1.1) Dense wavelength division multiplexing (DWDM)

The information age has been upon us for at least ten years now, and the unforeseen advent of the Internet has led service providers to the shocking realisation that their fibre optic links intended for voice traffic are instead being flooded with data traffic. With Internet traffic doubling every six months [1], carriers are looking toward dense wavelength division multiplexing (DWDM) to expand their capacity. WDM is the technology whereby multiple wavelengths of light (multiple channels) are launched into a single optical fibre. DWDM is a denser version of WDM resulting from advances made in the tuning of lasers and wavelength filtering [1]. The advantage of WDM is that no additional fibre link has to be installed, but rather modifications made to the network at its nodes, allowing for a more scaleable and easy upgradeable network. The recommendation of the international telecommunications union (ITU) for DWDM channel spacing is 100GHz (0.8nm), resulting in a potential total bandwidth of 430 Gbps [1].

Besides increasing the capacity of the network, these independent channels allow service providers to mix protocols and data rates on the fibre link, enabling a more direct connection between end-user applications and the optical layer. Optical networking implies that data entering the network at any node is routed, modulated, switched, multiplexed and de-multiplexed, all in the optical domain. Protocols, such as the synchronous optical network (SONET) in America, and synchronous digital hierarchy (SDH) in Europe, in conjunction with electronic devices, have to date allowed service providers to manage the long-haul fibre optic networks. They will be the mainstay until such time as the all-optical network has evolved sufficiently. In figure 1.1, the evolution of the optical network is presented [2].

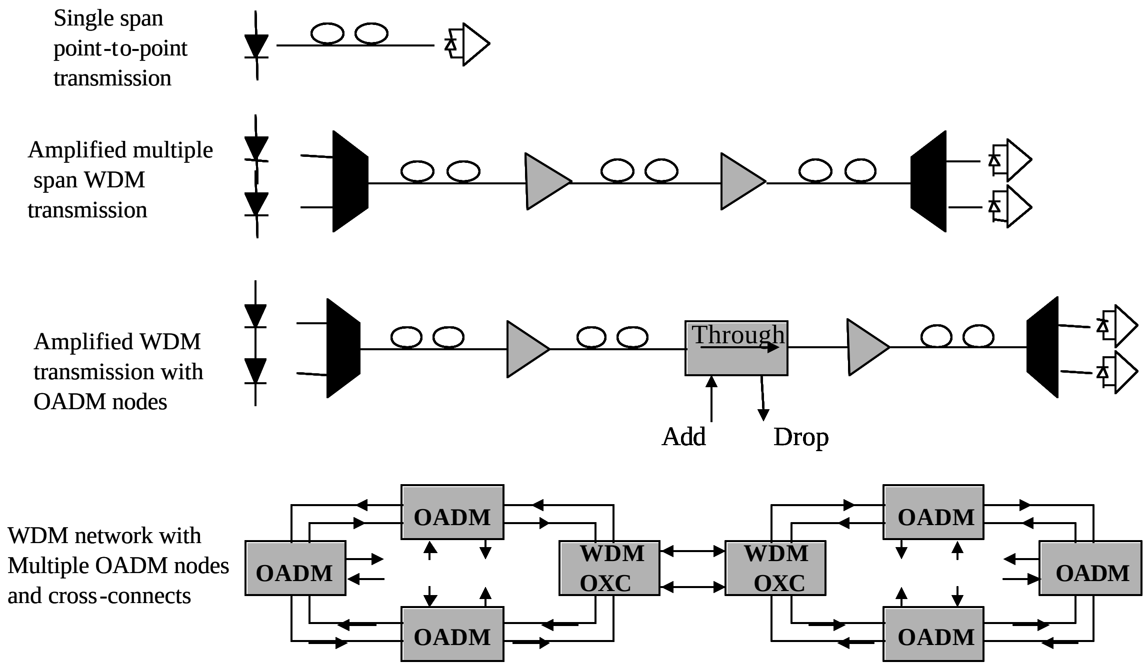

Figure 1.1: Evolution of the all-optical network

1.2) Optical network components

The realisation of the all-optical network relies heavily on the technological advances made in materials and devices for DWDM systems. In figure 1.1, the fully evolved network comprises an optical fibre, multiplexing and de-multiplexing components, optical amplifiers, optical switches, optical add drop multiplexers (OADMs) and optical cross-connects (OXCs) to create a photonic mesh. Recent fibre optic cable designs, such as given in [3 and 4], can improve the transportation of DWDM, but deployment is still in a starting phase. AWGs used for mutiplexing and demultiplexing are being manufactured by a host of companies at present, proving their position as a viable DWDM technology. All-optical amplifiers such as erbium-doped fibre amplifiers (EDFAs) are approaching full wavelength coverage and gain flatness across the useable spectrum [1].

OADMs can be realised in a myriad ways and made programmable. Optical switches and optical cross-connects are components requiring further research. The realisation of these components relies heavily on the successful integration of active and passive components and novel materials (such as organic material systems). The platforms for integrating these components on substrates are called planar lightwave circuits (PLCs), and photonic integrated circuits (PICs). The latter refers to circuits incorporating additional active functions such as modulation, while PLCs refer to passive waveguide circuits only. Progress has also been made with the exotic MEMS (miniature electro-magnetic systems) technology for all optical switching.

The realisation of an all-optical network is a realistic goal. Even though the telecommunications market and, more specifically, the optical communications market have been through a volatile period in the last three months [5], DWDM is a network solution worth pursuing. It allows for unimaginable end-user functions and for improved value-added networks.

1.3) Problem definition

DWDM networks rely on components that can filter the wavelength spectrum in such a way as to add functionality to the network. The aim of this project is to conduct an in-depth study of passive waveguides and components for filtering applications, and to design and simulate these components. The designs and simulations must take physical factors, such as material type and manufacturing capability, into account.

1.4) Proposed method of investigation

When designing components with software, such as the BeamPROP-CAD suite used in this thesis, it is possible to design and use as many different waveguide structures as one would like. In industry, however, companies spend months of research and testing to obtain reliable and reproduceable waveguide structures, to be used in the physical implementation of lightwave circuits.

This practical methodology leads to the concept of starting with simulations for the waveguide structure (in order to obtain “ball-park” estimates), manufacturing the waveguide and testing it, and returning to the simulation in order to modify its sensitivity to certain parameters, so as to ensure that the simulations are a good indication of practice. Once this has been done, components can be designed with the knowledge that the results will be useful in practice. As manufacturing facilities are very expensive, a reported waveguide structure will be used as the basis of the simulation tuning procedure.

1.5) Summary of chapters

This thesis starts with the basic waveguide theory that is necessary to facilitate an analytical *and* intuitive understanding of waveguides. Then a specific waveguide architecture is presented, followed by a modular build-up of components used in moving average (MA) filters.

1.5.1) Chapter 2

In this chapter, waveguide theory is presented. It begins with the basic concepts of the propagation constant and wave vector and moves on to waveguide modes. Solution techniques for modes are reviewed briefly, and the beam propagation method (BPM) summarised as it is the solution technique that is used in this thesis. Finally, material constraints such as dispersion and signal attenuation are discussed.

1.5.2) Chapter 3

An overview of waveguide manufacturing techniques is presented in this chapter, with the emphasis on passive waveguide systems. After the main material classes are discussed, the two generic methods of waveguide formation are discussed along with their advantages and disadvantages.

1.5.3) Chapter 4

The measured results of a reported manufactured waveguide system are used to compare then with simulated results of that specific system obtained by BeamPROP. By investigating the simulated properties of a curved waveguide, an assessment is made of how accurate the BPM is. The subsequent verification of the simulation results justifies the use of the BPM simulation method.

1.5.4) Chapter 5

The most fundamental waveguide components of a DWDM system, namely couplers, are presented in this chapter. Three coupler variants are identified and discussed, namely the bi-directional coupler, the multi-mode interference (MMI) coupler and the star coupler. The main focus is on bi-directional couplers, where a novel downscaling technique is presented to predict the behaviour of very small couplers.

1.5.5) Chapter 6

In this chapter, Mach-Zehnder interferometers and their application to DWDM systems are presented. The z-transform description is specifically used to analyse single-stage MZIs, and to derive a recursion technique for use in MZI lattice filters. This recursion program generates the coupling ratios needed to perform a certain filtering function. Finally, BPM simulations of tuneable couplers and designed lattice filters are presented.

1.5.6) Chapter 7

Arrayed waveguide gratings (AWGs) are the focus of chapter 7. The principle of operation is presented, followed by a detailed description of the Rowland circle geometry used in the star coupler. The theoretical derivation of section 7.3 indicates the vast design freedom for AWGs, whereas in section 7.5, a set design procedure is described to optimise the choice of variables. The issue of analysis standards is also discussed with relevance to AWGs.

Two AWGs are designed in this thesis, the one being for communications purposes, and the other for use in a multi-frequency laser (MFL). The MFL AWG makes use of a chirping procedure to suppress sidebands and in so doing relaxes certain design constraints. In conclusion, the various applications of AWGs are discussed.

1.5.7) Chapter 8

Concluding remarks, a critical scrutiny of the results and propositions for future work are given in this chapter.

1.6) References

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