Channel Modelling Ad Hoc

Task 1 – Static Channel Model

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Required Activities

• Define methodology for providing FDDI and (less urgently) OM2,3 fiber static channel models

• What are the required outputs?

- Outputs: Modal delay times, index perturbations etc. Reduced fiber count “highly challenging” and high fiber count “Monte Carlo” (general ad hoc)

- Interaction with input (launch) activity – particularly refractive index profiles (task 4)

- Validation (task 5)

• Agree perturbations, size & statistics of perturbations

- Need to compare “81 fiber” and “Monte Carlo” models and refine perturbations if necessary

• Inclusion of mode coupling along link and at connectors

- Currently proposed to use overlap integral methodology

• Validation

• Provision of data sets to task group

Generic Approach

- What's common to the 81 fiber and Monte Carlo models? – the principal components of both models are the *modal delay sets*
- The only significant difference between the models is how these modal delay sets are generated

81 fiber model

81 perturbed refractive-index profiles are input to a mode solver. Output scaled to a worst-case DMD

Monte-Carlo model

Modal delays sets are directly generated with statistics appropriate for the expected perturbations in the population

Modal delay sets

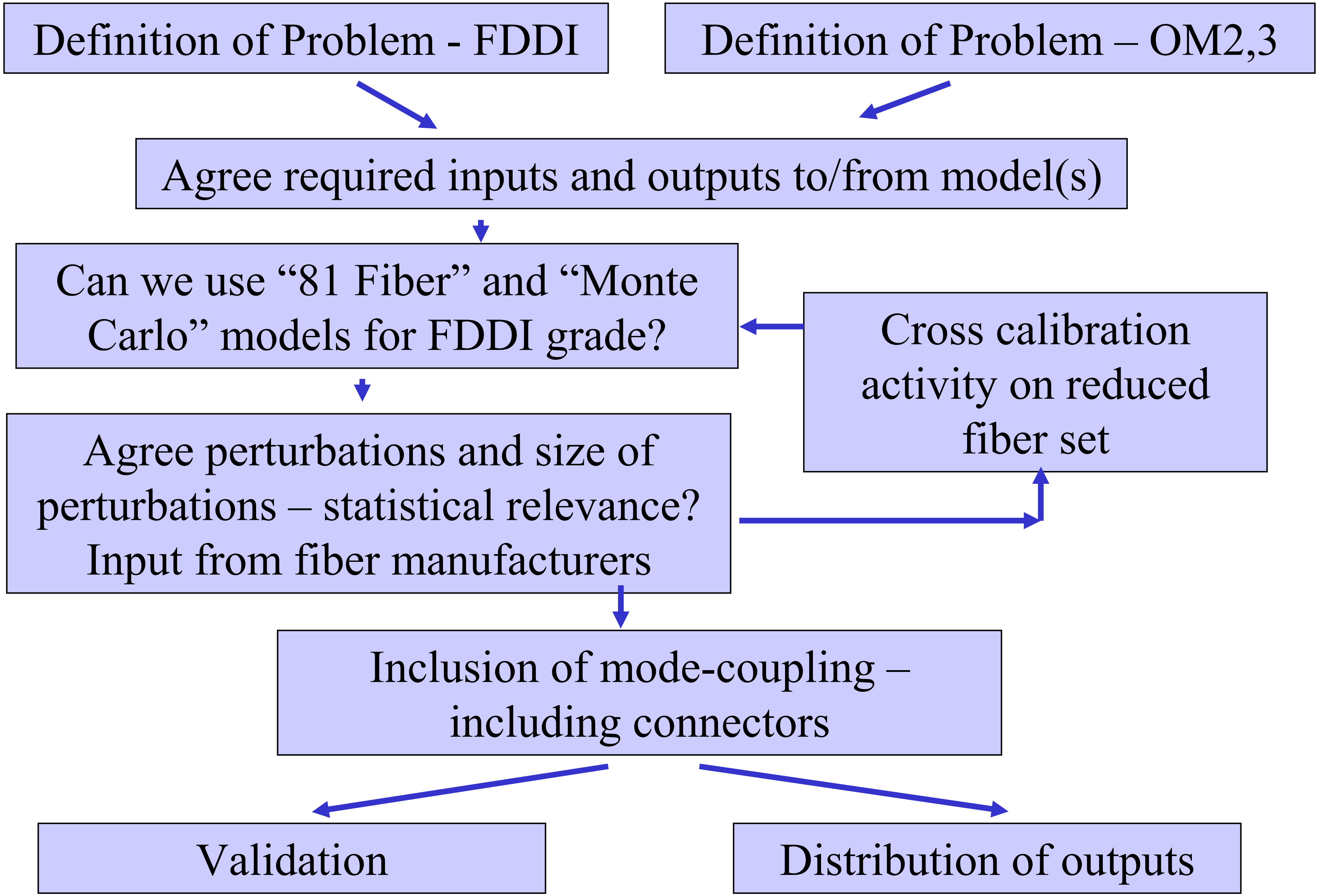
81 fiber model and **Monte Carlo model** share a common approach to calculating MPD for an arbitrary launch, based on overlap integrals. Connector treatment also common

Impulse responses, frequency responses *etc.*

Rationale to Methodology

- At Portland meeting it was agreed to move forward with both 81 fiber and Monte Carlo models (motion #6)
  - Similar approaches based on fiber modal delay sets, but with different approaches to perturbations
- 81 fiber model gives reduced “highly challenging” fiber set whilst Monte Carlo approach gives large fiber set with characteristics of general fiber populations
- Both rely on assumptions about the perturbations they use and these need to be checked and refined in the light of inputs from fiber manufacturers and users
- Allows flexibility from the user perspective
- But requires cross-validation to check that fiber sets show appropriately similar statistics

Flow Chart for Task 1 Activities



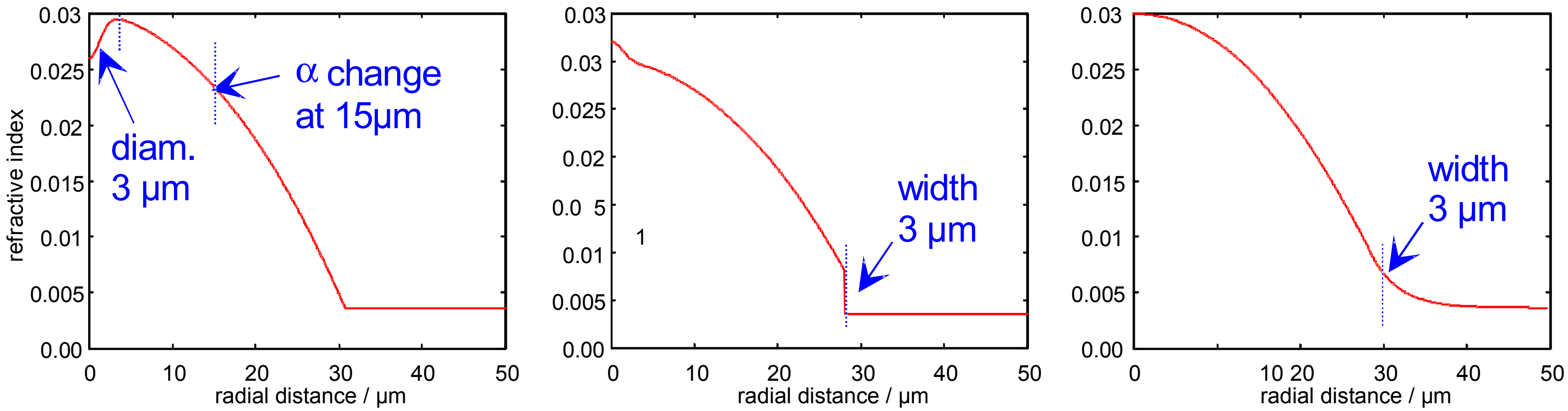
81 Fiber Model

81 fiber model - *overview*

- Generation of a set of perturbed MMF refractive-index profiles
- Calculation of OFL frequency response and bandwidth
- Calculation of impulse and frequency responses at beam offsets ranging across the entire fiber core radius, using overlap integrals
- Calculation of DMD from assessment of the impulse responses at each offset
- Comparison of DMD to 2ns/km – 5% of installed MMF has DMD > 2 ns/km for 62.5-µm MMF at 1300 nm
- Conversion to a set of "highly challenging" refractive-index profiles by scaling the perturbations in each of the original profiles
- Scaled index profiles then analysed for an arbitrary launch, to generate impulse responses and frequency responses

Slide from Jonathan Ingham

Original 81 fiber model - *perturbations*



4 different types of deviation from an ideal power-law index profile:

3 values for the inner profile parameter

3 values for the outer profile parameter

3 types of distortions on the fiber axis (peak / dip / none)

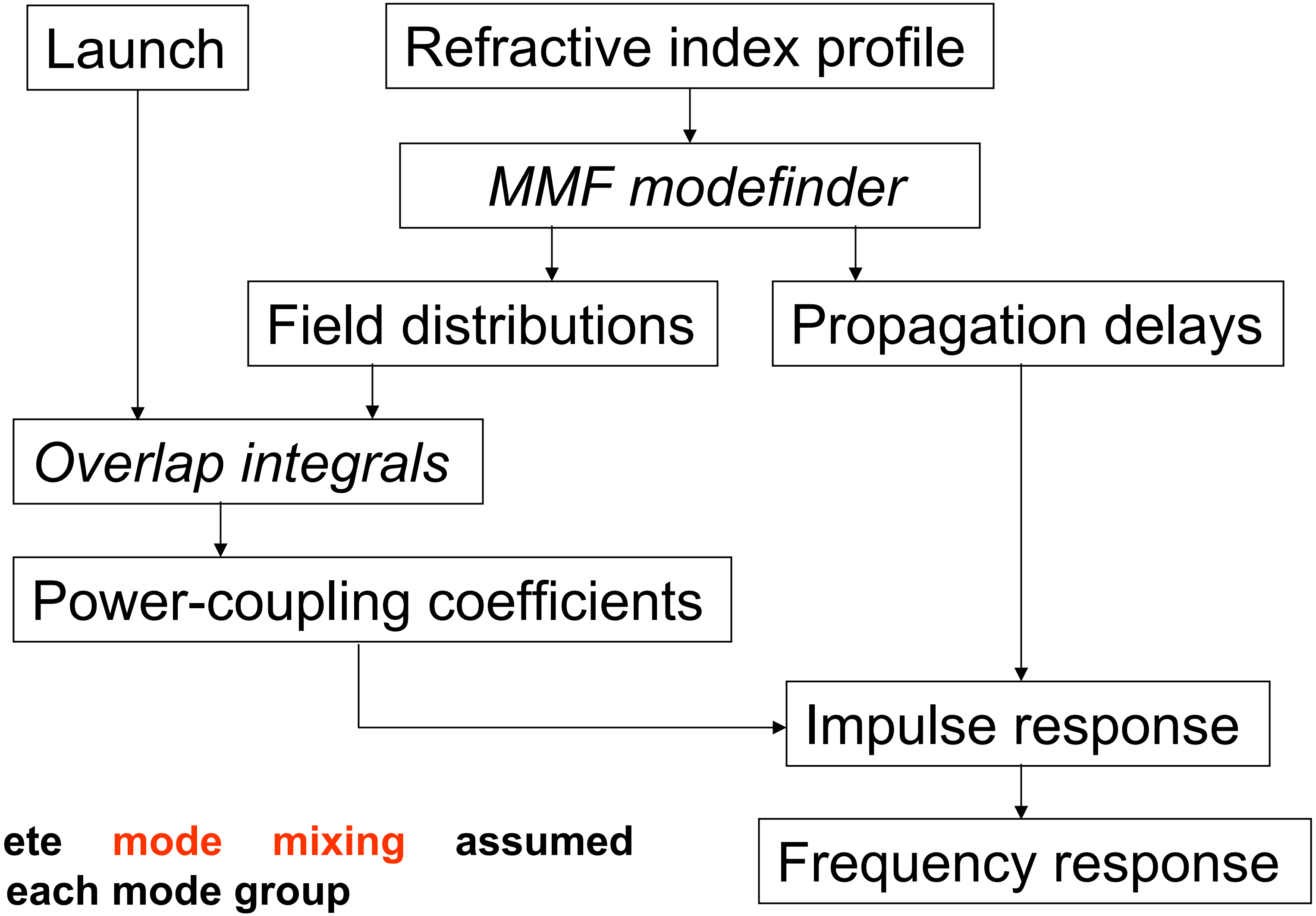
3 types of distortion at the core-cladding interface (sudden / exp decay / none)

81 representative fibers considered

For further details see: Jonathan Ingham, Richard Penty, Ian White, David Cunningham, "Proposal of an approach for statistical modeling of OM1 multimode fiber within the IEEE 802.3aq channel modeling ad-hoc committee," submitted to 10GMMF reflector on 22 June 2004

Slide from Jonathan Ingham

Restricted set fiber model – *MMF model*



- **Complete mode mixing assumed within each mode group**

Slide from Jonathan Ingham

Investigations since Portland Meeting

Scaling

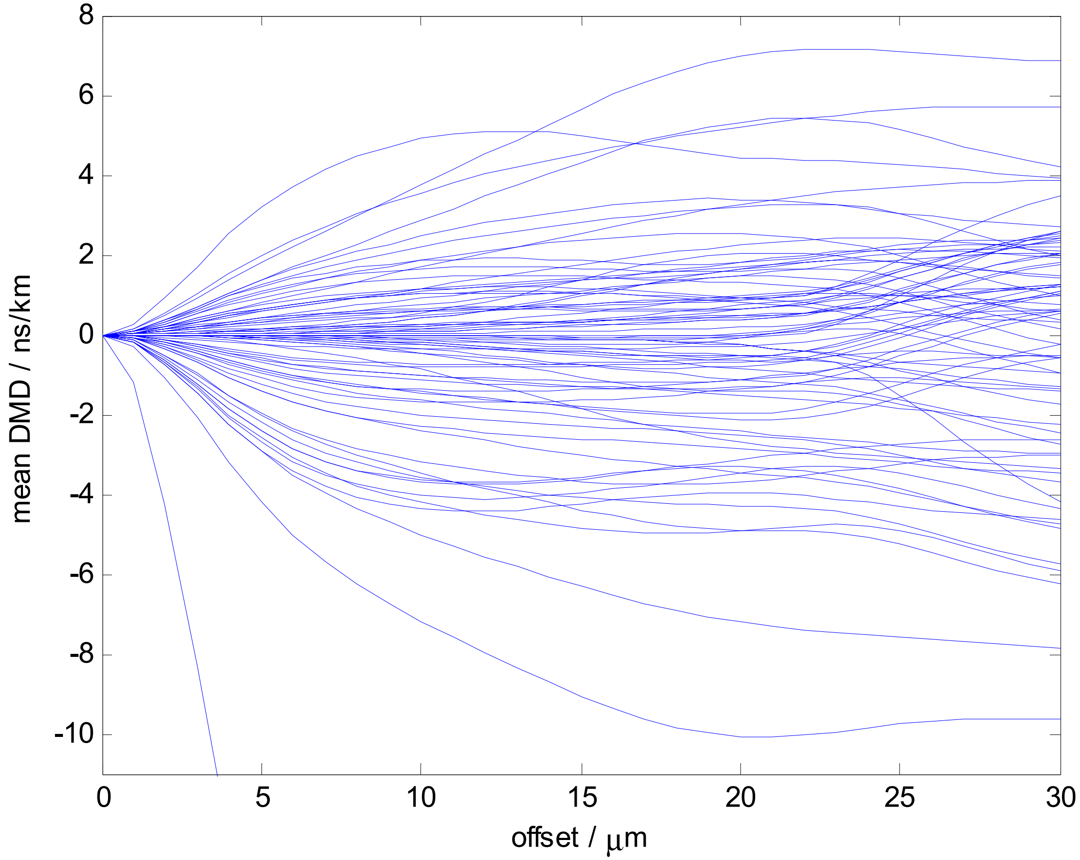
• The current approach is to scale to a worst-case mean DMD of 2 ns/km – this has the considerable advantage of being linked to the worst 5% of the installed base of FDDI-grade fiber

- However 16 fibers are rejected in the scaling process as having a bandwidth below 500MHz.km

• An alternative approach that is worthy of investigation is to scale to the OFL bandwidth-length product specification of 500 MHz km

• Also relevant to this discussion is the question of how to process failures from the DMD scaling process. One possible approach (the current approach) is to ignore the failures. An alternative is to retain the failures in some way, possibly generating an additional set of fibers.

Scaling to 500MHz.km

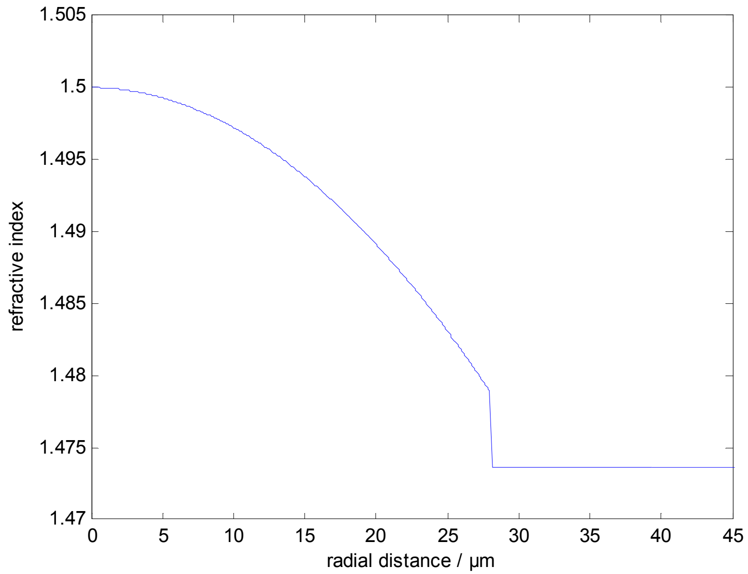


- Scaling all fibres to 500MHz.km results in a large number of fibers with very high centroid DMDs. This is unphysical. Such DMDs do not exist in reality

- A compromise suggestion (from Piers Dawe) - to scale original failing fibers to an OFLBW of 500 MHz.km with the remainder retaining the 2ns/km DMD scaling – was accepted as this did not skew statistics of original 81 fibers too much

Edge Perturbations

• Some discussion has taken place regarding the edge perturbations: the question of whether they are properly representative of perturbations in the installed base has been raised. Possibly too severe?



Possible approaches include:

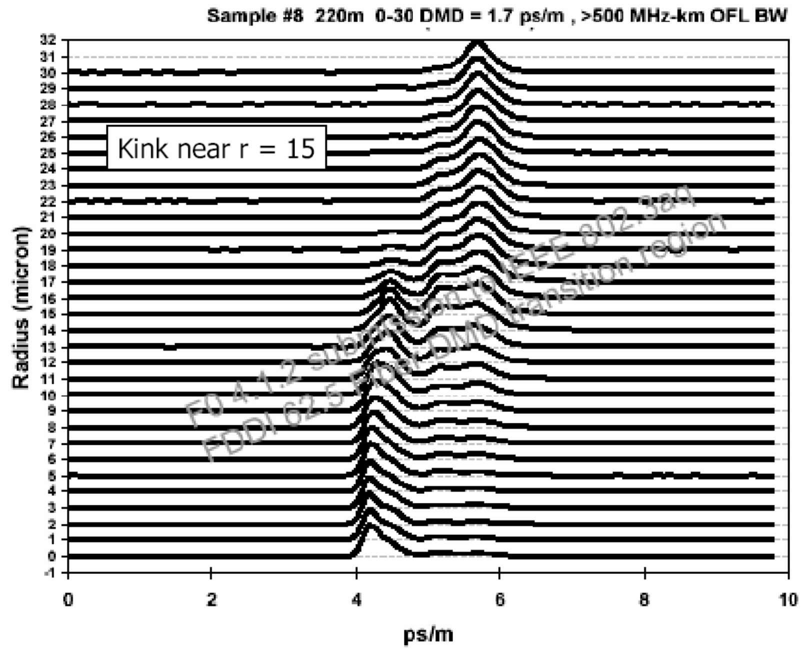
(i) Remove all edge perturbations and replace with another (possibly kink perturbation)

(ii) Do nothing (ie retain abrupt edge and exponential edge perturbations)

(iii) Remove abrupt edge perturbation but retain exponential

Kinked DMD profiles

• Paul Kolesar (kolesar_1_0704.pdf) has indicated the existence of fibers with "kinked" DMD characteristics, for example:

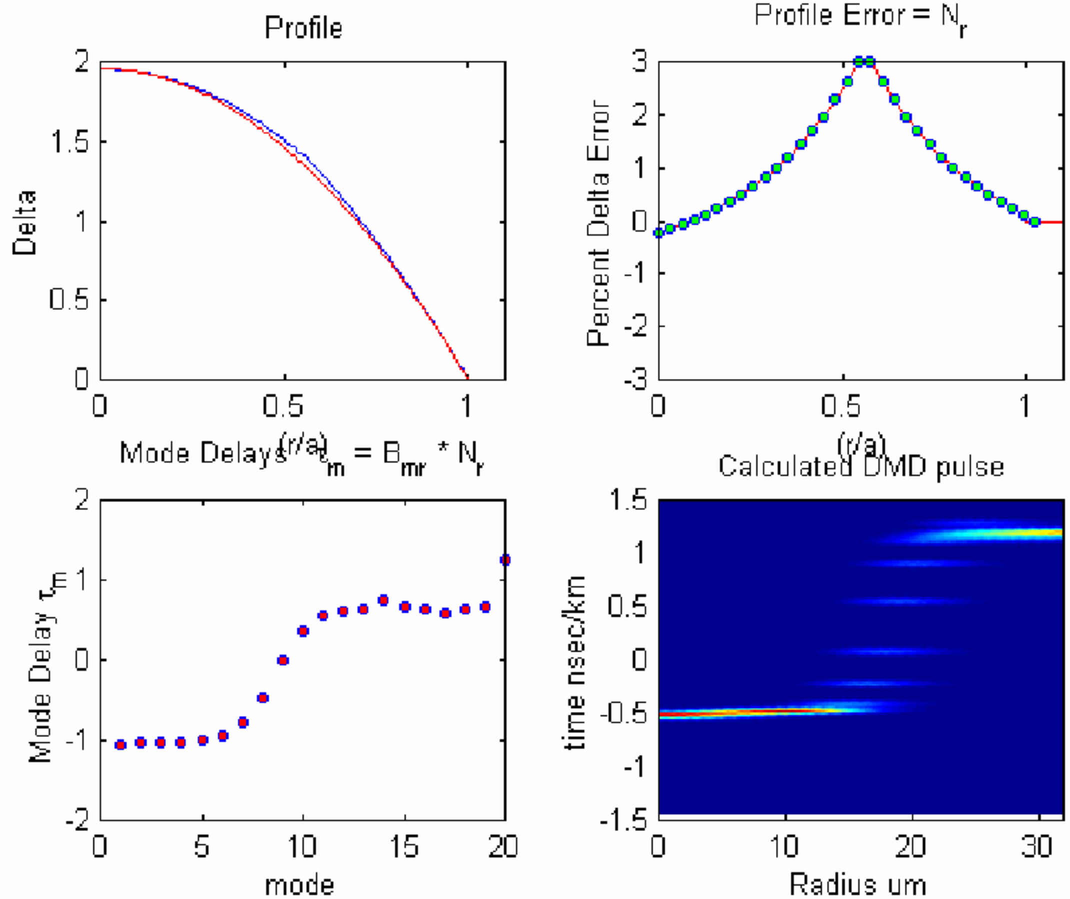


• At Portland it was agreed (motion #4) to consider including perturbations to reproduce this effect

• Not yet certain about how common this effect is in the installed base (guidance from the fiber manufacturers is still being sought)

Chosen kink perturbation

• John Abbott has suggested a perturbation which replicates this effect




```
b_k = 20*5/31.25;
D_N = 0.*x1;
r_k = .56;
for i_rad = 1:length(x1)
    D_N(i_rad) = a_k*(exp(-b_k*abs((x1(i_rad)-r_k)))-exp(-b_k*abs((x1(10)-r_k))));
end
D_N(101:111,1)=0.;
```

Four Possible Perturbation Sets

- Original 81 fiber set
- 81 fiber set with

  - Abrupt edge perturbation removed (leaving 54 fibers)

  - (Additive) kinked DMD perturbations with kink at 1μm steps (an additional 27 fibers)

  - Results in a new 81 fiber set
- New multiplicative perturbation set

  - Abrupt edge perturbation removed (leaving 54 fibers)

  - Multiplicative kink perturbation at 20μm (i.e. x2 factor)

  -Results in 108 fiber set
- New hybrid set

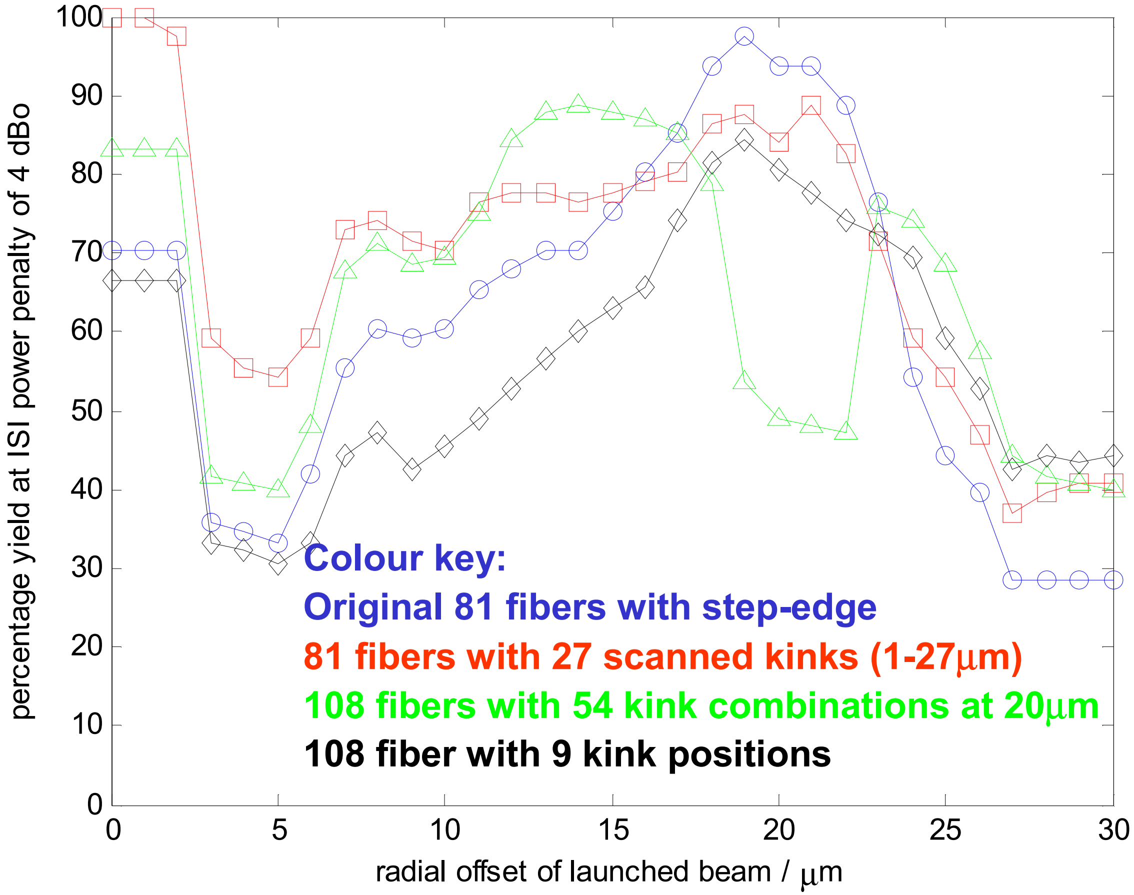
  -Abrupt edge perturbation removed (leaving 54 fibers)

  - Matrix of additional 54 perturbations - 9 kink positions with pseudo random distribution of other perturbations (suggested and circulated to Task 1 by Paul Kolesar)

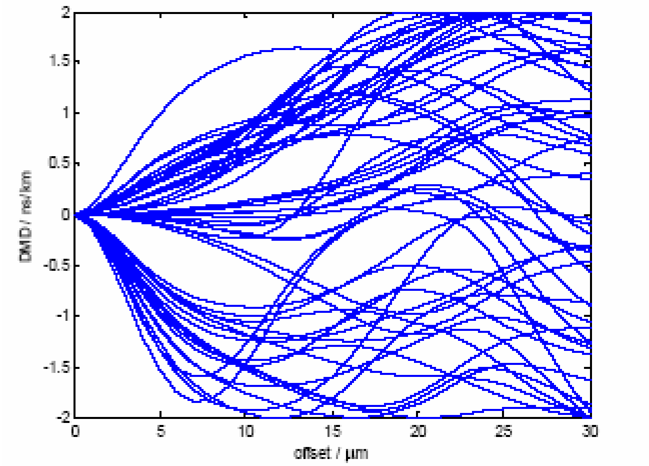
  - Results in 108 fiber set

  - 27 kink perturbation set also considered but the 54 set has examples kinks in combination with all other perturbations which is an attractive feature

Results



108 fiber (9 kink position) set



Centroid DMDs

Percentage of fiber sets passing conventional transmission with following parameters

- data rate 10.3125Gb/s PRBS $2^7 - 1$
- 4dBo penalty
- 7μm FWHM Gaussian scanned offset spot

Decision

- After looking at various perturbation sets (main ones described on slide 16) it was agreed via e-mail voting of the Task 1 participants to use the 108 fiber set with 9 kinked positions
- 12 “votes” for this set
- None for other options

Monte Carlo Model for FDDI Grade

Purpose of FDDI Monte Carlo set

The purpose of a large ‘Monte Carlo’ set of mode delays is to provide a large base of mode delays in approximately the proportion found in manufacturing, for purposes of modeling with a variety of ‘sources’.

The procedure was using in the TIA FO4.1.2 working group on modal bandwidth to develop for OM3 fiber for 300m 10GbE applications.

The IEEE 802.3aq application is slightly different, because the distribution is intended to approximate the ‘installed base’ of FDDI.

Criteria for generating the set

The initial approach for generating the set is to follow the same procedure as Ritger/Golowich/Abbott for the TIA OM3 development: the mode delays follow line segments whose slopes vary randomly like local alpha shifts. In addition, the inner modes are given additional random variation.

Upon review of initial modeling of a FDDI Monte Carlo set by this procedure and further review of the TIA Monte Carlo set, it was seen that the BW distribution produced is too broad, including BWs implausibly if not unphysically high. Adjusting the distribution to reduce the very high BWs tends to result in too many low BW fibers.

Criteria for generating the set

The solution followed was to include more variation in the mode delays, comparing to the example Corning "MBI310" data presented at the July 2004 Portland meeting.

Variations were tested and included which moved the OFL BW distribution closer to what was estimated from index profiles from 1998-99. In addition, aspects of the DMD centroid curve and offset bandwidth were checked for consistency.

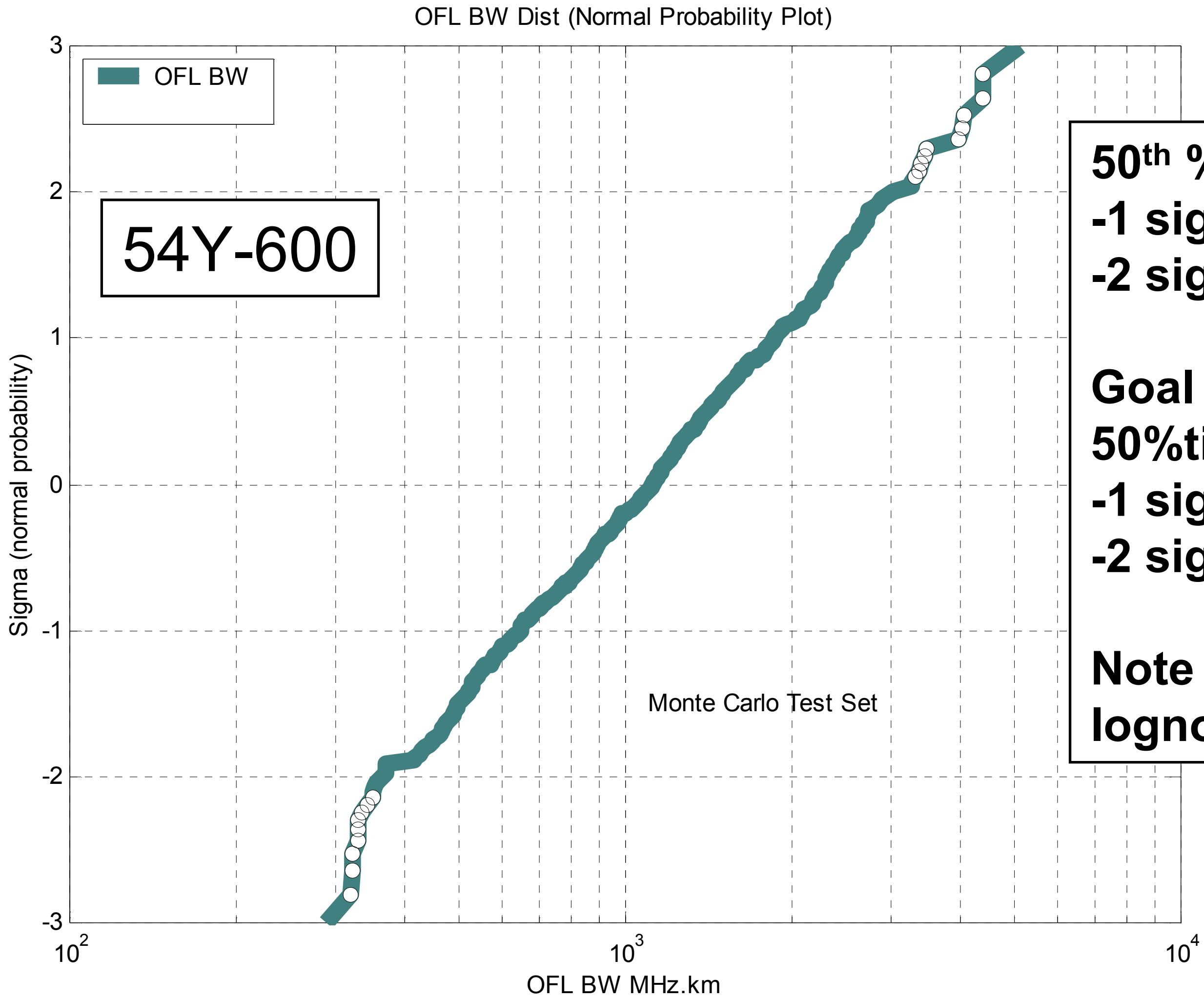
OFL BW distribution data was shared by fiber manufacturers and is compared to the test set data. DMD data will also be compared to the test set data.

Gen54YY test set data

After more than 50 iterations a test set of 1000 mode delays Gen32a was shared with Jonathan Ingham and the Cambridge group. The main observations were that approximately 5% of the fibers had centroid DMD ranges of about 1.5-2.5nsec/km, more or less as 'expected', but that a higher percentage of fibers had BWs below 600/500/400MHz.km than 'expected'.

After approximately 20 additional iterations a set Gen54YY of 5000 mode delays was generated for additional testing and review. This test set data (or subsets) is presented here.

Gen5P54Y: OFL norm prob plot



50th %tile ~ 1000+MHz.km
-1 sigma ~650MHz.km
-2 sigma~350-400MHz.km

Goal was
50%tile ~ 900-950
-1 sigma~600
-2 sigma~400

Note curve retains lognormal form.

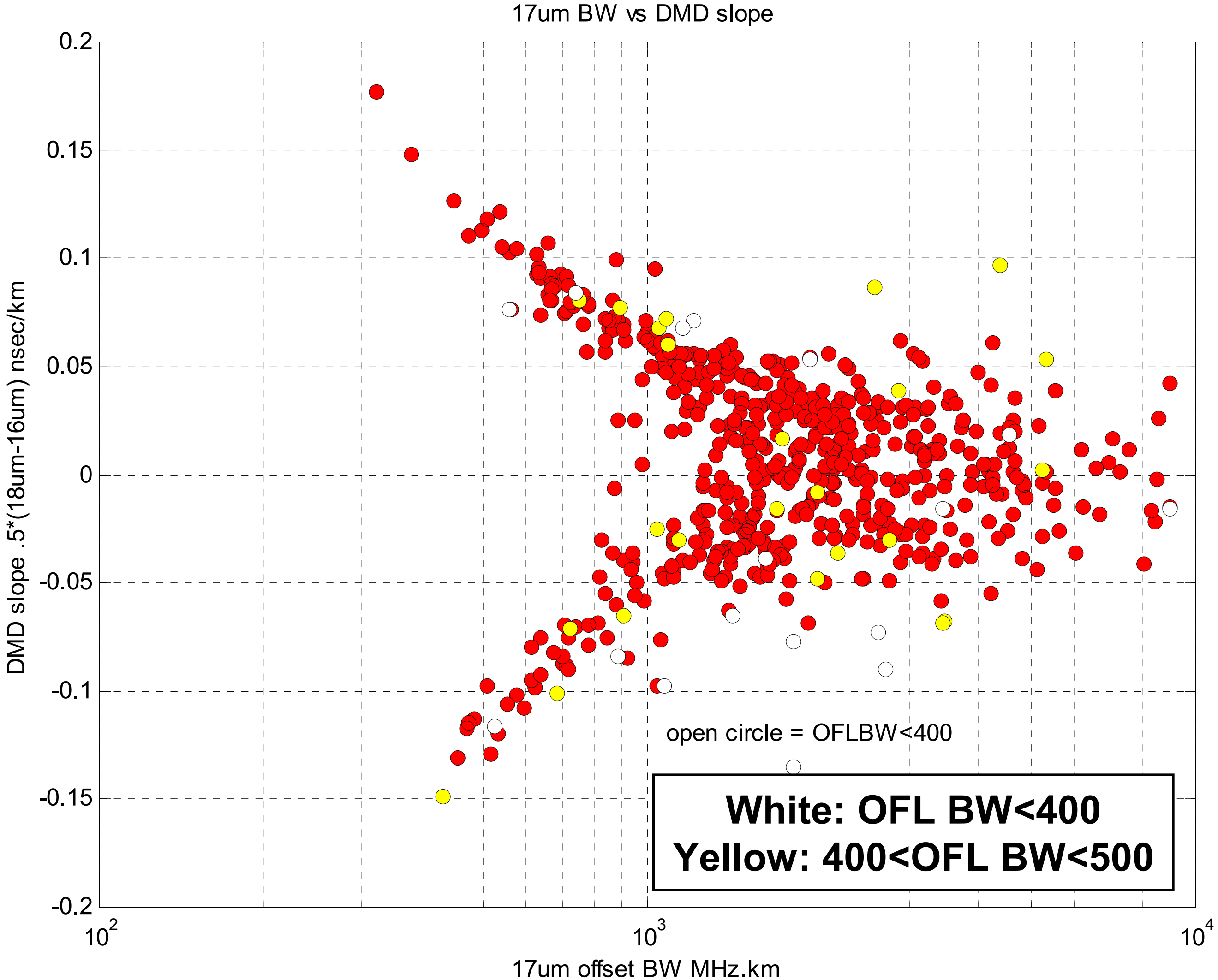
600 fibers in this subset

Gen5P54-54Y: DMD range vs. offset BW

54Y-600

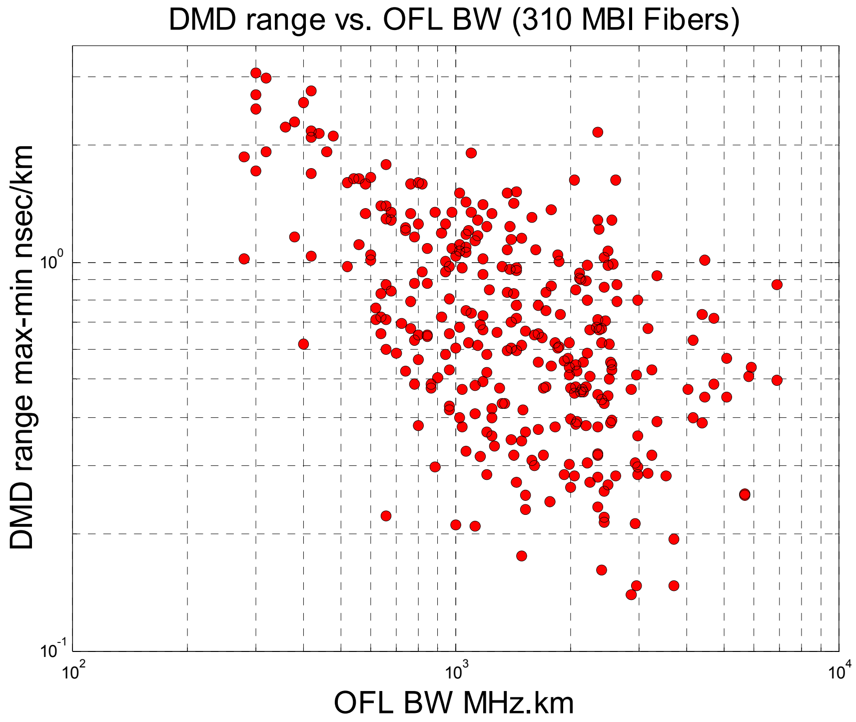
The plot of DMD slope vs offset BW at 17um has this characteristic shape in both MBI310data and the Cambridge Rev2 65 fibers.

Low BW is due to a slope in the DMD.

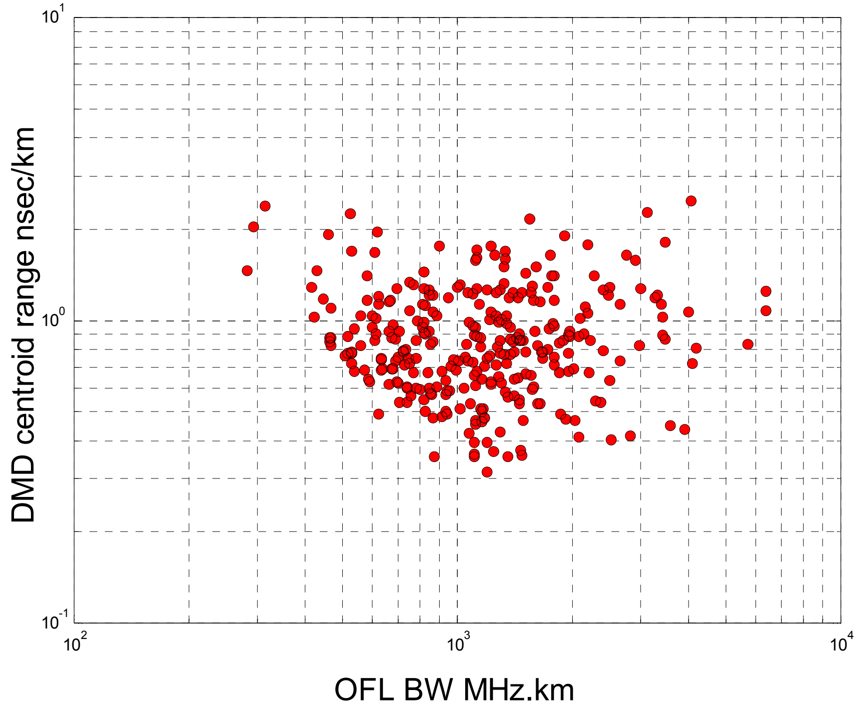


600 fibers in this set

DMD range vs. OFL BW

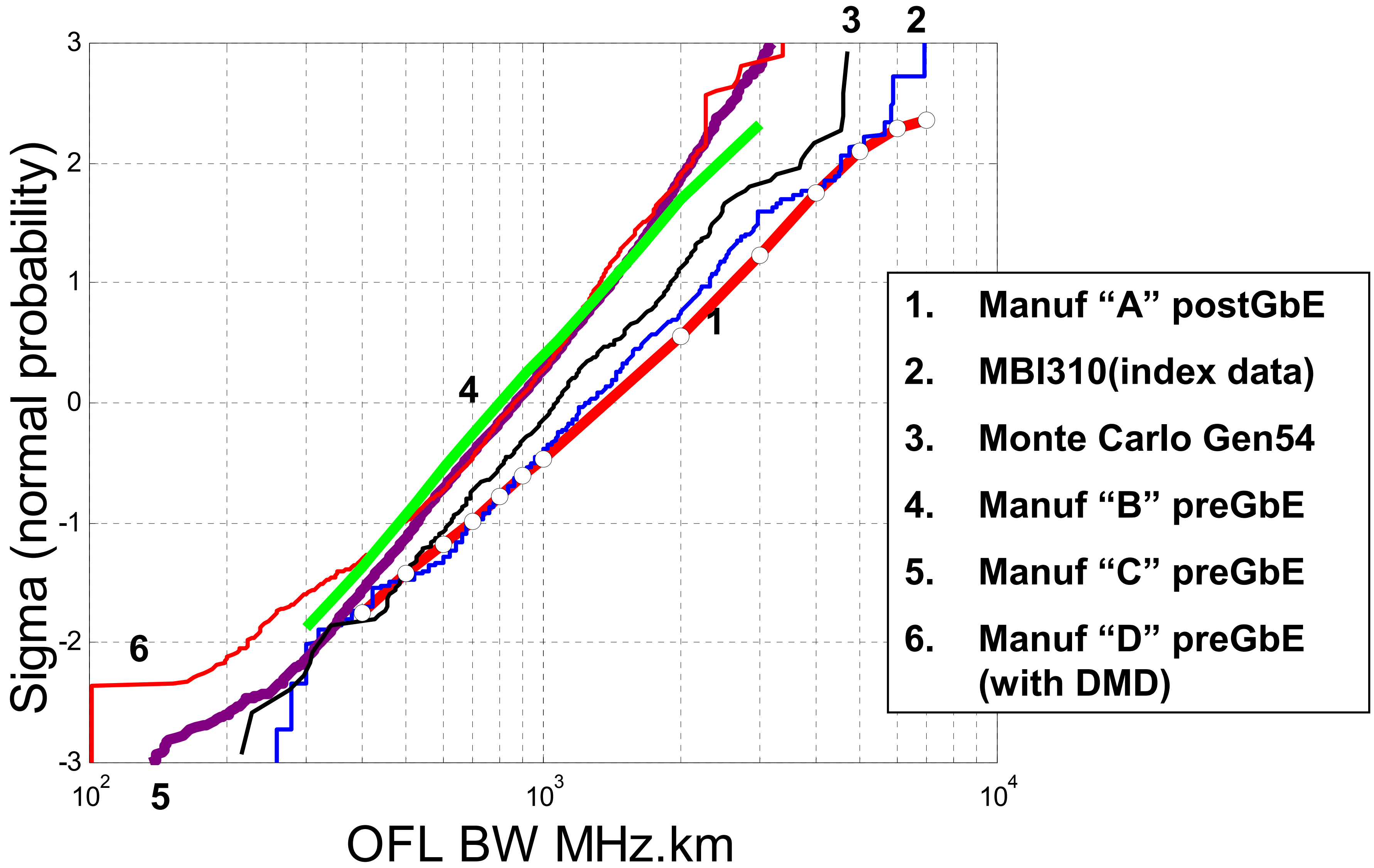


MBI310



GEN54YY

Comparison to available data



Discussion

a. Continue looking for better “knobs” to adjust data set to match details of OFL & DMD distributions.

b. Data is optimistic compared to installed base.

c. Different purpose than TIA OM3 set (did not use tail of distribution for TIA OM3 data set).

Conclusions

- Much work carried out on the channel models – with particular thanks to the following
  - Jonathan Ingham on 81/108 fiber model for FDDI
  - John Abbott on Monte Carlo model for FDDI grade
  - Paul Kolesar for many useful inputs/suggestions
  - Petar Pepeljugoski for work on OM3 Monte Carlo modelling and connector report (with apologies for not having time to show these)
- Study/discussion of appropriate perturbation sets has resulted in agreement on deletion of step-edge and inclusion of kinked perturbations resulting in 108 fibers
- Monte Carlo adapted for FDDI grade
- Task 1 puts these forward for adoption as working static channel models