FUNDAMENTALS OF BIDIRECTIONAL TRANSMISSION OVER A SINGLE OPTICAL FIBRE

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Volume 2

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Fundamentals of Bidirectional Transmission over a Single Optical Fibre

by

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Foreword

Interactivity is a key issue in future broadband telecommunication services. For the business market bidirectional transmission is already a common requirement for virtual private networks, LAN-LAN interconnections, video conferencing and other multimedia applications.

For the consumer market a migration can be expected from services with asymmetric data transfer (like broadcast or download type services, or world-wide-web browsing) to services which require higher uplink data rates (like video telephony, interactive games, video uploads, and fully interactive internet access).

The growth in bandwidth requires a flexible future proof optical network. For an upgrade of the bandwidth a choice can be made between several options: using spare fibres, increasing the electronic data rate, or using multi wavelength communications. A large collection of publications on the comparison of these options is available.

Much less attention has been paid on the migration to bidirectional services, as mentioned above. In this case, a choice can be made between options like using spare fibres (if available), multi wavelength communications or applying a set of innovative possibilities for using a single optical fibre in both directions.

This book addresses many problems concerning bidirectional communications in optical networks. I would like to congratulate the author with this book, which can be considered as the first standard work on bidirectional optical communications systems.

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Preface

Bidirectional transmission of optical signals over a single optical fibre or network (without optical isolators or optical amplifiers) is equivalent to that of electrical signals over a twisted-pair cable or a coaxial cable, radio signals through the "ether" and acoustical signals (sound) through the air. In all these cases the medium is reciprocal, i.e. symmetrical with respect to the direction of propagation. The main motivation for considering bidirectional transmission over a single optical fibre instead of "two-times unidirectional" is the reduction of the infrastructure (fibres, optical splitters and optical amplifiers) by a factor two and the potential cost reduction by an integrated transceiver design. Of course, bidirectional transmission introduces other costs and extra complications to the system design. A special optical component is required to "duplex" the bidirectional signals at the transceiver and the crosstalk between the bidirectional signals should be kept small.

The aim of this book is to provide a comprehensive overview of bidirectional transmission in optical networks. It offers fundamental insights as well as practical application/implementation of bidirectional transmission systems. Many technical aspects of bidirectional transmission are dealt with: network aspects, physical aspects, transmission aspects and polarisation handling. Although both direct-detection systems and coherent systems are investigated, the work is focused on coherent systems for two reasons. Firstly, the investigation of bidirectional coherent transmission is complementary to the existing work on direct detection. Secondly, coherent transmission adds several aspects that are not considered in direct-detection systems, e.g. polarisation aspects and frequency management. Many new ideas and insights are presented both theoretically and experimentally in the form of numerous demonstration systems and detailed measurements.

Rayleigh backscattering is one of the fundamental mechanisms in optical fibre that may cause crosstalk by the reverse channel. It can be considered as an unavoidable background reflection level. Rayleigh backscattering (or many small reflections)

yields a fluctuating crosstalk power and therefore it affects bidirectional transmission more severely than an equally large single reflection. A theoretical analysis and an experimental verification of this difference is presented for coherent systems. The polarisation properties of Rayleigh backscattering are relevant for both direct-detection and coherent bidirectional systems. They have been derived using Stokes calculus, and experimentally verified.

Brillouin scattering is another fundamental mechanism that may cause bidirectional crosstalk. It results in two new backward-propagating waves at 11 GHz optical-frequency difference (at 1550 nm) above and below the input signal. Brillouin scattering is a non-linear effect. The lower-frequency wave may grow exponentially with input power, for powers above a few mW. The polarisation properties of Brillouin scattering have been derived in a similar way as for Rayleigh backscattering, and also experimentally verified.

A systematic overview of the duplexing techniques is given and the "crosstalk-suppression ratio" of a duplexing technique is introduced. Some crosstalk suppression is usually required in bidirectional direct-detection systems, because of the unavoidable Rayleigh backscattering. It was shown that subcarrier duplexing and polarisation duplexing may not give very high crosstalk suppression. Channel spacings near 0 GHz and 11 GHz should better be avoided in bidirectional systems, because of Rayleigh and Brillouin scattering, respectively. The impediment of transmission at these channel spacings has been quantified theoretically and experimentally for coherent transmission.

Bidirectional optical amplification is possible, provided that the gain is sufficiently small in order to avoid penalties from multiple reflection/Rayleigh echoes. The main interaction between bidirectional channels in an erbium-doped fibre amplifier is homogeneous gain saturation. Other effects are the possible laser action of the amplifier due to reflections, enhanced bidirectional crosstalk from amplified reflected signals and an increased noise figure for deep saturation. All effects have been investigated both theoretically and experimentally for coherent transmission and a bidirectional optical amplifier that has been built at KPN Research.

Polarisation handling is essential in coherent transmission systems. The polarisation handling of several channels may be combined in a bidirectional and/or multichannel coherent transmission system. The possibilities and limitations of two of such techniques have been investigated in detail, theoretically and experimentaly. Both techniques are applicable in unidirectional and in bidirectional systems and they may provide large cost savings if coherent transmission is applied.

Several other aspects related to bidirectional transmission have been studied.

- The two polarisation calculuses ("Jones" and "Stokes") have been extended for reflections and bidirectional propagation. A new theorem was found on the preservation of polarisation orthogonality of counterpropagating waves and verified experimentally.

- Network topology considerations are illustrated with a number of examples. It was shown that the choice of network topology depends on the type of service, a star-tree topology for the distribution of channels and a tree-tree topology for bidirectional services.

- Two frequency-stabilisation schemes have been presented for the remote transmitters in a bidirectional (coherent) multichannel network. One scheme locks all transmitters to a centrally issued distributed frequency comb. The other scheme locks a remote transmitter to an incoming channel. Both schemes have been experimentally demonstrated.

- It was found theoretically and verified experimentally that the four-wave mixing interaction between counterpropagating waves is very small.

Finally, a practical interpretation of this book is given in the form of guidelines for designing and testing bidirectional optical communication systems.

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M. Oskar van Deventer December, 1995

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