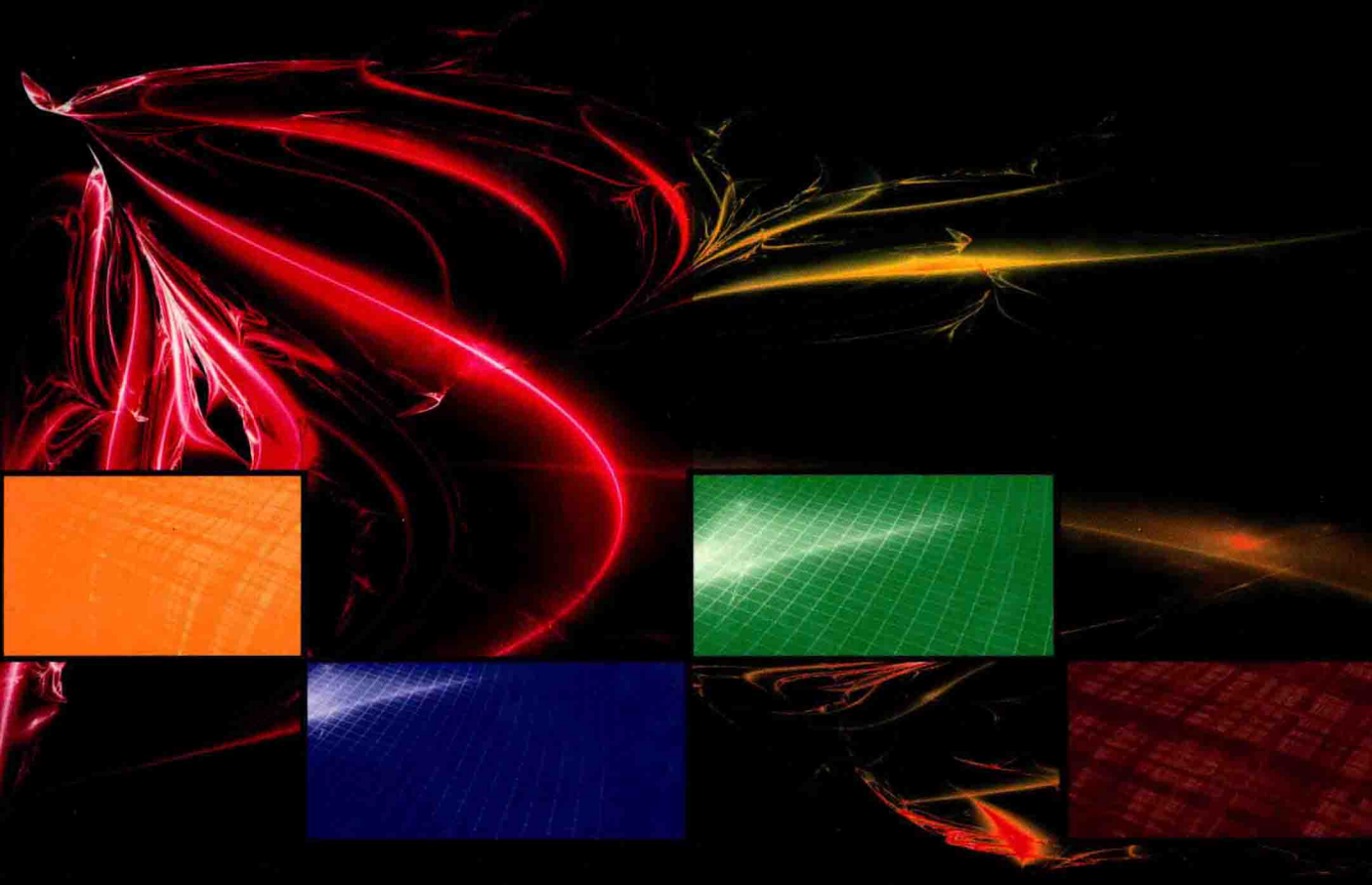
Optically Amplified WDM Networks



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For the loving memory of my mother Maya,
and to my wife Sonali, daughter Srishti and sister Sushma, with love

- Atul Srivastava

Dedicated with love to the memory of my father Professor Harold Zyskind

- John Zyskind

Foreword

Rod Alferness
Bell Labs, Alcatel-Lucent

The power of light, harnessed with an array of components to generate, modulate, manipulate, and detect it, and supported by low-loss optical fiber for transmission that ushered in a new era of information transmission systems in the 1970s, is an incredible gift to mankind. One could have hardly expected more, but—almost on queue—the invention and development of the optical amplifier in the late '80s and early '90s completed the technology suite, unleashing the full potential and power of optics for communication networks. The resulting cost-effective, robust, high-capacity optical networks, together with packet-based data networks that ride over them, enabled the world-wide web that has dramatically revolutionized our daily lives.

The global growth of WDM (wavelength division multiplexing) optical networks over the last 10 years has been remarkable. While most optical networks are generally not directly visible to the typical consumer, the very visible internet would be impossible without them. Spanning continents, crossing oceans, reaching across metropolitan areas and now also providing direct fiber to home connections, commercially deployed optical transmission systems with per fiber capacity as high as several Terabit/sec provide the enabling high-capacity connectivity that underpins the world-wide web. No longer simple point-to-point links, today's optical networks are flexible, switchable wavelength routed networks, both ring and mesh, that provide wavelength granular networked pipes inside the physical fiber with all-optical on and off ramps in much the way time slots are used in time-division-based transport networks.

None of this would be possible without the optical fiber amplifier. The optical amplifier is truly a gift of nature that is as close to ideal as one could expect. It is spectrally matched to fiber's low-loss window and provides highly efficient, broadband, low noise gain. Critical for its enabling of WDM, it has a temporal response that allows essentially unlimited signal data rates while allowing multiple wavelengths to be amplified without cross-talk between independent communication signals carried by neighboring wavelengths.

The potential of WDM to tap the bandwidth of fiber, without requiring super-high bit rates and the necessary enabling high-speed electronics, had been well known for some time. But, WDM was not a cost-effective solution for high-capacity systems as long as each wavelength channel had to be separated and regenerated individually by a discrete electronic regenerator. However, the optical amplifier, with its ability to amplify multiple wavelengths simultaneously, first and foremost, made DWDM (dense wavelength division multiplexing) the cost-effective approach to building very-high-capacity optical transmission systems. That capability alone—first demonstrated in commercial products in the mid-1990s—was revolutionary.

What at the time was far less obvious to most, even if a few could foresee it, was that in enabling DWDM transmission, the optical amplifier was also preparing the way to a fundamentally new network architecture using wavelengths as the networked parameter—the common unit of "currency" for enabling and managing a network. These WDM networks, while they also depended on an array of other new technologies, including, most importantly, optical switching elements to build the wavelength add/drop multiplexers and wavelength cross-connect networking elements, depended on optical amplifiers not only to enable WDM transmission but also to compensate for the losses in these switching elements. WDM networks offered the potential to provision, manage, and protect capacity based on wavelength "chunks" via fully flexible, switched wavelength networks. It is these WDM networks that are the focus of this book.

While to many this vision appeared far-out, it was actually a very natural consequence of adopting WDM for transmission systems. Nevertheless, a tremendous world-wide research effort was required to provide the knowledge base needed to answer key questions, invent and develop new technologies, and refine and demonstrate the value proposition of WDM networks to convince service providers around the globe to deploy these networks for both long-haul and metro networks. The editors of *Optically Amplified WDM Networks*, John Zyskind and Atul Srivastava, who played key roles in taking optical networks from a vision to reality, have assembled a group of world-known researchers and engineers to address the critical areas of the field. This comprehensive book covers the broad areas important to WDM networks. From the dynamics of optical amplifiers critical to the inherent power transients in reconfigured networks, to basic (and not basic) amplifier design, to the considerations and design of wavelength add/drop multiplexers, to a perspective of future market trends—all are well covered. Not limited to fiber amplifiers—erbium-doped and Raman—they also address the potential role of semiconductor amplifiers with its somewhat less ideal temporal characteristics but possible cost advantages, especially when integrated on a single photonic integrated circuit with other optical functions. That role seems particularly interesting for future metro and access applications.

This book provides a wealth of information, insight, and reference information presented in many cases by the people who did the original work in the field. As such the book should prove very helpful to researchers and practicing engineers in or entering the field, including students. It is also a useful resource for researchers addressing the next frontier for optical networking—high-speed optical packet switched networks—which is expected to benefit from many of the same technologies and is at a stage today that WDM networks were about 15 years ago.

Author Biographies

CHAPTER 1. (*ATUL SRIVASTAVA AND JOHN ZYSKIND*)

Atul Srivastava has over 30-years of research and development experience, and is credited with many advances in the field of optics, semiconductor opto-electronics, and high-capacity optical fiber networks. At Bell Laboratories he was responsible for several key inventions in optical amplifiers including the ultra-wideband EDFA, fast gain control in amplifiers and the first demonstration of the 100-channel long distance terabit capacity WDM transmission He facilitated founding of a start-up company, Onetta in 2000 and as the Vice President of Technology at Onetta, led research and development of optical amplifiers and WDM sub-systems. He is currently president of a new technology consulting startup OneTerabit.

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Dr. Zyskind has published over 200 refereed papers and conference presentations, has delivered 35 invited talks, holds 26 patents and has published two book chapters.. He has taught 18 short courses at OFC and CLEO. Dr. Zyskind is a Fellow of the Optical Society of America.

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Peter Roorda has over 15 years experience in the design and development of agile optical networks and their key subsystems. In various technical roles at Nortel Networks and Innovance Networks, Peter has developed product concepts and architectures for emerging WDM, ROADM, optical amplifier and high speed transmission technologies. Currently at JDSU, Peter is product line manager for ROADM products.

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Dr. Jörg-Peter Elbers received the diploma and the Dr.-Ing. degree in electrical engineering from Dortmund University, Germany, in 1996 and 2000, respectively. From 1999-2001 he was with Siemens AG – Optical Networks, last as Director of Network Architecture in the Advanced Technology Department. In 2001 he joined Marconi Communications (now Ericsson) as Director of Technology in the Optical Product Unit. Since September 2007 he is with ADVA AG Optical Networking, where he is currently Vice President Advanced Technology in the CTO office.

Dr. Elbers authored and co-authored more than 70 scientific publications and 15 patents. He is member of the IEEE LEOS (Laser and Electro-Optics Society) as well as the German VDI (Association of German Engineers) and VDE (German Association for Electrical, Electronic & Information Technologies). Dr. Elbers serves in technical programme committee of the European Conference on Optical Communication (ECOC). He is also member of the VDE expert committee for optical communications engineering.

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1 Optical Amplifiers for Next Generation WDM Networks: A Perspective and Overview

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CHAPTER OUTLINE HEAD

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