Tools for Design, Analysis, and Simulation of Multimode Data Communication Systems

Brent K. Whitlock
Gary Shaulov

RSoft Design Group, Inc.
200 Executive Blvd.
Ossining, NY 10562

www.rsoftdesign.com

Introduction - Background

- TIA standards development for laser optimized multimode fiber (TIA/EIA-492AAAC) required new modeling and simulation approaches
  - P. Pepeljugoski, S.E. Golowich, A.J. Ritger, P. Kolesar, A. Risteski, "Modeling and simulation of next-generation multimode fiber links," *Journal of Lightwave Technology*, Vol. 21, No. 5, May 2003
- RSoft Design Group, recognizing industry need for commercially available and supported tools providing these capabilities, participated in TIA working group on modal dependence of multimode fiber bandwidth since 2001 and developed tools to address industry needs
- These tools have been validated and are now used by industry
- This work has been supported by a U.S. Navy SBIR contract (through Gair Brown of the Naval Surface Warfare Center Dahlgren Division) and a NIST ATP contract (through the PCAD Consortium)
- RSoft is committed to serving the industry in modeling and simulation of optical communication systems and components, including research, standards activities, and proprietary development

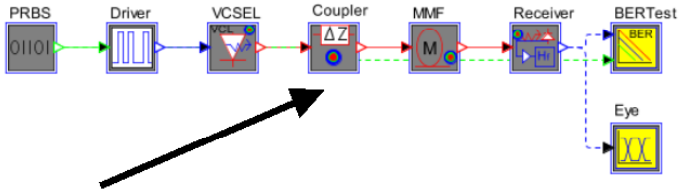
Multimode Modeling Requirements

- Model and simulate spatial characteristics of multimode fiber
  - Modal and chromatic dispersion
  - Differential mode delay (DMD)
  - Mode coupling coefficients
  - Mode power distribution (MPD)
  - Polarization
- Model modal fields as well as transient responses of multimode components
- Model 3 dimensional launch conditions into and out of fiber
  - X, y, z offsets, angular offsets, plus polarization
- Model and simulate encircled flux (EF)
- Model and simulate effective modal bandwidth (EMB)
- System simulation to also flexibly and accurately model other system components including lasers and receivers taking transient behavior, nonlinearities, and noise into account
- Take temporal and modal characteristics into account for total system simulation performance including signal to noise ratio, BER, signal waveforms, eye diagrams, power penalties, etc.

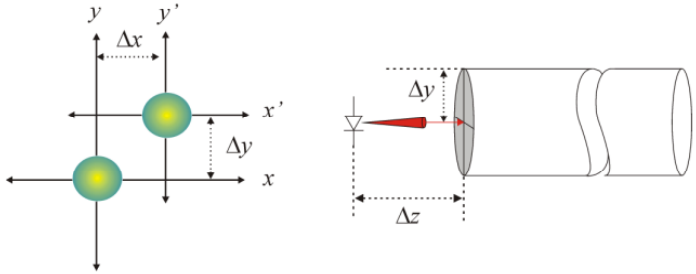
ModeSYS™ Simulation Tool

- Inclusion of spatial effects in multimode models within a system-level simulation framework
- Signal representation includes both temporal (waveforms) and spatial (modes) characteristics
- Component models for system components including pattern generators, laser drivers, lasers, multimode fiber, electrical and optical filters, receivers, BER tester, analyzers, etc.
- Can optionally be tightly integrated with *OptSim*™ simulation tool adding hundreds of component models for a wide range of applications including WDM, CATV, FTTx, solitons, Raman and EDFA amplified systems, etc.
- Interfaces also provided for device-level tools for waveguide and filter design and simulation (e.g. *BeamPROP*™ and *GratingMOD*™) as well as MATLAB® for custom model development and results analysis
- General approach allows parameters to be easily varied, scanned, and optimized while also taking statistical variations into account

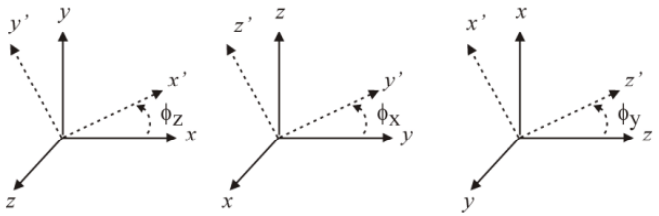
Spatial Simulation Example

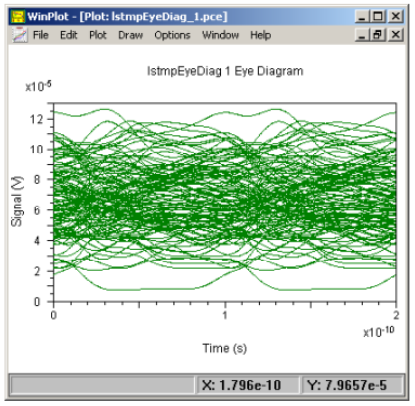


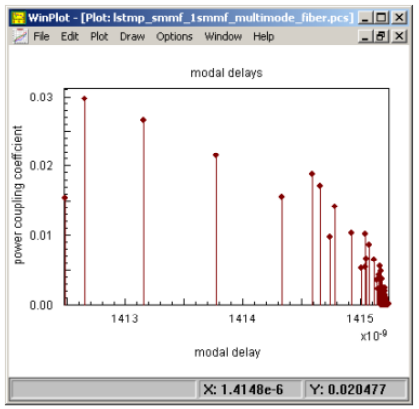
Coupler models impact of translation (Δx, Δy, Δz)

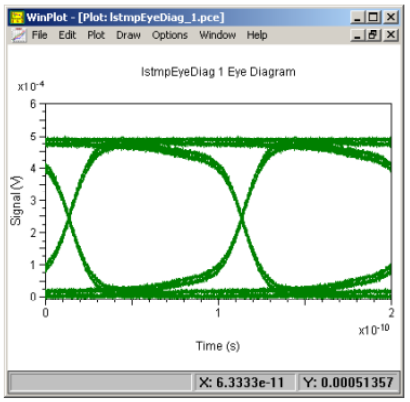


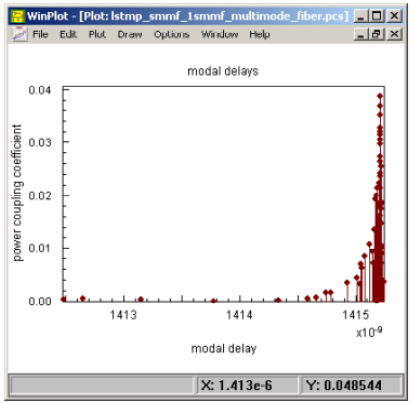
Also models effects of rotation (ϕ_x, ϕ_y, ϕ_z)







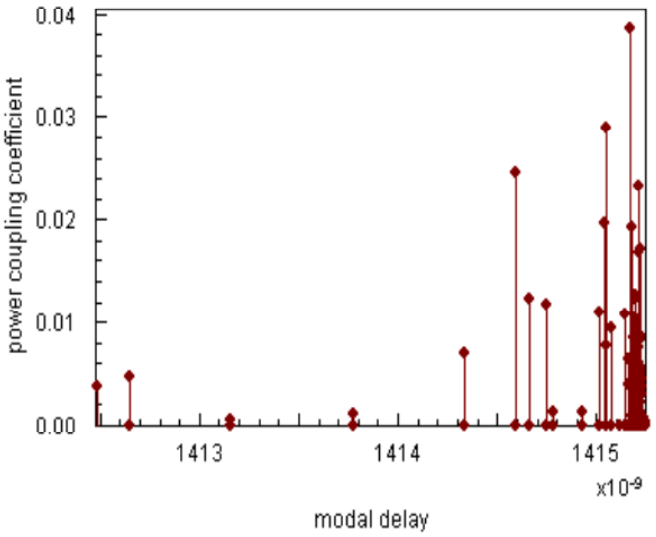




Temporal: 10 Gb/s, 1 mW, PRBS signal Spatial: Gaussian beam, 2.5 μm waist, radial offsets of 20 μm (bottom) and 25 μm (top), 50 μm parabolic index multimode fiber

Multimode Fiber Model

Modal Delays

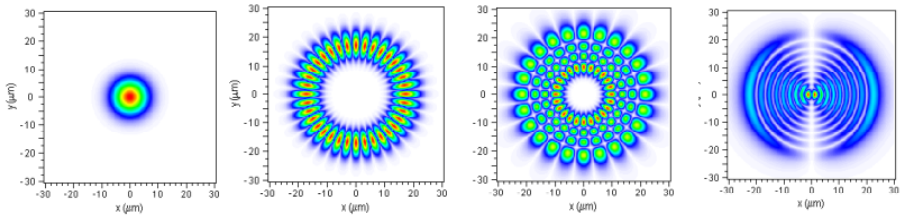


Coupling Coefficients

$$E_{input}(x,y) = \sum_{i=1}^{n} c_i E_i(x,y)$$

$$c_i = \iint E_{input}(x,y) E_i^*(x,y) dxdy$$

Representative Fiber Modes



- Fiber refractive index profile used to accurately calculate modes and delays
- Index profile can be defined analytically, by numerical file, by functional representation, or by device library
- Both modal and chromatic dispersion are modeled
- Mode power distribution (MPD) calculated through overlap integration
- Helmholtz equation solved numerically by simulator

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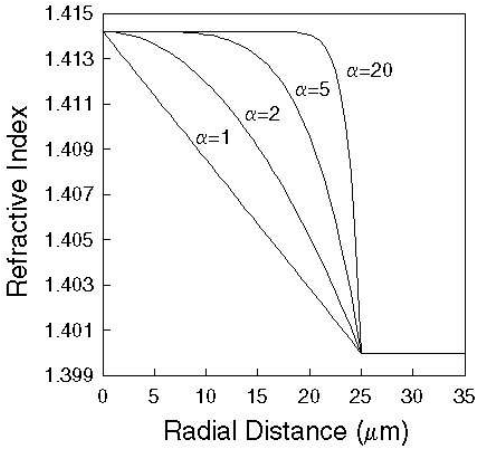
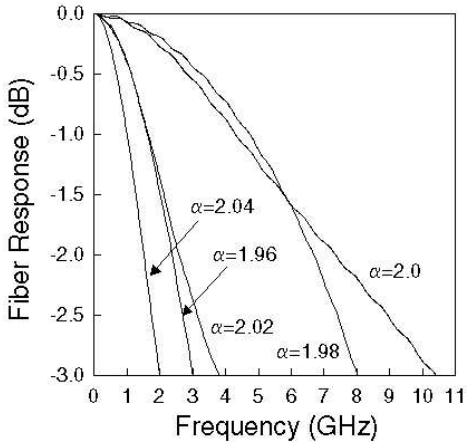
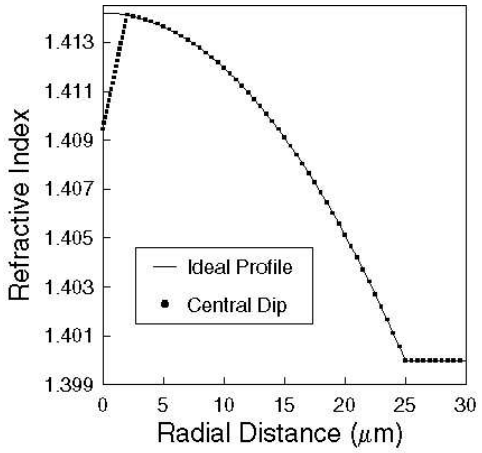
System-Level Studies of Index Variations

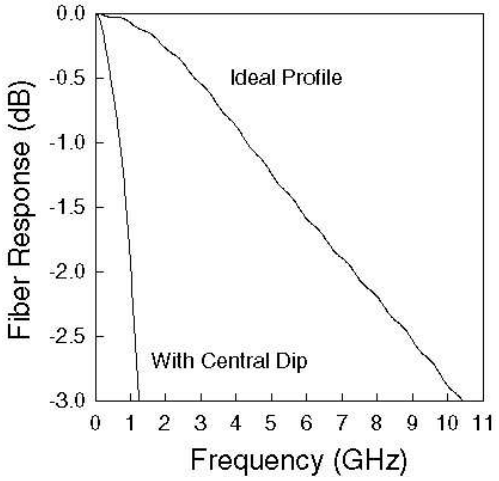




$$n^2(r) = n_1^2\left[1 - 2\Delta\left(\frac{r}{a}\right)^{\alpha}\right]$$

- As $\alpha \to \infty$, step index profile
- $\alpha = 2$: truncated parabolic profile
- 3 dB frequency strong function of α
- $\alpha = 2$ shown to be optimal





- Some manufacturing processes can cause distortions in refractive index profile
- *Central dip* distortion occurs at center of parabolic index profile
- Index profile n(r) can be specified as an explicit function or data file
- System bandwidth seen to be dramatic function of index quality

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Summary

- *ModeSYS* combines the detail of device simulation with the flexibility and efficiency of system simulation
- Spatial models include multimode lasers and fibers, detectors, couplers, lenses, and analysis tools
- Industry-standard measurements such as DMD and EF are supported
- Supports simulation of multimode fiber with arbitrary index profiles and index perturbations
- Supports simulation of arbitrary launch conditions with arbitrary modal fields
- Simulation outputs include DMD, EF, EMB, signal waveforms/eye diagrams, signal spectra, mode profiles, BER, and more
- Simulation and design capabilities supporting standards development work and proprietary system development made available to industry through commercially available and supported software

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