ARRAYED WAVEGUIDE GRATING

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TO

My beloved father and mother.

My brothers (Waleed, Hisham and Tariq)

My lovely sister (Hiba).

My Uncles and Aunts.

All those I love.

All my friends.

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ABSTRACT

If compared to other kinds of communication networks, it is found that fiber optics networks are the most rewarding communication networks, since It has been suggested that if the full potential of fiber optic communication is realized, a single fiber would be sufficient to serve the needs of telecommunication users (heavy data traffic demands) throughout the world. Fiber optics is the channeled transmission of light through hair thin glass. The explosive growth of optical networks has brought forward an increased need for guided wave optical components for the sake of multiplexing and routing. Arrayed waveguide grating is one of the component that serves as a multiplexer and de-multiplexer, also if connected with other device can work as an add drop multiplexer for dense wave length division multiplexing, This is due to the fact that AWG-based devices have been proven to be capable of precisely de-multiplexing a high number of channels, with relatively low loss. The purpose of this project is to investigate the operation function of the arrayed waveguide grating and understand the performance parameters of the device, and then we investigate those performance parameters and try to find out how those parameters can affect crosstalk of the device. We make our study about only the crosstalk because crosstalk is the most important parameter that can affect the overall performance of the device. We used the waveguide spacing as a key that relates all other parameters to the crosstalk, since there is an inverse relationship between the spacing and the crosstalk. The result from this project is that there should be a tradeoff between the crosstalk and the waveguide spacing, where small waveguide spacing is required for compact design, and at the same time whenever the spacing is small crosstalk will be high.

ABSTRAK

Jika dibandingkan dengan lain-lain kaedah rangkaian komunikasi, rangkaian *fibre* (gentian) optik merupakan kaedah yang mempunyai potensi tinggi sejak dilaksanakan penggunaannya lagi. Sejak gentian adalah mencukupi untuk membaikan kemudahan kepada pengguna-pengguna telekomunikasi (permintaan penghantaran data-data besar) di dunia. Gentian optik merupakan saluran penghantaran berasaskan cahaya menggunakan kaca senipis helaian rambut. Penggunaan rangkaian optikal secara meluas menyebabkan peningkatan terhadap komponen-komponen yang memandu gelombang optikal untuk kebaikan bagi proses ‘multiplexing’ dan ‘routing’. Kekisi pemandu gelombang teratur merupakan salah satu komponen yang digunakan sebagai ‘multiplexer’ dan ‘de-multiplexer’, disamping bertindak sebagai pembolehubah ‘multiplexer’ jika disambung dengan peralatan lain. Untuk mengukur ketebalan gelombang mengikut fakta, peralatan berasaskan AWG telah terbukti berupaya ‘demultiplex’ bilangan yang besar pada saluran-saluran dengan tepat dan kurang kehilangan data. Objektif projek ini adalah untuk menyiasat fungsi pengoperasian bagi kekisi pengawal gelombang teratur dan memahami serta menyiasat keupayaan parameter-parameter pada perkakasan bagi mendapatkan bukti bagaimana setiap parameter boleh mengakibatkan ‘crosstalk’ pada setiap perkakasan. Pemilihan ‘crosstalk’ adalah disebabkan oleh kepentingan yang boleh mengakibatkan kesan terhadap keupayaan keseluruhan perkakasan. Ruang-ruang pemandu gelombang dijadikan kunci bagi setiap parameter sehingga terdapat hubungan songsang di antara ruang-ruang dan ‘crosstalk’. Hasil daripada projek ini, terdapat hubungan timbal balik diantara ‘crocctalk’ dan ruang-ruang pemandu gelombang. Ruangan pemandu gelombang yang kecil diperlukan untuk rekabentuk yang padat dan pada masa yang sama apabila ruangan kecil maka ‘crosstalk’ akan menjadi tinggi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

λ_c	-	Central wavelength
m	-	Diffraction order
n_{eff}	-	effective refractive index
β	-	Propagation constant
R_{FPR}	-	Radius of the free propagation region
Δf_{FSR}	-	Free spectral range
f_c	-	Central frequency
θ_{max}	-	Maximum dispersion angle
S_{max}	-	distance to the outermost output waveguide
D	-	Required dispersion
ds	-	Displacement of the focal spot on the image plane
df	-	The change in frequency to cause this displacement
$\Delta\ell$	-	Length increment
Ňg	-	Group refractive index
d	-	Pitch length
n_c	-	Core refractive index
Δx	-	Waveguide spacing
$\Delta\lambda$	-	Channel Spacing

L_f	-	Focal length of the FPR
N	-	Number of Channels
P	-	Number of Arrayed Waveguides
ω_g	-	the mode field radius of the central guide
L_u	-	Loss non uniformity
ΔV_{lu}	-	frequency shift corresponding the outermost output waveguide
σ_g	-	Gaussian Parameter

CHAPTER 1

INTRODUCTION

1.1 Objectives of this Project:

In recent years, arrayed waveguide gratings (AWG, also known as the optical phased-array—Phasor, phased-array waveguide grating—PAWG, and waveguide grating router—WGR) have become increasingly popular as wavelength multiplexers/de-multiplexers (MUX/De-MUX) for dense wavelength division multiplexing (DWDM). This is due to the fact that AWG-based devices have been proven to be capable of precisely de-multiplexing a high number of channels, with relatively low loss.

Main features of the M (input) x N (output) AWG MUX/De-MUXes are low fiber-to-fiber loss, narrow and accurate channel spacing, large channel number, polarization insensitivity, high stability and reliability, and being suitable for the mass production. Table 1 provides a summary and comparison of most characteristics of WDM MUX/De-MUX technologies used in the current WDM optical communications.

Because the fabrication of the AWG is based on standardized photolithographic techniques, the integration of the AWG offers many advantages such as compactness, reliability, large fabrication tolerances and significantly reduced fabrication and packaging costs. The inherent advantages of the AWG also include precisely controlled channel spacing (easily matched to the ITU grid), simple and accurate wavelength stabilization, and uniform insertion loss.

Table.1.1 Comparisons of WDM de-multiplexing technologies

Specifications	Interference filter	BG filter	AWG	Etching grating
Channel spacing	>100GHz	>100GHz	>25GHz	>10GHz
Absolute λ	Angle tuning	Strain tuning	Thermal tuning	Thermal tuning
Loss	nonuniform	Low, nonuniform	Very low	Very low
Cross talk (adj)	-25~ -33 dB	-30~ -35dB	-25~ -35 dB	-25~ -35 dB
Cross-talk (bkg)	Very low	Very low	-25~ -35 dB	<-32 dB
PDL	0.25dB	Excellent	0.5dB	0.5dB
Packaging	discrete	discrete	integration	integration
size	large	large	small	small
reliability	Good(epoxy)	Poor (tuning)	Very good	Good
Cost/channel	$500	$3000	$50	$30
Comment	For small channel	For small channel	For 16+ channel	For 16+ channel

The devices are based on a fundamental principle of optics that light waves of different wavelengths do not interfere with each other. If each channel in an optical communication network makes use of light of a slightly different wavelength, then the light from a large number of these channels can be carried by a single optical fiber with negligible crosstalk between the channels. The AWGs are used to multiplex channels of several wavelengths onto a single optical fiber at the transmission end and are also used as de-multiplexers to retrieve individual channels of different wavelengths at the receiving end of an optical communication networks.

The objectives of the project are therefore:

1. Design an arrayed waveguide grating device and its functions.
2. Studying the AWG performance parameters and their effects on crosstalk.
3. Design an arrayed waveguide grating device AWG.

1.2 Scope of the Project:

The project has three aims which are:

1. To study and understand the function, concepts and operation of optical devices used as multiplexing and de-multiplexing techniques for the optical networks.

2. Studying some of the AWG performance parameters such as cross-talk, insertion loss, free spectral range (FSR), and of course the polarization dependence dispersion of the device.

3. Concerning the crosstalk as an important performance parameter and finding out the parameters that can affect the crosstalk.

1.3 Statement of the Problem:

Optical fiber is a popular carrier of long distance communications due to its potential speed, flexibility and reliability. Attenuation and dispersion problems in fiber, which limit the practical speed and distance of communication, were partially resolved with the advent of the Erbium Doped Fiber Amplifier (EDFA)[1],eliminating problems caused by attenuation. However, the dispersion qualities of an optical fiber still force a compromise between transmission distance and bandwidth, making it necessary to refresh high-speed signals at intervals using opto-electronic repeaters. Solving the dispersion problem in this manner is expensive, due to the additional cost of high-speed electronics, and maintaining and upgrading the link is made more difficult and costly (especially with a buried or under-water link). A more elegant solution is found using Dense Wavelength Division Multiplexing (DWDM), which effectively increases the useable bandwidth in a system without electronic repeaters, and allows realization of a true photonic network.

The recent surge in demand for photonic components that meet economic criteria as well as technical requirements in the telecom and datacom industries has opened the door for novel technologies that enable unique functions and/or unconventional high-yield manufacturing without sacrificing high performance.

The project concerns with following problems:

1. Design an AWG device that is able to multiplex large number of wavelength into single optical fiber so as to increase the robustness and capacity of transmission of optical networks.

2. The device should be able to retrieve individual channels of different wavelengths at the receiving end.

3. The AWG device is sensitive to the performance parameters such as the crosstalk, diffraction order, loss non uniformity, polarization dependence loss, insertion loss.

1.4 Project Background:

Dense Wavelength Division Multiplexing (DWDM) is an efficient method where several channels, each carried by a different wavelength, are transmitted through a single optical fiber, utilizing more of the available bandwidth without increasing the effects of dispersion [2]. Each channel, since it is effectively separated from the others, can be independent in protocol, speed, and direction of communication. DWDM also helps realize an all-optical network architecture where signals are routed according to wavelength without the need for electro-optical conversion. As a result, this type of network is potentially faster and more flexible, and can be less costly to maintain when compared to other methods. Arrayed Waveguide Gratings (AWGs) are optical wavelength (de)multiplexers used in DWDM. As well as performing basic (de)multiplexing functions, they can be combined with other components to create add/drop multiplexers, Figure 1.1, used to pipe single wavelengths on and off the network, and Cross Connects, Figure 1.2, used for routing. These devices can be passive, where the signal routing is fixed according to wavelength, or active, as in Figures 1.1 and 1.2, where optical switches are utilized to dynamically route the signals. Both circuits shown are transparent to the data format, can allow bi-directional transfer of information, and function entirely in the optical domain. These functions allow the construction of different transparent optical network topologies, examples of the three major types of these are described in the following subsection.

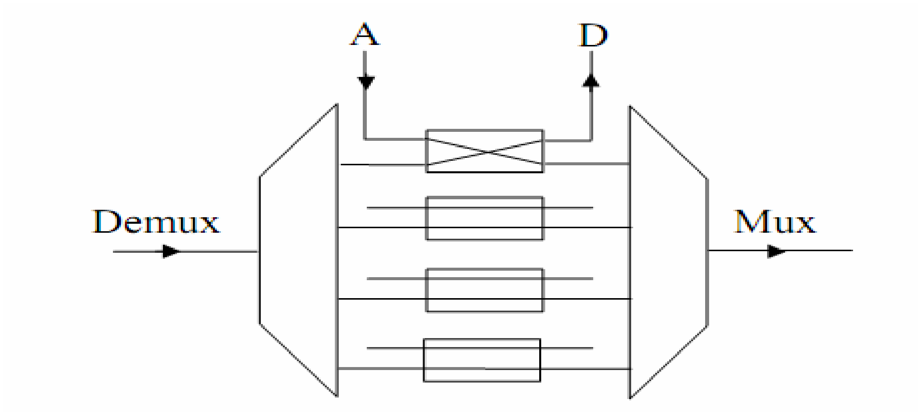

Fig 1.1 An add drop multiplexer (ADM)

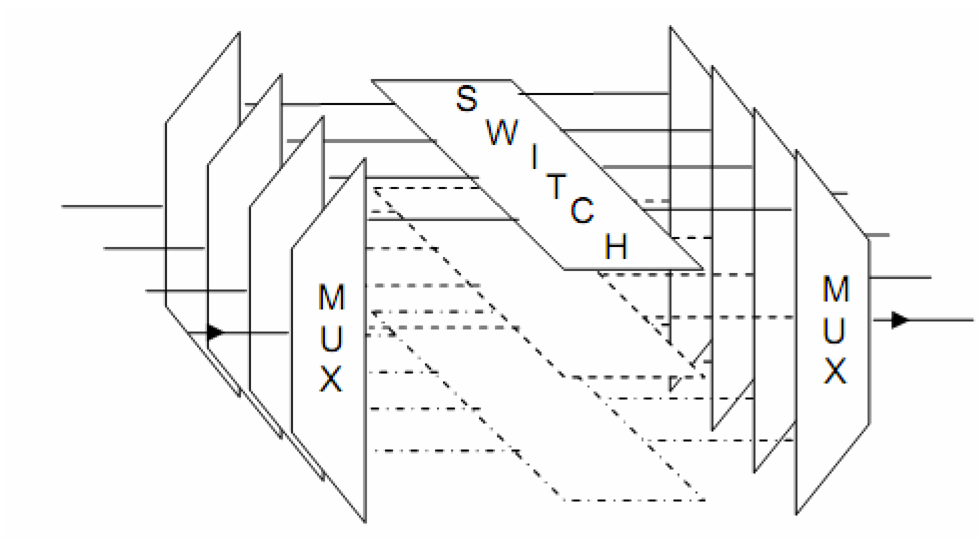

Fig 1.2: An Optical Cross Connect (OXC) employing a space division switch for each wavelength.

1.4.1 Photonic Network:

The simplest form of optical network is the point-to-point network. Optical multiplexers and de-multiplexers are required at each end of the link. In this Configuration, DWDM simply increases the number of channels available through one fiber. Passive Optical Networks (PONs) (Figure 1.3) use a wavelength (de)multiplexer as a passive optical router, each wavelength servicing an Optical Network Unit (ONU). This allows the ONUs to share a single long optical fiber link back to the central office (CO) [3].

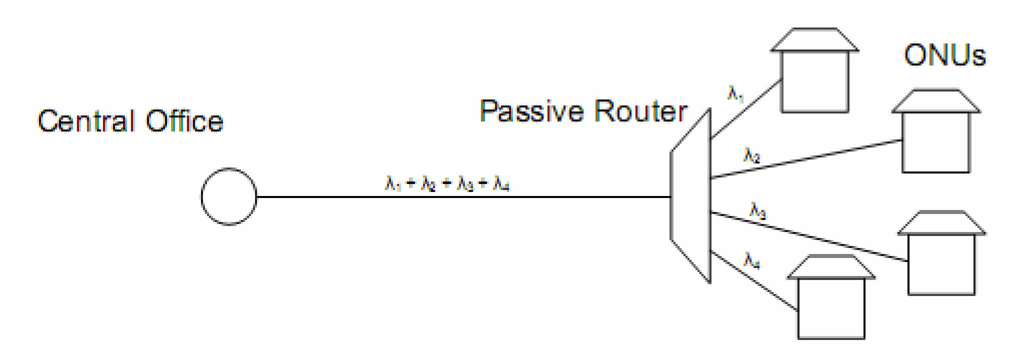

Fig 1.3: A Passive Optical Network

Long haul networks tend to have more than one point where channels are added to and removed from the system, for example to provide a bi-directional channel to an optical network unit. To add and remove channels optical add drop multiplexers (OADMs) and Optical Cross Connects (OXCs) are utilized (Figures 1.1 and 1.2), to allow single channels to be individually piped off the network, and to route channels between sections of the network respectively. Figure 1.4 shows an example configuration of a Long Haul network.

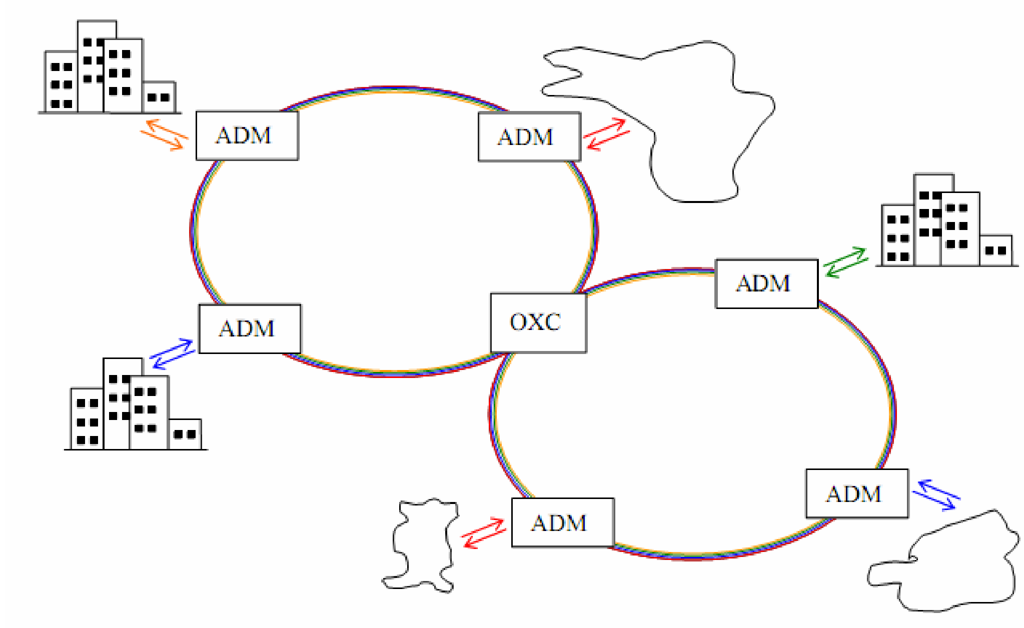

Fig 1.4: A Long Haul Network, utilizing Add-Drop Multiplexers (ADMs) and Optical Cross Connects (OXCs)

The Arrayed Waveguide Grating (AWG) plays a crucial role in the realization of modern optical networks [4]. The next section introduces the principles of operation of the AWG, and then examines the design process.

1.5 Overview of this thesis:

In chapter 1 a quick introduction of the AWG and some background of WDM and DWDM are discussed. The objective, scope of the project and the problem statement are described.

Chapter 2 introduces the optical communications and optical waveguides. It covers the applications, technology, transmitter, amplifiers, receivers, WDM, dispersion and attenuations.

Chapter 3 introduces the AWG device, its operation, functions, and then over viewing the performance parameters that affect the performance of the device.

Chapter 4 taking these performance parameters deeply and finding out their importance.

Chapter 5 is for the results discussion, analysis and results of the project.