# Channel Modeling Ad Hoc

# Task 1 – Channel Model Methodology Proposal

Richard Penty (task chair)

Participants : (alphabetical order)

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Portland Plenary Meeting – July 2004

# Required Activities

- Define methodology for providing FDDI and (less urgently) OM2,3 fiber channel models
- What are the required outputs for other aspects of Ad Hoc, for Task Force?
  - Outputs: Modal delay times, refractive index profiles, index perturbations etc. Reduced fiber count “worst case” and high fiber count “Monte Carlo” (task 3)
  - Interaction with input (launch) activity (task 2)
  - Interaction with dynamic model activity (task 4)
  - Validation (task 8)
- 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

# Required Outputs (Task 3)

- Provided data must be sufficient for users to generate their own models at the block function level
  - modal delay time set ✔
  - clear method for deriving impulse response ✔
  - refractive index profile set ✔
  - method for deriving transmission performance for arbitrary launches ✔
  - mode profiles for each mode ✕?

# What Isn't Required

- Modal fields – can be obtained from commercial mode solvers from provided refractive index profiles
- Impulse response sets – should be generated from the data provided
- Internal workings of models beyond public domain information – unless volunteered by participants

# FDDI Static Channel Model – Inputs to Date

- Modal delay and power coupling set provided for 81 fiber model (allows IPRs to be generated) to >25 companies (NB using current scaling assumptions)

- Perturbation discussion document from John Abbott

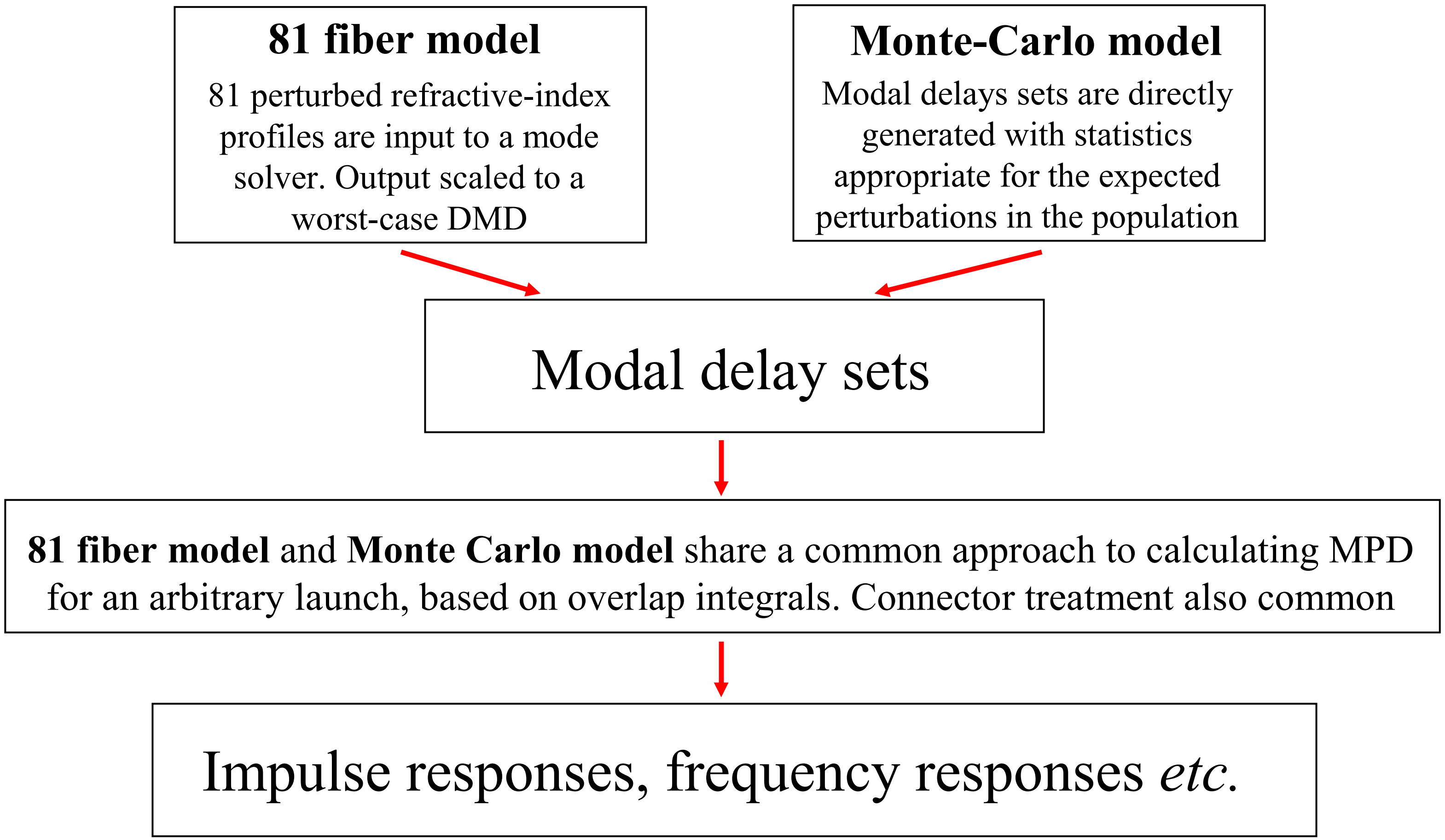
- Offer from fiber companies to provide DMD data on current and historical FDDI fiber to inform discussion (to be submitted via Paul Kolesar)

- Offer from Petar Pepeljugoski to provide 5000 Monte Carlo delay sets for OM3 scaled to 1300nm

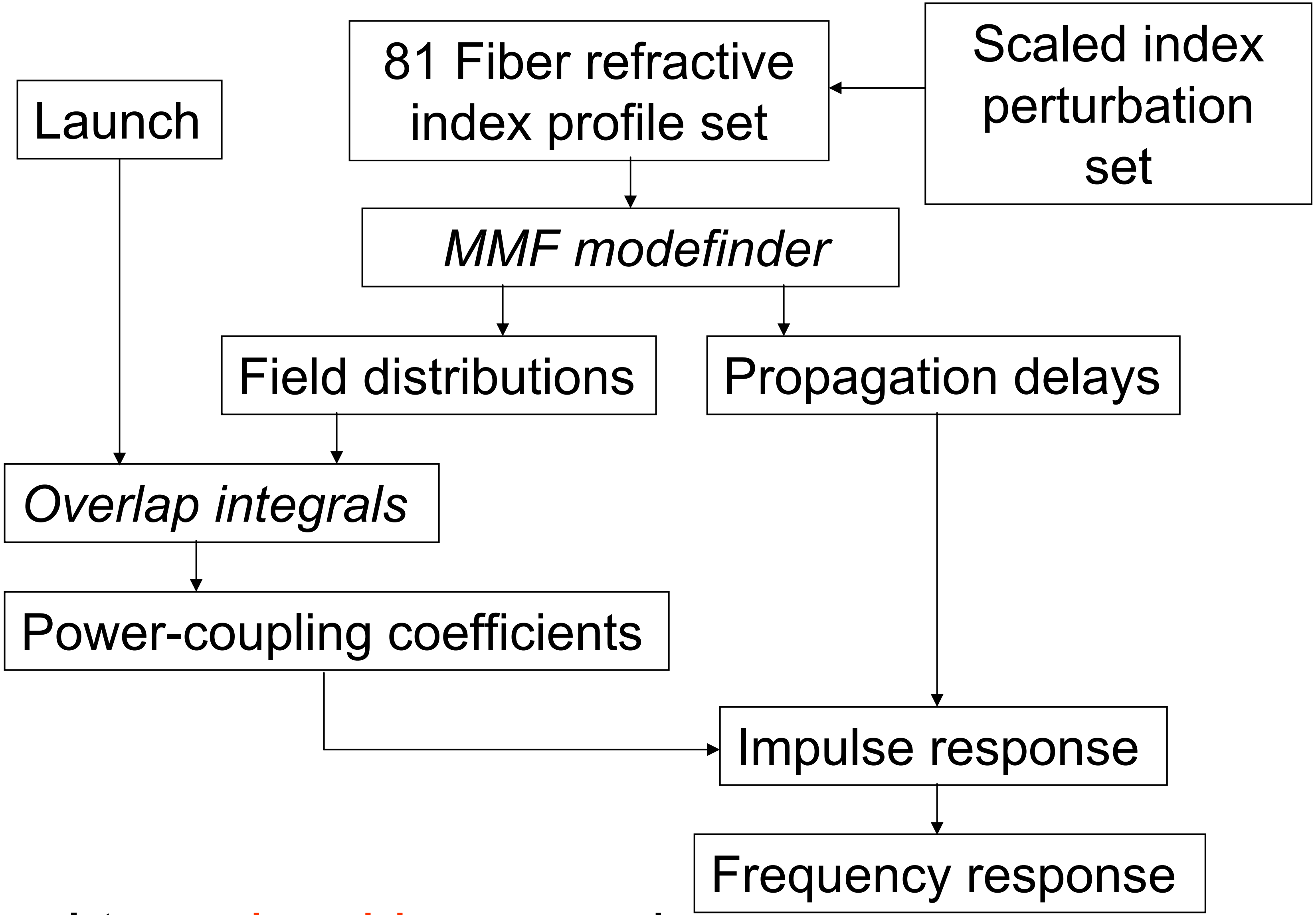
- Agreed at July 1st telecon to go forward with both 81 fiber and Monte Carlo Models for FDDI – following further development

# 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



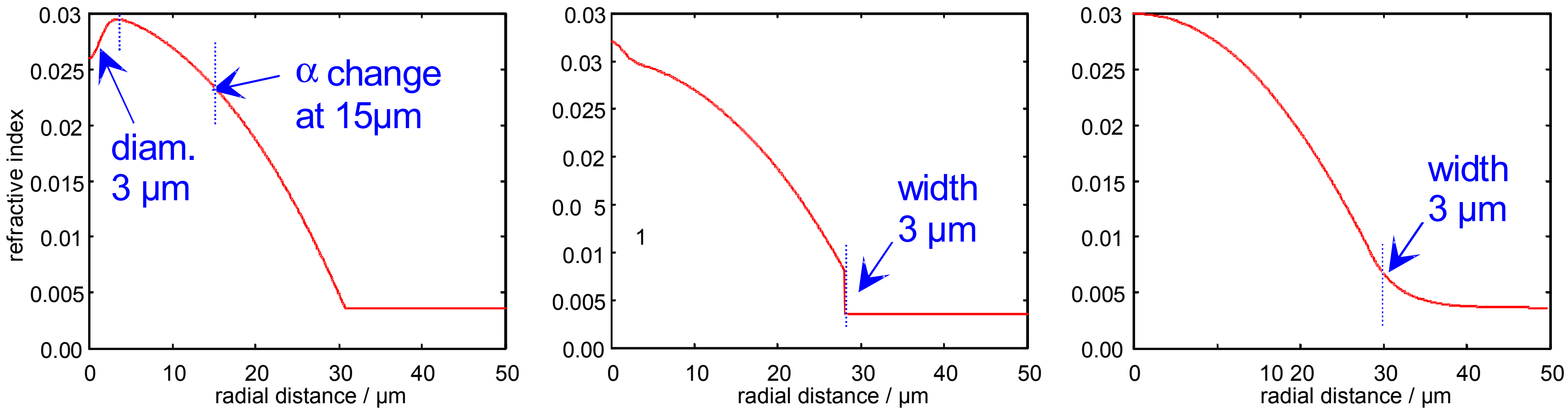
# 81 Fiber Model – Flow Chart




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

Slide from Jonathan Ingham

# 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

# 81 Fiber Model – DMD Scaling

- Ensure that the results are representative of the *worst-case fibers* in the field, to generate a manageable small output set DMD is a common parameter to fiber manufacturers
- Worst-case DMD numbers were provided at time of GbE standardisation, e.g. 2 ns/km for FDDI-grade MMF – capability exists to work with any desired DMD if new numbers become available for the evolving MMF population
- Perturbations of refractive-index profile are then adjusted to create a new index profile which has the desired worst-case DMD figure.

**If the DMD is scaled by, S, then the total perturbation of the refractive index is given by:**

$$\delta n(r) = S\delta n(r)_c + S\delta n(r)_e + \delta n(r)_{gs1} + \delta n(r)_{gs2}$$

**Where** $g_{s1} = S(g_1 - g_o) + g_o$

$g_{s2} = S(g_2 - g_o) + g_o$

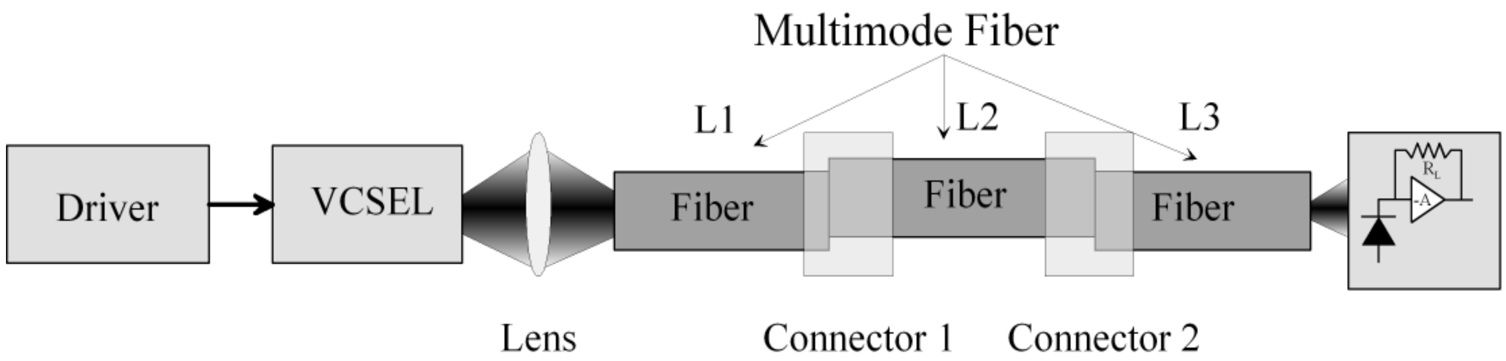
Outputs of the model include: scaled index profiles, modal delay sets, mode profiles, impulse and frequency responses

**For further details see:** Ingham, Cunningham, Penty & White, "More information on statistical modeling of MMF optical fiber links," IEEE 802.3, Long Beach, May 2004.

Slide from Jonathan Ingham

# Monte Carlo Link Simulation

- Structure of MMF Link Model follows typical structure of Ethernet Links
- Monte Carlo approach assumes random inputs with a given (and different) pdf for most link parameters:
  - Fiber mode group delays
  - Laser launch conditions (offsets, tilt, mode structure, beam size etc.)
  - Connector offset
- Assume worst case parameters for driver, laser and receiver
- ISI penalty, DJ and RTW (retiming window) are among model outputs

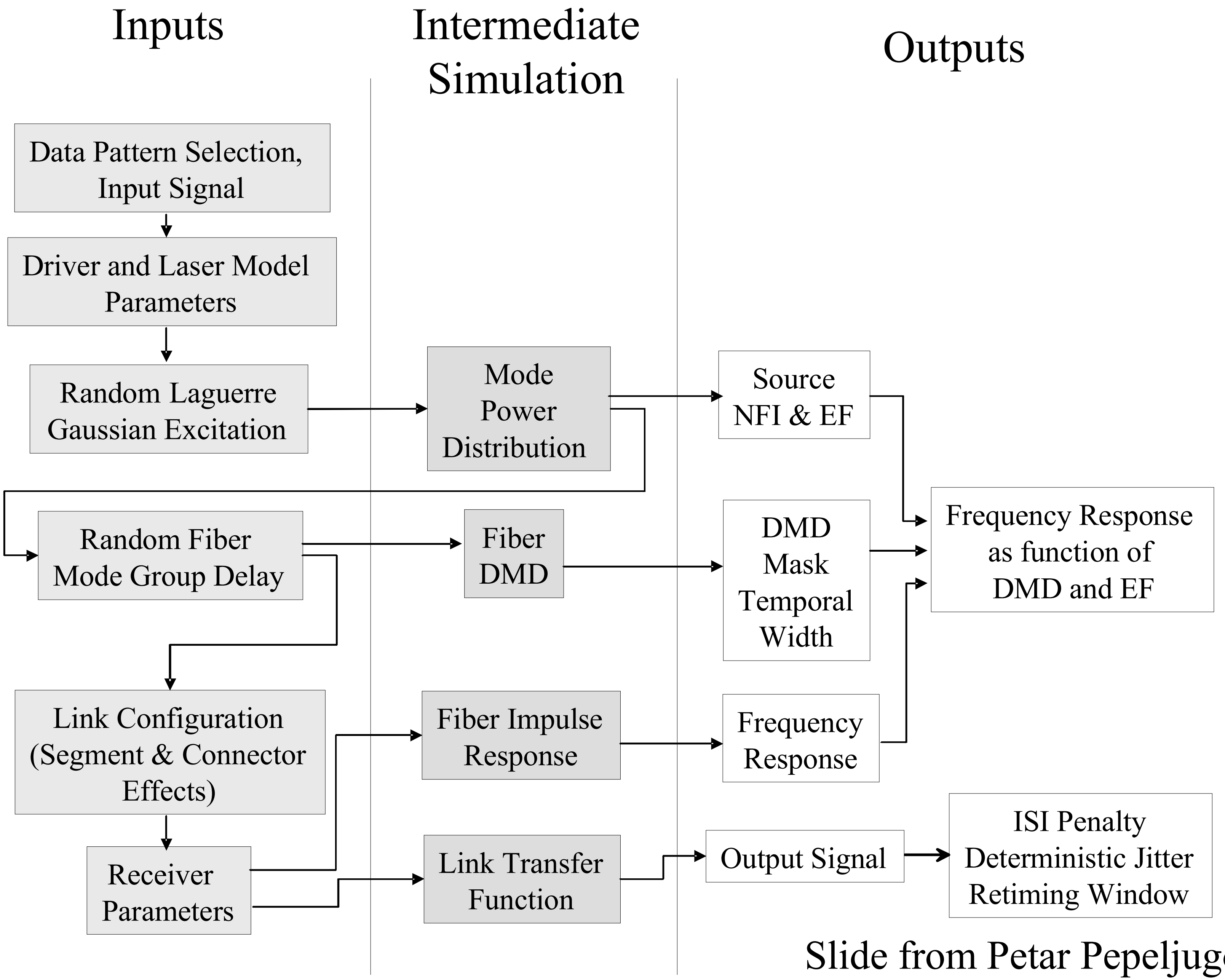



**References:**


1. Pepeljugoski et al: "Modeling and Simulation of Next Generation Multimode Fiber Links", IEEE JLT, May 2003
2. Pepeljugoski et al: "Development of System Specification for Laser-Optimized 50 mm Multimode Fiber for Multigigabit Short Wavelength LANs", IEEE JLT, May 2003


Slide from Petar Pepeljugoski

# Simulation Block Diagram

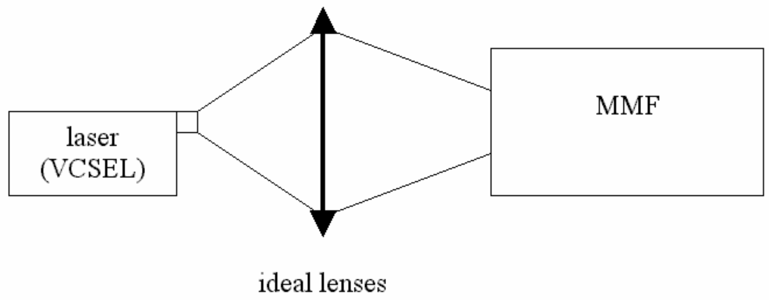



Slide from Petar Pepeljugoski

# Laser-Fiber Interaction

Laser mode $l_l$, $q_l$ is coupled into fiber mode $l_f$, $q_f$ (overlap integral):

$$c_{l_l,q_l;l_f,q_f} = \int_A E^*_{l_l,q_l}\, \psi_{l_f,q_f}\, dA$$




Modal power distribution (MPD) of the mode group with $PMN = i = 2q_l + l_l + 1$

$$MPD(i) = \sum_{q_l,l_l} S(l_l, q_l) \left( \sum_{\substack{q_f,l_f \\ 2q_f+l_f+1=i}} | c_{l_f,q_f;l_f,q_f} |^2 \right)$$

$S(l_l, q_l)$ is the power coefficient of laser mode $l_l$, $q_l$

**From here we have the Mode Power Distribution (MPD) in the fiber for fiber transfer function calculation**

Slide from Petar Pepeljugoski

# Fiber Connector Degradations

- Connector offset introduces mode mixing, attenuation
- Connector model uses connector transfer matrix $C_{PMN}$ – calculated using overlap integral:

$$\mathbf{MPD}_2 = \mathbf{MPD}_1 \times \mathbf{C}_{PMN}$$

- $\mathbf{C}_{PMN}$ is diagonal matrix for perfect alignment, MPD does not change

Slide from Petar Pepeljugoski

# Computation of the Connector Transfer Matrix

1. Find coupling coefficient between modes of two fibers:

$$c_{l_1,q_1;l_2,q_2} = \int_A \psi^*_{l_1,q_1} \psi_{l_2,q_2} \, dA$$

2. Find elements of the connector matrix

$$C_{PMN}(i,j) = \frac{1}{j} \sum_{\substack{1 \\ 2q_1+l_1+1=i}}^{M} \; \sum_{\substack{1 \\ 2q_2+l_2+1=j}}^{M} | c_{l_1,q_1;l_2,q_2} |^2$$

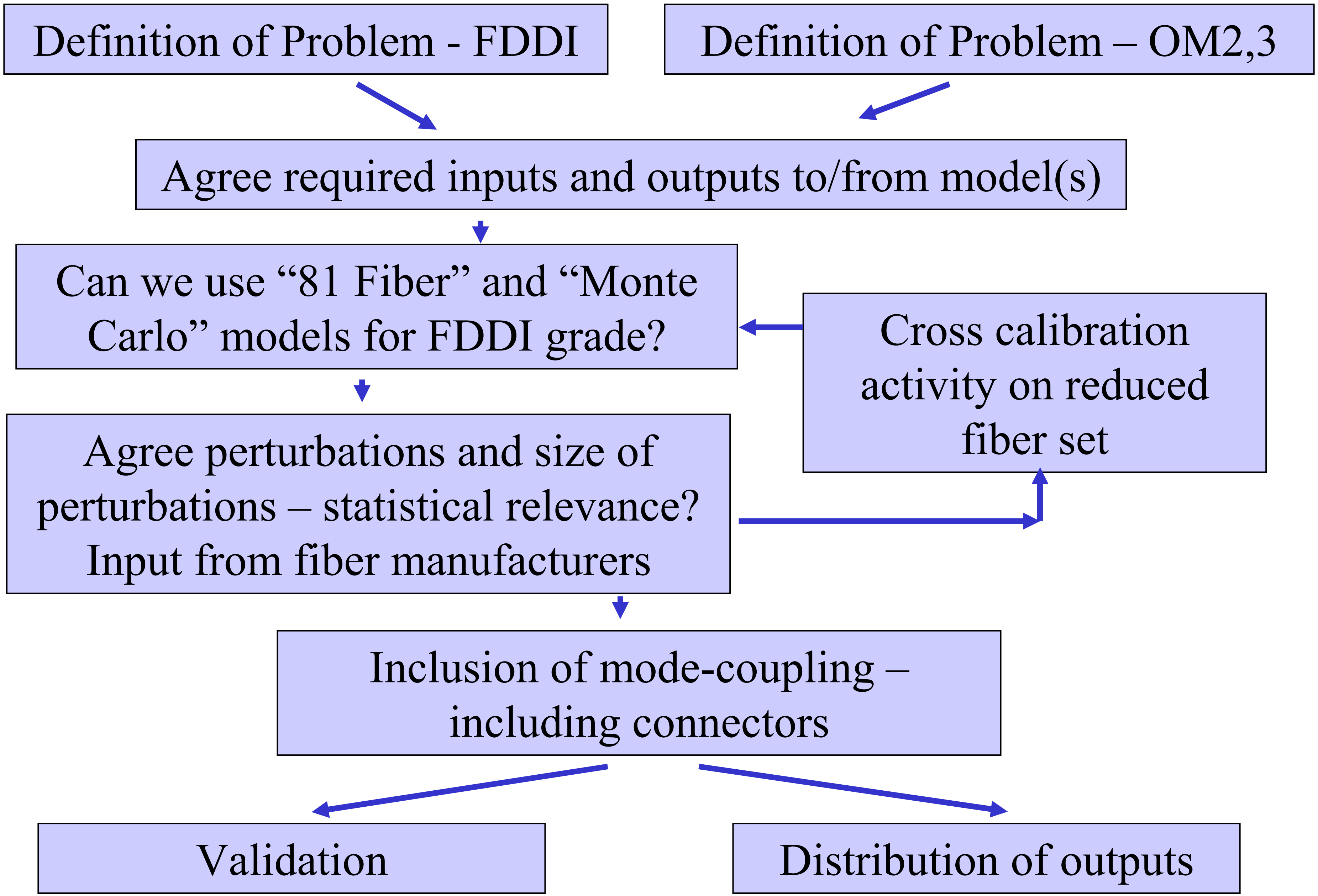
MPD in receiving fiber:

$$MPD_2(j) = \sum_{i=1}^{N_{\max}} MPD_1(i) C_{PMN}(i,j), \quad j = 1, 2, \ldots, N_{\max}$$

**From here we have the Connector Transfer Matrix to take into account mode mixing at connectors**

Slide from Petar Pepeljugoski

# Suggested Flow Chart for Task 1 Activities



# Rationale to Methodology

- Currently propose to move forward with both 81 fiber and Monte Carlo models
  - Similar approaches based on fiber modal delay sets, but with different approaches to perturbations
- 81 fiber model gives reduced “worst case” 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
- Reduced fiber set can be employed by users to do first pass designs and then use full Monte Carlo set for final design set
- Allows flexibility from the user perspective
- But requires cross-validation to check that fiber sets show appropriately similar statistics

# DMD Information

- Enhancement of initial 62.5 μm fiber model may be required based on new DMD data from fiber manufacturers.
- Data shows existence of perturbations such as:
  1. variation in the radial width of perturbations at the core center,
  2. central perturbation complexity such as index peaks surrounding a dip,
  3. central defect in otherwise near-perfect profile,
  4. mid-radial α (power-law) shifts occurring at a variety of radial positions,
  5. multiple α shifts along the mid-radial region,
  6. abrupt changes in α over a very short radial interval (“kinks”) occurring at various mid-radial positions

Slide from Paul Kolesar

# Recommendations from FO-4.1.2 to Enhance Cambridge Model

- Extract group delays from these DMD plots
- Include representative delay sets in model if not already present
- Re-examine core-clad perturbations
  - Magnitude of high order DMD overly dominant
- Scale all delay sets to 500 MHz-km OFL BW without limiting DMD to 2 ps/m
  - Scaling uniformly may not produce delay sets representative of observed fibers
  - Examine other scaling approaches, such as scaling as a function of local index delta

Slide from Paul Kolesar

# Suggested Timelines for Task 1 Activities - FDDI

| | |
| --- | --- |
| Definition of Problem – FDDI, OM2,3 | Completed |
| Agree required outputs | Completed |
| First Pass Methodology | Completed |
| ← Plenary meeting (July) | |
| Input on FDDI DMDs from Fiber Manufacturers | Mid July |
| Refine perturbation assumptions for two models – 1st pass data sets supplied to ad hoc | End July |
| Test fiber coupling approach | End Aug |
| Test perturbation approach – refine if necessary | Mid Sept |
| Adopt static channel model(s) | ← Interim (Sept) |
| Contingency | ← Plenary (Nov) |