VPIsystems Industry Training Program on Computer-Aided Design of Fiber-optic Communication Systems

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ABSTRACT

In industry today, professional Photonic Design Automation (PDA) tools are a necessity to enable fast development cycles for the design of optical components, systems and networks. The training of industrial personnel is of great importance in facilitating the full usability of PDA tools tailored to meet these demands. As the market leader of design and planning tools for system integrators and manufacturers of optical transmission systems and components, VPIsystems offers a set of two-day training courses. Attendees are taught on the design of metro WDM networks, high-speed DWDM and ultra long-haul WDM systems, analogue and digital cable access systems, EDFA and Raman amplifiers, as well as active devices and circuits. The course work compromises of: (1) lectures on physical and modeling background topics; (2) creation of typical simulation scenarios and; (3) the analysis of results. This course work is facilitated by guided, hands-on lab exercises using VPIsystems software for a variety of practical design situations. In classes of up to 15, each attendee is allocated a computer, thereby allowing for a thorough and speedy training for the individual in all of the covered topics as well as for any extra-curriculum topics to be covered. Since 1999, more then 750 people have graduated from over 60 training courses. In this paper, details of VPIsystems Industry training program will be presented.

Keywords: Professional industry training program, continuing education and training, training using computer-aided design tools, photonics, CAD, optical communications, photonic design automation

1. INTRODUCTION

Until the late 1980s, optical communications systems were mainly limited by fiber loss and dispersion, and the performance of the transmitter and receiver units[1]. There was no stringent need for extensive computer simulations. However, with the advent of optical amplifiers, which enabled high signal powers and long unregenerated fiber spans, fiber nonlinearities have a far more significant effect, which cannot be approximated with simplified analytical calculations for system level design[2]. In addition, modern high-speed WDM systems may suffer severely from polarization dependent propagation effects such as polarization mode dispersion (PMD). These new phenomena have necessitated the need for extensive numerical modeling when designing optical communication systems.

Furthermore, new problems have arisen requiring further computer-aided design (CAD) algorithms and features. An example is in the design of components for dense WDM systems, with tens to hundreds of channels. With the decreased channel spacing these systems are now operating with new, sophisticated modulation techniques, and optical filter designs for wavelength multiplexers and demultiplexers become crucial for overall system performance. The system to be designed could cost hundreds of millions of dollars: in comparison, the individual components could cost only tens of dollars. It would be far too expensive to develop and optimize every component by testing it within the complete system. Also, it would take a considerable amount of time to optimize components' design by developing a series of prototypes. However, the telecommunications industry is demanding rapid improvements and lower costs.

Considering today's design constraints, new design methods must be found[3]. An attractive approach is to employ computer-aided design and optimization to carefully model the photonic system before performing laboratory experiments and field trials. The designer is faced with a huge design space, which can only be reduced by analytical approximations and computer modeling using powerful simulation tools. This would also replace several manufacturing cycles of hardware prototypes, which brings with it time and cost savings. Modern PDA tools, which are capable of

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accurately reproducing the behavior of real systems and components, can provide a feasible substitute to real laboratory experience, without the prohibitive infrastructure and maintenance costs.

Advantages of professional PDA tools include:

- Low cost of virtual laboratory and experiments
- Flexible and easy change of system configurations
- Low maintenance effort
- Investigation of novel and innovative designs possible
- Capability of switching on and off various physical effects to provide insights
- Easy communication and documentation of software simulation setups and results
- Facility of group work, project management, class management etc.

VPIsystems has developed such PDA tools for designing and analyzing photonic devices, systems and networks. These tools offer a wide range of numerical models representing photonic devices and subsystems, which work with a set of sophisticated signal representations allowing for the modeling of a wide range of photonic systems and circuits[4]. The simulation models of components and subsystems are based on well-researched mathematical models and are solved with sophisticated numerical techniques to provide accurate and fast simulation results. Simulation results are regularly verified against published experimental results, to ensure their reliability and accuracy. Incorporated within VPIsystems PDA tools are the expert knowledge, analytic methods and design rules that are based on previous successful designs[5] as well as the rich experience of system and component specialists.

Professional CAD software tools help engineers and scientists in various industrial organizations and research establishments perform their tasks efficiently when analyzing and designing photonics systems and components. This requires the user to be competent in using the software, the applied numerical models, and photonics theory. VPIsystems offers a set of training courses, mainly for industry and research personnel, where attendees are taught on the usage of PDA tools for solving sophisticated design problems. The application of CAD software tools in the teaching of a photonics course is beneficial as it offers the possibility of the visualization and understanding of complex physical problems. In the following sections, we will describe VPIsystems CAD-assisted industry training program on the design of photonic subsystems and fiber-optic communication systems.

2. VPISYSTEMS PHOTONIC DESIGN AUTOMATION TOOLS

First, however, details about VPIsystems suite of PDA tools for the physical layer design are outlined in this section to give an idea of the range of topics in which these tools can be used to aid teaching. The four design tools are

VPItransmissionMaker™ WDM,
VPItransmissionMaker™ Cable Access,
VPIcomponentMaker™ Fiber Amplifier,
VPIcomponentMaker™ Active Photonics.

VPItransmissionMaker™ WDM is used to simulate all types of optical communication systems (WDM, TDM, soliton) at the physical level. Over 500 models of physical components and subsystems are supplied that can be assembled to form transmission links and optical networks. These modules include, for instance, optical fibers, laser sources, passive network devices (couplers, splitters, circulators, multiplexers etc), optical amplifiers, receivers, signal processing elements, and data visualizers (optical spectrum analyzers, oscilloscopes, bit-error-ratio (BER) estimators, eye diagrams etc).

VPItransmissionMaker™ Cable Access provides a specialized set of tools for the analysis and design of cable access and cable TV networks. It supports the simulation of analog, digital, mixed-analog-digital, HFC, DOCSIS and novel access technologies focused on subcarrier multiplexing. The effects of modulators, lasers, feedback, fiber dispersion and nonlinearities can be included.

VPIcomponentMaker™ Fiber Amplifier covers the specialist topic of doped-fiber, Raman and hybrid optical amplifier designs, which can be made up from many components and multiple stages. It also provides black box model abstraction and uses the latest highly sophisticated algorithms for obtaining simulation results for long amplifiers quickly and accurately.

VPIcomponentMaker™ Active Photonics simulates large-signal dynamics of multi-element photonic circuits and lasers over a wide spectral bandwidth. It includes time dependence, bidirectional interactions, dynamic effects, transient effects, and others. The design tool is used for the detailed analysis and design of transmitters, optical signal processors, wavelength converters, ultra-high speed photonics circuits and semiconductor optical amplifier applications.

As described above, the PDA tools cover a wide range of topics, which raise the demand for training. Also supplied with these tools is a wide range of application demos that help understanding the general design philosophy and show possible application scenarios. These application demos are selected for their:

- Use as templates for typical problems in well-known industry areas, like metro, long-haul and submarine WDM systems
- Ability to investigate advanced design problems such as polarization mode dispersion (PMD), optical crosstalk, spectrally-efficient modulation techniques and bidirectional Raman amplifiers
- Insight into simulation techniques and the selection of the most appropriate modules for a simulation task
- Tutorial value, both in component operation and simulation technology.

The four PDA tools described above are used to capture a design and the relationships between components and systems. They all share one graphical user interface where the various components and subsystems of a transmission scenario or photonic system may be laid out and schematically connected (see Figure 1).

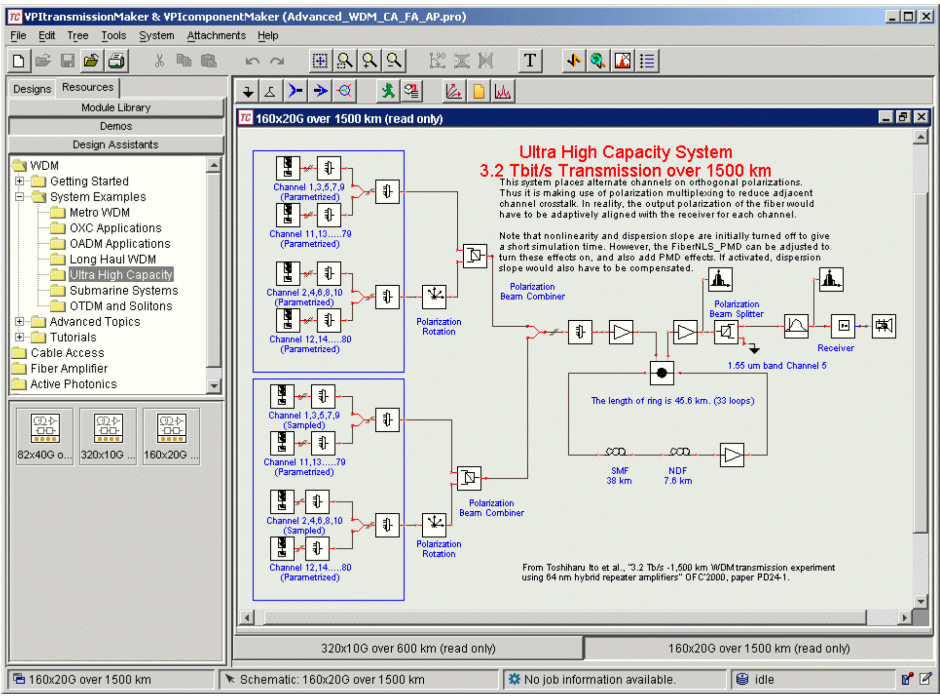

Figure 1: The VPIsystems PDA tool Graphical User Interface

Other useful features that have been incorporated into the VPIsystems PDA tools include:

- Programmable design assistants and wizards, which help to automate various tasks. Among others, this includes laying out component modules, setting up standard parameter values, laying out systems with standard topologies, carrying out standard metrics and system verification tests, and performing global component substitution.

- Parameter sweeps for assessing system sensitivity to one or more parameters, e.g., BER versus optical amplifier span length, or power penalty due to the drift in component specifications.
- Module sweeps for component comparison within a system, e.g., the effect of different amplifier designs on the overall system performance.
- An embedded scripting language to enable more sophisticated parameter sweeps and design optimization.
- The integration of third party software for greater flexibility, and the incorporation of existing, and/or proprietary, numerical component/system modules (Matlab, C++ and Python).

The schematics, designs, and data generated by the PDA tools, and any associated documents need to be managed as well. This can be done with the *VPIdesignManager*^{TM}. It is part of the *VPIdesignCenter*^{TM}, which integrates the four aforementioned PDA tools to provide a single, integrated platform that acts as an engineer's working environment (see Figure 2). *VPIdesignCenter*^{TM} enables teams of people to work collaboratively within a common framework and access all required documents and tools (PDA and other third party software) easily, in the correct context and place. Features for project management, to manage data flow, to track changes and for document versioning are also provided, which ease the coordination of activities and efforts of a large and a diverse range of personnel.

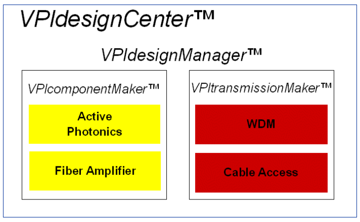

Figure 2: *VPIdesignCenter*^{TM} and its underlying tools.

3. VPIsystems INDUSTRY TRAINING PROGRAM - ACHIEVEMENTS

VPIsystems develops and runs the industry training program since February 1999. During the first two and a half years compact three-day courses were offered. They started from an introductory level education on the PDA tools and ended with sophisticated designs in all kind of applications areas during the three days. The training material is taught using a mixture of

- Technical lectures on topics of computer modeling and physical background,
- Guided tours, where the whole class is lead step-by-step through the graphical user interface and a first, very simple design.
- Practical hands-on lab exercises, where students solve a series of complex design tasks on their own. A detailed task description and solution path guide the students.

Figure 3 shows a typical agenda of the offered courses.

Tentative Agenda (I) - Getting Started

Day 1

9.00 - 9.30 Introduction
9.30 - 10.30 GUI 1 - Getting Started
10.45 - 12.00 Simple Loss-limited Transmission System (1)
12.00 - 13.00 Lunch Break
13.00 - 15.00 Dispersion Compensated 10 Gbit/s System (2)
15.15 - 17.15 Repeated TDM 40 Gbit/s System (3)
17.15 - 17.30 Scripted Simulations

Tentative Agenda (II) - Getting Hooked

Day 2

9.00 - 10.00 Software Architecture & Signal Representations
10.15 - 12.30 Optical Fiber Amplifiers and OSNR (4)
12.30 - 13.30 Lunch Break
13.30 - 16.00 WDM Systems & Fiber Nonlinearities (5)
16.00 - 16.30 GUI 2 - Design Assistants and ASCII Interfaces
16.30 - 17.30 Designing WDM Systems (6)

Tentative Agenda (III) - Getting Addicted

Day 3

9.00 - 9.15 GUI 3 - Products, Profiles and Licensing
9.15 - 12.00 Open Session I
- Advanced WDM design
- Fiber Amplifier Design
- Cosimulation

12.00 - 13.00 Lunch Break
13.00 - 16.00 Open Session II
- as in the morning

16.00 - 17.00 Extras / Closing up

Figure 3: Typical agenda of the compact three-day training course offered by VPIsystems until August 2001.

In 1999, VPIsystems organized 10 three-day training courses, where 107 engineers and researchers attended. In 2000, there were 21 courses offered. 271 engineers and researchers graduated from them. In total, there are approximately 700 engineers and researchers trained during the last three years using VPIsystems PDA software tools. The majority of the courses were held as open, invited sessions. The other courses were organized as customized onsite courses at industrial corporations or research organizations.

Engineers from well over a hundred industrial corporations and researchers from 20 universities and research organizations attended the courses, which were held in 13 different countries. The quality of the course material, the instructor capabilities and the satisfaction with the offered course content were monitored via questionnaires at the beginning and the end of the courses. Successful attendees were presented with a Certificate of Accomplishment.

Figure 4: Typical classroom setup of an open training course.

4. VPISYSTEMS INDUSTRY TRAINING PROGRAM – CURRENT OFFERINGS

Recently, we switched the course offering to a set of more flexible two-day courses. They allow better consistency of the level of experience and interest areas among the attending students. In the following, the syllabuses of these courses are described in some detail.

Introduction to Photonic Design Automation

This two-day training course is designed to teach the general functionalities of VPIsystems physical layer design software. No prerequisite knowledge about PDA tools is required. The main goal of this course is to train the students on how to efficiently build up their design problems on VPIsystems PDA tools, and interpret the simulation results. A moderate understanding of optical fiber communications systems is helpful to follow the design examples, which are used to explain the usage of the tools.

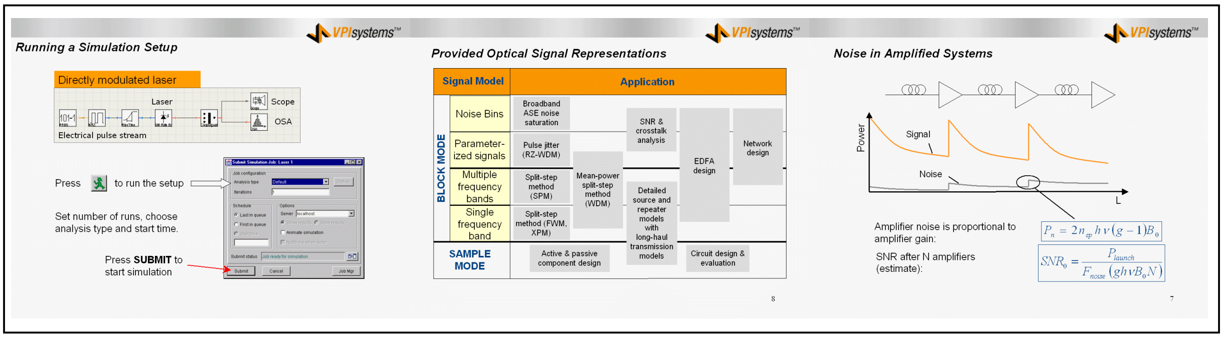

Figure 5: Exemplary lecture slides of the training course *Introduction to Photonic Design Automation*.

The course addresses the following topics

- Overview of *VPIdesignCenter*™ and its professional design tools
- Handling of the graphical user interface
- Description of available signal models and simulation techniques
- Setting up of automated parameter sweeps
- Visualization of simulation results
- Automated system design and analysis

- Survey through the application demos

Application examples focus on design of single channel and WDM transmission systems with bit rates ranging from 1 Gbit/s to 40 Gbit/s. The design examples include modeling of:

- Optical transmitters employing direct and external modulation schemes
- Direct detection optical receivers
- Fiber chromatic dispersion and possible compensation techniques
- Nonlinear fiber impairments (SPM, XPM, FWM, SRS)
- Noise accumulation and OSNR analysis
- Estimation of BER, Q-factor, eye-closure penalty

Professional WDM System Design

This two-day training course is offered to advanced PDA tool users and design engineers, who are interested to learn about professional techniques of WDM systems design. The course material and associated exercises are designed to enhance the students understanding of how complex WDM systems behave and how to evaluate all the design tradeoffs. Central to this course is a systematic design methodology, which is presented by Dr. Stephen Evangelides.

The students learn how to use VPIsystems PDA tools to quickly and accurately model complex DWDM systems. Strategies will be shown for reducing the task of evaluating designs of complex transmission lines to a series of much simpler tasks, which are less computationally intensive.

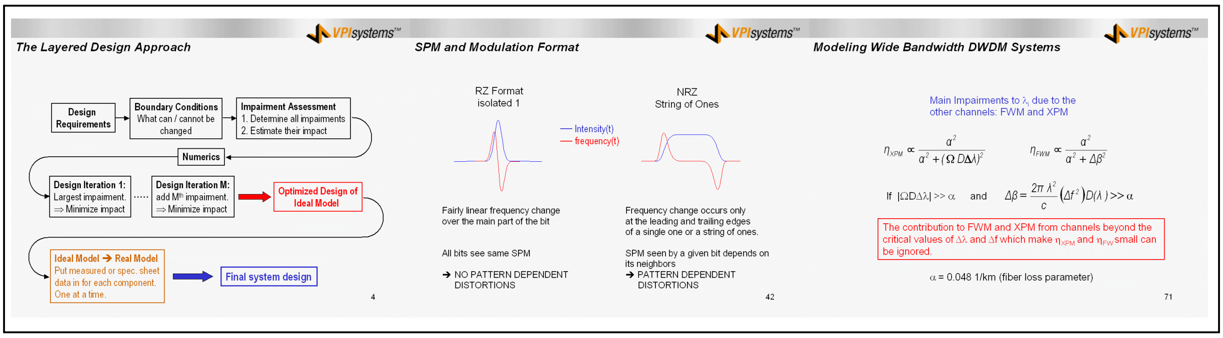

Figure 6: Exemplary lecture slides of the training course *Professional WDM System Design*.

The course covers the following topics:

- Basics of setting up a WDM system model
- Numerical considerations when determining simulation parameters
- Effects of fiber dispersion and Kerr effect on transmission fidelity
- Impact of amplifier noise, span lengths and gain shape on system performance
- Effects of PMD on system performance
- Survey of how transmitter and receiver design can effect the overall system performance

Included in the course is a series of small exercises that are designed to enhance the student's intuition about linear and nonlinear processes in the fiber. Additionally, there is a complete WDM system design exercise given to reinforce the concepts presented in the lectures. The course is appropriate for people with little of no system design experience, as well as those with experience who wish to learn more. This course is also appropriate for those who wish to evaluate the performance impact of components or subsystems on overall system performance. Basic knowledge about VPIsystems PDA tools is required. Typically, this course is given in conjunction with the aforementioned course.

Applications of Photonic Design Automation

VPIsystems also offers customized training courses, which are designed to demonstrate the broad range of applications the PDA software tools are able to model. Date, location, duration and content are flexible and can be arranged to meet individual needs. Additionally, advanced simulation techniques may be explained during these courses.

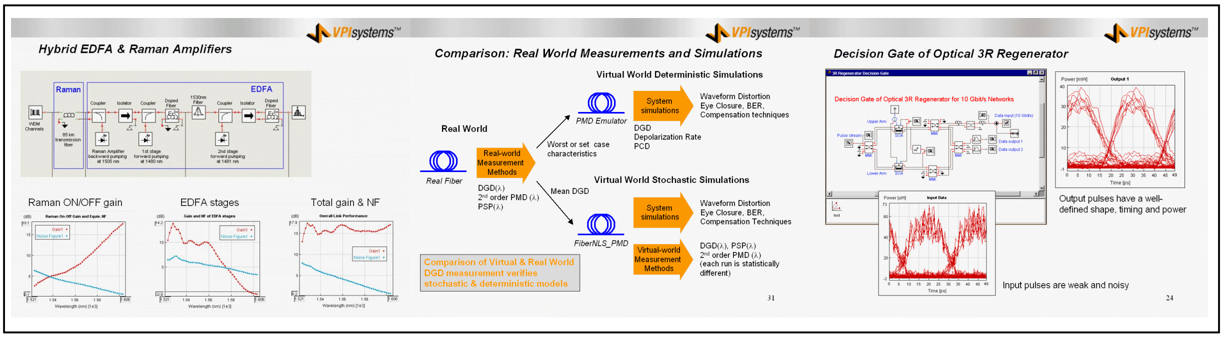

Figure 7: Example lecture slides from the training course *Applications of Photonic Design Automation*.

The following list shows topics a customized training course can be build of.

WDM subsystem and system design

- In depth investigation nonlinear fiber impairments (SPM, XPM, FWM)
- Techniques for estimating BER, Q-factor, eye-closure penalty
- Modeling of a dense WDM system design
- Modeling of PMD in high-speed transmission systems
- Design of PMD emulators and compensators
- Raman amplification in WDM systems
- Accumulation of timing jitter in long-haul RZ WDM systems
- Crosstalk in optical networking

EDFA and Raman amplifier design

- Single and multi-stage EDF amplifiers for C and L band
- Hybrid Raman/EDF amplification
- Automatic gain flattening and control

Analogue and digital system design for the cable access market

- Impairments in analogue fiber propagation
- Digital QAM Cable Access systems
- Mixed systems employing analogue CATV and digital QAM

Design of active devices and circuits

- Introduction into Laser design
- Design of 3R Regenerators
- Decision Gate of Optical 3R Regenerator
- 40 GHz All Optical Clock Recovery
- Overview of active circuits applications

Advanced Simulation Techniques / Others

- Co-simulation (integration of 3rd party source code into VPI software)
- Scripted simulations and automated system design

- ASCII Interfaces

If requested, additional topics or problems could also be covered during these customized training courses. Prerequisite knowledge about VPIsystems PDA tools is required. A moderate understanding of fiber-optic communications systems is helpful.

5. SUMMARY

It has been motivated that professional photonic design automation tools are a necessity to enable fast development cycles for the design of optical components and systems. The need for training of industrial personnel in the usability of these PDA tools has been outlined. VPIsystems offers such a CAD assisted training program. Attendees are taught in two-day courses on the design of photonic components and systems. The course work compromises of: (1) lectures on physical and modeling background topics; (2) creation of typical simulation scenarios and; (3) the analysis of results. It is facilitated by guided, hands-on lab exercises using VPIsystems software for a variety of practical design situations. The syllabuses of these courses have been presented. Since 1999, more then 700 people have graduated from courses offered in VPIsystems' industry training program.

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