

Design of Fiber Amplifiers & Lasers

Fiber Amplifier and Laser Simulation

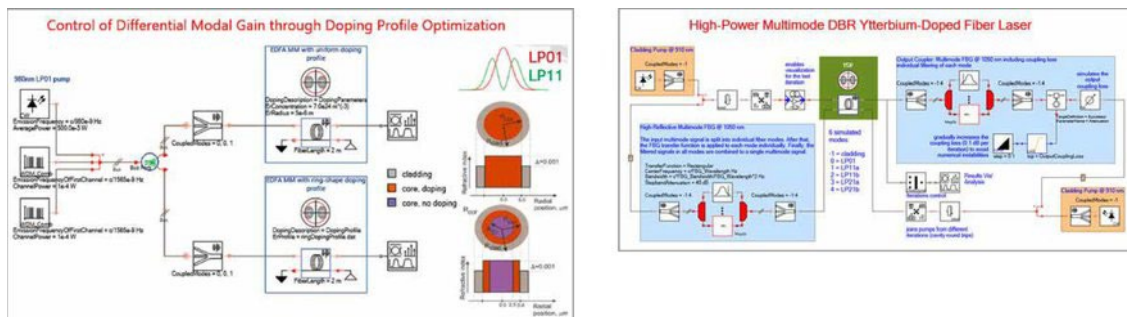
Design of Fiber Amplifiers & Lasers

Keysight Fiber Amplifier and Laser Simulation (VPIcomponentMaker Fiber Optics) is an R&D tool for modeling, optimization, and design of single-mode and multimode fiber-based optical devices such as doped-fiber, Raman and parametric amplifiers, CW and pulsed optical fiber sources, multimode amplifiers for SDM, optical signal processing for telecommunication, high-power and ultrafast applications.

The signal and noise models based on single- and multimode, full-wave and parameterized representations are ideally suited for efficient analysis. The stationary and dynamic Er/Yb/Tm- or co-doped fiber and waveguide models calculate the fiber modes and simulate signal amplification, noise generation, and higher-order limiting effects in configurations with single-mode or multimode signals and pumps, core- or cladding pumping at single or multiple wavelengths. The undoped fiber model simulates linear and nonlinear optical effects due to chromatic dispersion and PMD, Kerr nonlinearity, Raman, Brillouin and Rayleigh scattering.

Based on elementary building blocks, simple and sophisticated amplifier and laser topologies including active and passive components, signal monitors, control elements and feedback loops can be defined by the user. The general optimization capabilities can be combined with specialized heuristic and deterministic algorithms. Virtual instrumentation provides versatile means to characterize the designed equipment.

Benefits



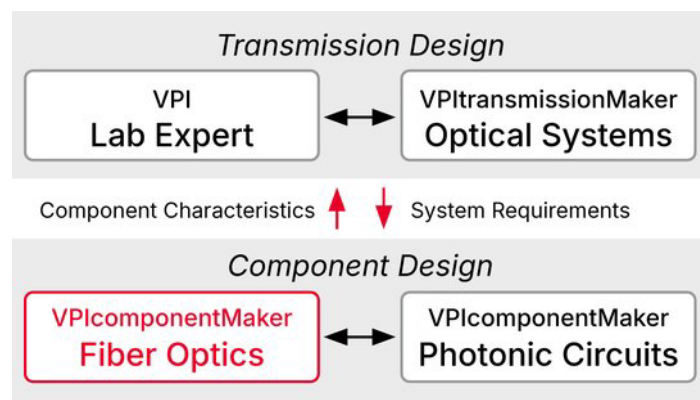
- Design fiber-based lasers, amplifiers and optical signal-processing schemes
- Modulate ultrafast phenomena in optical fibers
- Professional simulation environment with powerful optimization and automation capabilities
- Identify the impact of different physical effects in your designs
- Reduce the need for physical experimentation in the lab
- Increase productivity of R&D work by identifying critical parameters and design flaws
- Improve communication between members of collaborative projects & through the supply chain

Keysight Photonic Simulation Environment (VPIphotonics Design Suite)

VPIphotonics Design Suite embeds expert knowledge in one shared, flexible software environment to support requirements in design, analysis and optimization, providing the most powerful numerical algorithms as a professional solution for Photonic Design Automation (PDA). Beside *VPIcomponentMaker Fiber Optics* the suite includes:

- Optical Transmission System Simulation (VPItransmissionMaker Optical Systems)
- Photonic Integrated Circuit Simulation (VPIcomponentMaker Photonic Circuits)
- Test Signal Generation and Analysis (VPIlabExpert)

VPIphotonics Design Suite



Applications

- Design and optimize lasers and amplifiers based on doped and undoped fibers
- Prototype power boosters, in-line amplifiers and preamplifiers in **C-, L- and S-bands** for telecommunications
- Develop **high-power** large-mode-area cladding-pumped fiber lasers and amplifiers
- Investigate different design concepts for **multimode** doped fiber amplifiers in **SDM applications**
- Study and optimize diverse **multistage, multiband and multipass** amplifier designs
- Perform spectral **gain flattening** with Gain Equalization Filters (GEF)
- Suppress **power transients** by dynamic electrical or optical gain control schemes
- Minimize **differential modal gain** by optimizing fiber design and pump configuration
- Design **co-doped waveguide amplifiers** from waveguide dimensions upwards
- Assess implementation options for **Raman amplifiers and lasers**
- Investigate and optimize bidirectional **Raman multi-pump** configurations
- Develop cascaded **Raman** amplifiers and lasers with **higher-order pumping**

- Realize phase-sensitive and phase-insensitive **parametric fiber amplifiers**
- Study implementation options for continuous-wave and Q-switched **pulsed fiber lasers**
- Investigate implementation options and behavior of active and passive **mode-locking** schemes in fiber lasers
- Generate and propagate **ultrashort pulses** in nonlinear dispersive fibers
- Study applications based on **soliton** effects
- Investigate physical processes leading to **super-continuum** generation
- Perform **optical signal processing** based on nonlinear effects in fibers

Features

Signal Models

- Full-wave and parameterized signal and noise models supporting a single and multiple spatial fiber modes

Doped Fibers

- Steady-state and dynamic Er/Yb/Tm-doped fiber models
- Embedded single- and multimode-capable mode solver
- Single- and multimode propagation models spatially resolved in transversal and longitudinal directions, fast overlap approximation-based models
- Core- and cladding, single- and multimode pumping in normal, few-mode, and large-mode-area fibers
- Giles and cross-sections fiber parameters
- Conversion to a rapid blackbox model
- Spectral-Hole Burning, Concentration Quenching, Excited State Absorption
- Rayleigh backscattering and background loss
- State of polarization for ASE and signals
- Temperature dependence of amplifier gain
- Kerr Nonlinearity

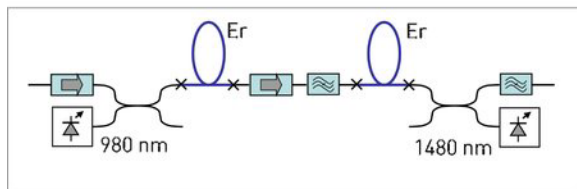
Undoped Fibers

- Linear effects: chromatic dispersion, PMD, and Rayleigh scattering
- Nonlinear effects: Kerr nonlinearity, Raman, and Brillouin scattering
- Polarization-averaged and polarization-resolved modeling options
- Bidirectional signal/pump/noise propagation in multiple fiber spans
- Fiber splices defined by OTDR data or fiber parameters
- Multidimensional constrained optimization of Raman pump wavelengths and powers

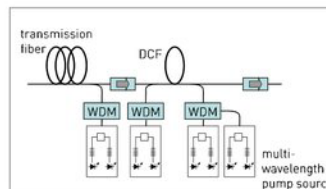
Specialist Instrumentation

- Test sets for measuring gain, noise and power characteristics of amplifiers
- Post-processing and visualization of signals in time and frequency domain, including waveforms, phase and magnitude characteristics, polarization properties, filtering, fitting, etc.

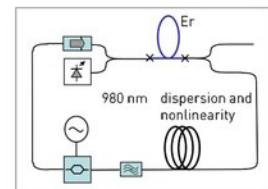
Two-Stage EDFA



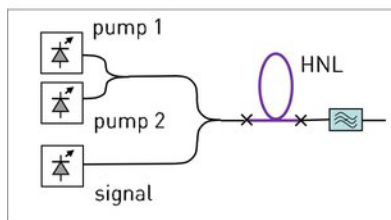
Raman Amplifier



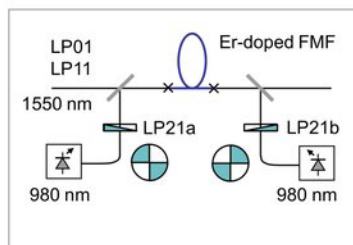
Mode-Locked Laser



Parametric Amplifier

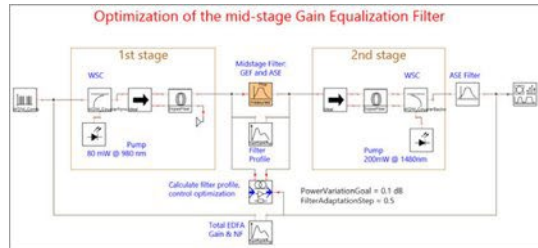
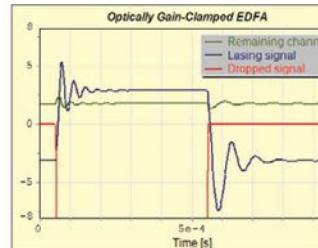
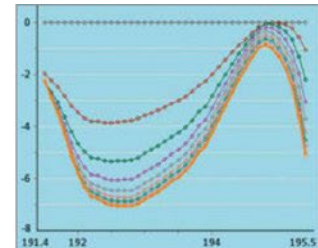


Multimode EDFA



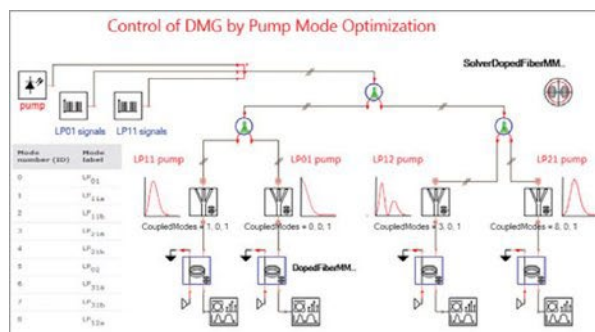
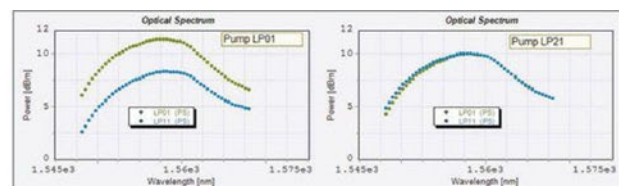
Design Examples

Single-Mode Doped-Fiber Amplifiers



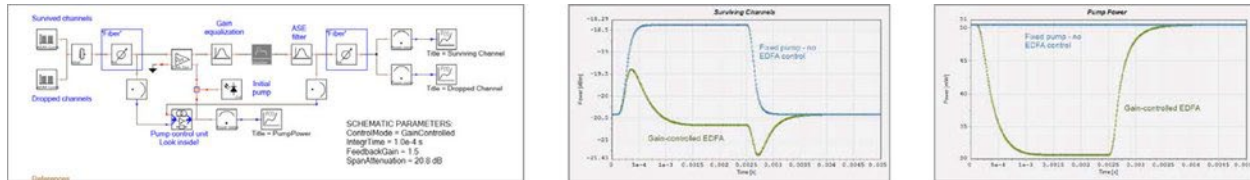
- Design of multistage Er-, Yb-, Tm-, or co-doped, cladding- or core-pumped amplifiers
- Seamless integration with *VPItransmissionMaker Optical Systems* simulations without modification of the amplifier schematic, or by abstraction the amplifier design to a black-box model
- ESA, SHB, temperature dependence, concentration quenching, Kerr nonlinearities, Rayleigh scattering, fiber-end loss/reflections

Multimode Doped-Fiber Amplifiers for SDM



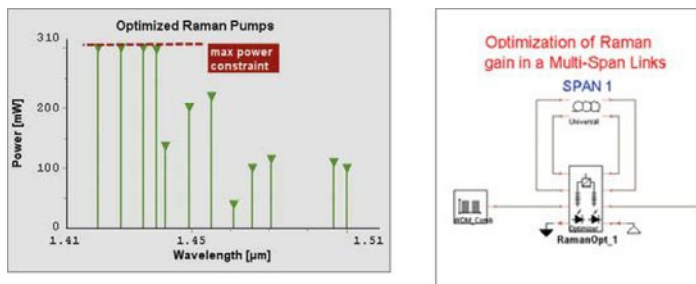
- Multimode amplifier design, embedded mode solver, two-level description of Er-, Yb-, or Tm- ions
- Mitigation of the Differential Modal Gain (DMG) for Space-Division Multiplexing (SDM) applications
- Spatially resolved model in both transversal and longitudinal directions, bidirectional propagation of signals and pumps, mode coupling, visualization of the modal fields and inversion

Dynamic EDFA Simulations



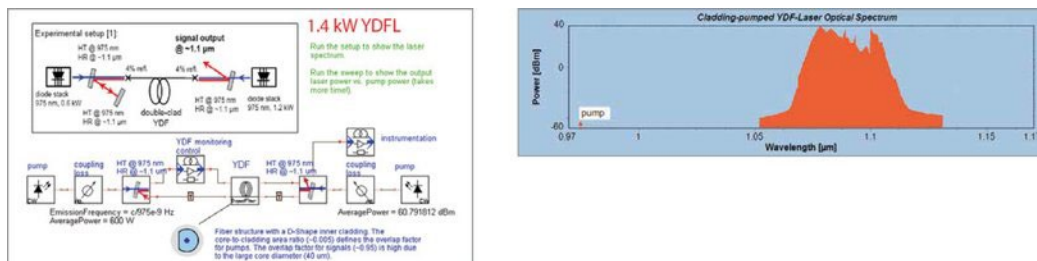
- Analysis of power transients in a mesh network caused by the network reconfiguration, packet switching, cable damage, etc. using dynamic amplifier models
- Design of the amplifier control circuitry to mitigate power cross-talk between WDM channels and to diminish transient response
- Estimation of requirements for various network elements to operate in nonstationary power conditions

Multipump Raman Amplifiers



- Advanced fiber model for design of Raman amplifiers
- Supports bidirectional interactions between the pumps, noise and signals, reflections and scattering along the fiber length
- A robust optimizer finds the optimum Raman pump wavelengths and powers to achieve the best fit to the amplification goal, taking various optimization constraints into account

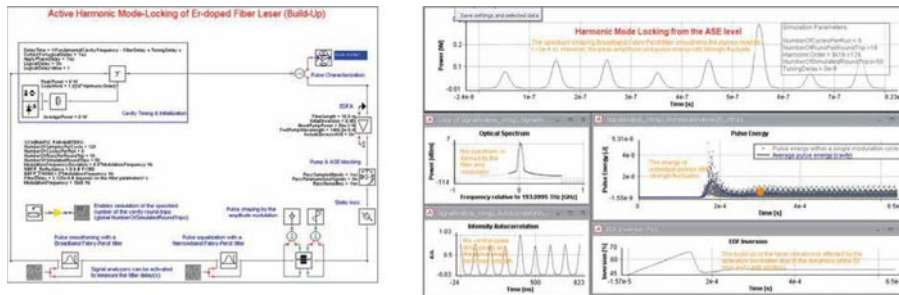
High-Power Fiber Lasers



- Simulation of high-power fiber lasers using single-mode or multimode cladding-pumped large-core doped fibers

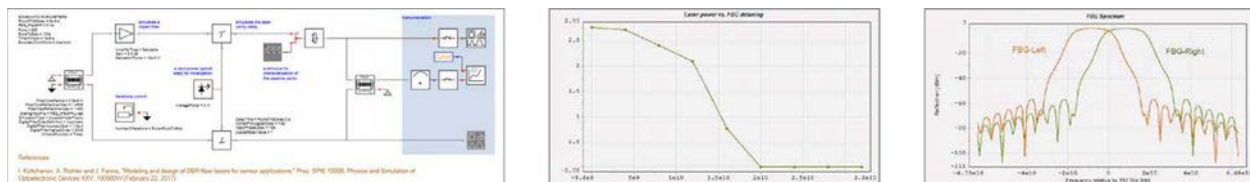
- Model library for various building blocks of the laser cavities like FBG-based reflectors, couplers, isolators, polarization components
- Virtual instrumentation to measure various amplifier characteristics, for example, gain and noise spectra, power conversion efficiency, etc.

Pulsed Fiber Lasers



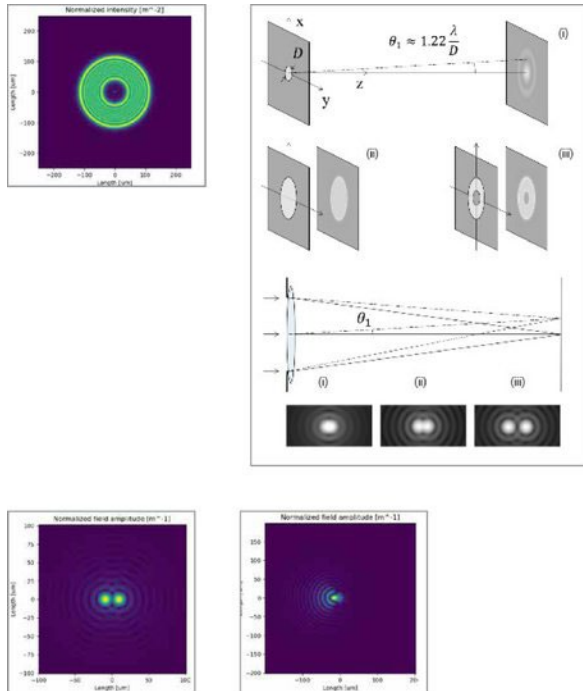
- Generation of short optical pulses using active or passive mode locking, or Q-switching
- Simulation of the radiation build-up from the ASE noise, and of various pulse shaping mechanisms
- Advanced virtual instrumentation to measure and visualize pulse shape, chirp, spectrum, intensity or field autocorrelation function

DBR Fiber Laser for Sensor



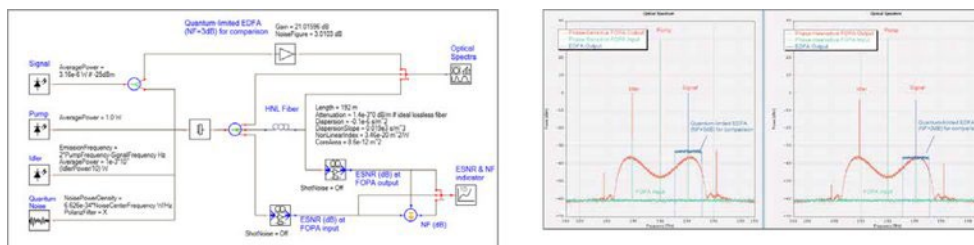
- Modeling DBR fiber laser sensors in the time domain using iterative approach to represent thousands of light round trips in the laser cavity
- Dynamic doped fiber model describes the amplifying medium
- FBG design addresses the trade-off between FBG length, reflectivity and high spectral selectivity; the automated design of digital filters accurately reproduces the grating spectra in the time domain

Diffraction and Aberrations in Imaging Systems



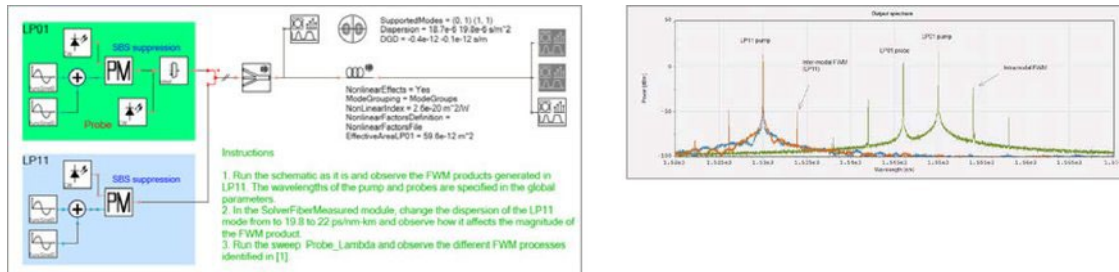
- Modeling free space propagation between fibers and lasers, for example, to design fiber launch systems
- Using Fourier Optics (FO) methods to model imaging systems with lenses, apertures and Spatial Light Modulators (SLM)
- Taking into account diffraction and aberration effects

Fiber-Optic Parametric Amplifiers (FOPA)



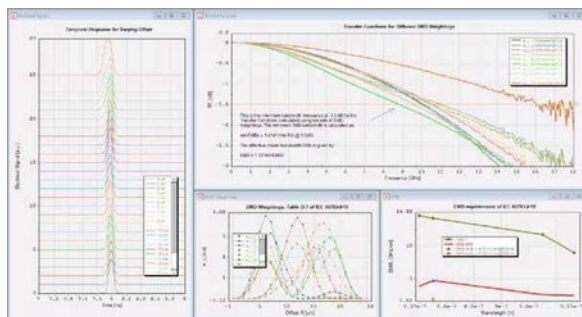
- Simulations of phase-sensitive and phase-insensitive Fiber-Optic Parametric Amplifiers (FOPA) using Highly Nonlinear Fibers (HNL)
- An advanced fiber model takes into account chromatic dispersion, Kerr nonlinearity, PMD, and other effects
- Virtual measurement of gain and noise figure

Intermodal Four-Wave Mixing in Few-Mode Fibers



- An advanced multimode fiber model can simulate the intra-modal and intermodal nonlinear effects such as Four-Wave Mixing (FWM) or Cross-Phase Modulation (XPM), in addition to the conventional linear effects
- An embedded mode solver can calculate the linear and nonlinear fiber parameters required for the propagation model from details of the fiber design

Design and Characterization of GI-Multimode Fibers



- An advanced multimode fiber model and various test benches to design and characterize the graded-index multimode fibers for short-range applications, such as OM3, OM4, OM5
- The virtual test benches follow the standardized IEC test methods to measure DMD, EMBc, OMB, and Dispersion characteristics

Arbitrary wavelength-dependent transverse refractive index profiles can be specified to support optimization of the doping distribution during the fiber design

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