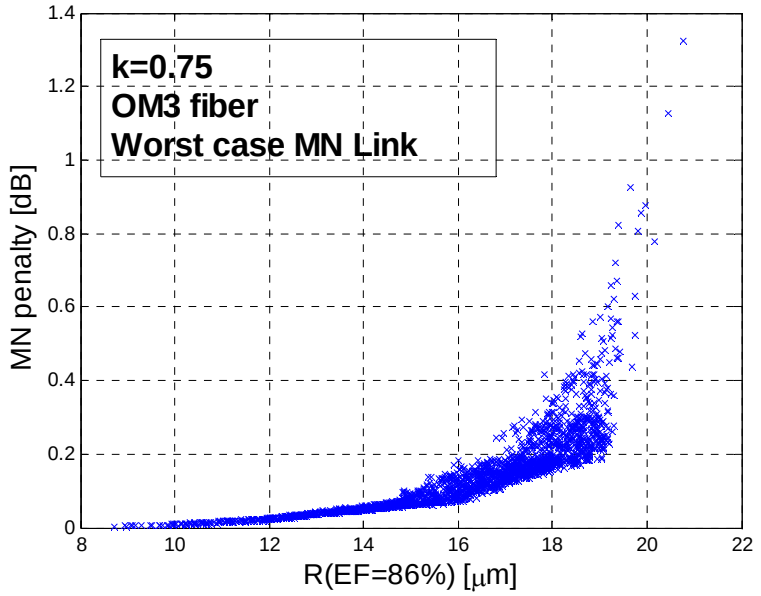


62.5 μm MMF

Comparison of OFL Launch and MMF Launches for OM3 fiber

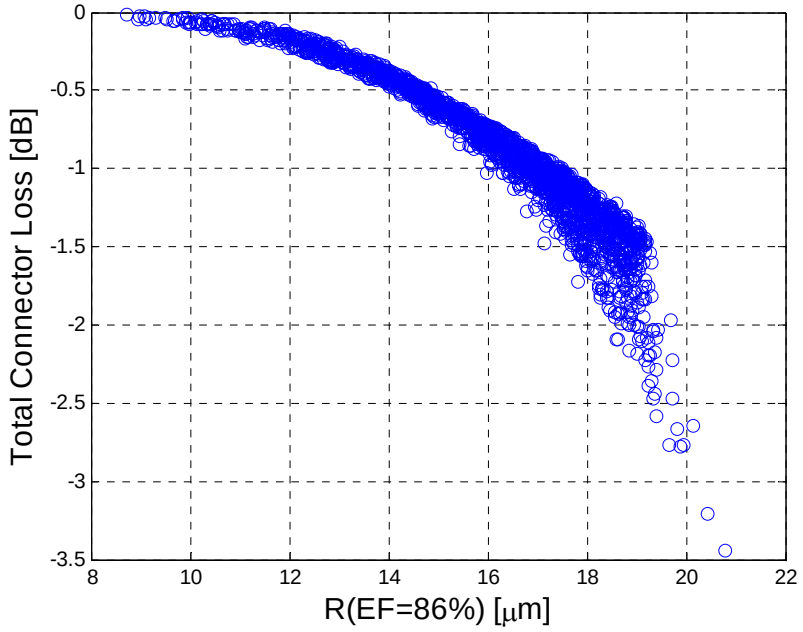
- Laser launch impacts the modal noise penalty
- Higher encircled flux = higher modal noise penalty
  - But we need to evaluate the impact of the MMF launch on the equalizer performance
- Need to control encircled flux, steep rise in penalties for R(EF=86%)>18μm
- Similar results expected for OM1 and OM2 fiber

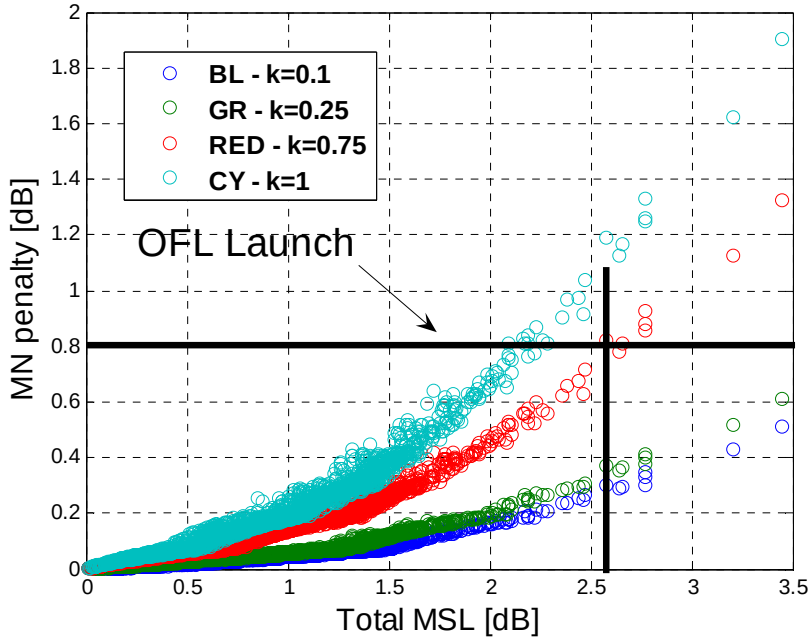




Penalty vs. Total MSL

- Relationship between EF and MSL not linear
- Penalty curves follow expected trend, but at lower level
- Limiting encircled flux to 18 μm would guarantee low modal noise penalty





Conclusion

- Improved MN penalty calculations
  - Takes into account launch conditions, fiber properties
- SMF launch (both offset and center launch) acceptable - fall in low MN penalty region
- MMF launch may be also acceptable if encircled flux is limited to 18 μm
- Need to check the impact of launch conditions on yield and residual ISI
  - Compare center launch with offset launch
  - Find the yield for MMF
- Measurements underway!