A PASSIVE OPTICAL ADD/DROP MULTIPLEXER (P_OADM) FOR WAVELENGTH DIVISION MULTIPLEXING (WDM) SYSTEM

RUZITA ABU BAKAR

FK 2001 41
A PASSIVE OPTICAL ADD/DROP MULTIPLEXER (P_OADM) FOR WAVELENGTH DIVISION MULTIPLEXING (WDM) SYSTEM

RUZITA ABU BAKAR

MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA
2001
A PASSIVE OPTICAL ADD/DROP MULTIPLEXER (P_OADM) FOR WAVELENGTH DIVISION MULTIPLEXING (WDM) SYSTEM

BY

RUZITA ABU BAKAR

Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Engineering
Universiti Putra Malaysia

February 2001
To my dearest Mom, Husband and Children

Shafizal Maarof
Nuratiqah
Mohd Haikal Fakhrullah
Uzair Ikram
Mohammad Farhan Syazwan

With Lot of Love
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

A PASSIVE OPTICAL ADD/DROP MULTIPLEXER (P_OADM) FOR WAVELENGTH DIVISION MULTIPLEXING SYSTEM (WDM)

By

RUZITA ABU BAKAR

February 2001

Chairman: Dr. Borhanuddin Mohd Ali

Faculty: Engineering

The revolutionary of optical networks is linked to Wavelength Division Multiplexing (WDM) to provide additional capacity on existing fibre. This creates a vision of an all-optical network where all management is carried out in the photonic layer. Optical Add/Drop Multiplexer (OADM) is one of the important components to realize the WDM technology for optical fibre communication systems. OADM functions as the optical sub-system to facilitate the evolution of the single wavelength point-to-point optical network to the WDM networks by selectively removing and reinserting individual channels, without having to regenerate all WDM channels. This thesis presents prototyping of a novel passive OADM called as Passive Optical Add/Drop Multiplexer (P_OADM). This thesis describes the development, characterisation and analysis of P_OADM to be used in WDM system. Two types of P_OADM have been studied; a P_OADM with single channel drop system and a P_OADM with dual channel drop system. The advantages of P_OADM are lower loses, lower cost of production and easier to customise the
channels to customers' demand. In this study thorough characterisation on the components has been performed prior to system development and characterisation. The most important parameters explored are functional test, insertion losses, crosstalk, return loss, and wavelength flexibility. The results testified that P_OADM could be used for WDM system by dropping and adding the intended channel. The test result showed that the P_OADM performed within the acceptable range. The insertion lost measured was at 8.28 dB for single channel input test and 10.30 dB for two channels input test. The crosstalk measured at the drop port was 19.90 dB and 20.32 dB at the output port and the return loss was 4.93 dB. The P_OADM can be improved in term of insertion loss using circulator, or combiner but with slightly higher cost.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENGELUARAN / PENYISIPAN MASUK PEMULTIPLEKS (P_OADM) PASIF UNTUK SISTEM PEMBAHAGIAN PEMULTIPLEKS PANJANG GELOMBANG (WDM)

Oleh

RUZITA ABU BAKAR

Februari 2001

Pengerusi:  Dr. Borhanuddin Mohd Ali
Faculti:  Kejuruteraan

Revolusi gentian optik telah dikaitkan kepada sistem Pembahagian Pemultipleks Panjang Gelombang (WDM) untuk menyediakan keupayaan tambahan keatasan gentian optik yang sedia ada. Kaedah ini menawarkan satu lagi visi bagi rangkaian gentian optik keseluruhan di mana semua penyelenggaraan dilakukan pada lapisan gentian optik. Untuk merealisasikan teknologi WDM pada sistem komunikasi gentian optik, beberapa komponen-komponen optik telah dibangunkan. Pengeluaran / Penyisipan Masuk Pemultipleks (OADM) telah menjadi satu komponen yang penting. Ianya berfungsi sebagai satu subsistem optikal untuk mendorong evolusi satu panjang gelombang rangkaian optik titik-ke-titik kepada rangkaian WDM dengan memilih sesalur-sesalur individu untuk di keluarkan dan di sisip semula tanpa perlu untuk menjana semula semua sesalur-sesalur WDM. Tesis ini membentangkan satu rekaan contoh ulong pasif “OADM” yang terunggul dikenali sebagai P_OADM. Penyelidikan yang dijalankan ini berfokuskan kepada pembangunan, pencirian dan
analisis P_OADM untuk di gunakan pada sistem WDM. Dua jenis P_OADM telah
diselidiki: P_OADM dengan satu sistem sesalur pengeluaran dan P_OADM dengan
dua sistem sesalur pengeluaran. Kebaikan yang ditawarkan oleh P_OADM adalah
mempunyai kadar kehilangan kuasa yang rendah, kos pembuatan yang murah dan
menawarkan kemudahan melanggan sesalur-sesalur menurut permintaan pelanggan.
Dalam penyelidikan ini ujian pencirian yang terperinci telah di kemukakan ke atas
komponen-komponen yang digunakan, diikuti kepada pembangunan sistem dan
penyelidikan keatas P_OADM secara keseluruhannya. Parameter yang penting
dipelopori adalah seperti ujian berfungsi, kehilangan sesipan, cakap silang, “return
loss” kehilangan kembali dan kebolehlenturan panjang gelombang. Keputusan-
keputusan ujian ini telah menunjukkan bahawa P_OADM berjaya digunakan pada
sistem WDM dengan pengeluaran dan pensisipan masuk sesalur yang dikehendaki.
Semua keputusan ujian didapati dalam lingkungan julat yang boleh diterima. Ujian
kehilangan sesipan didapati pada 8.28 dB untuk ujian satu saluran masukan dan pada
10.30 dB pada dua saluran masukan. Ujian bagi cakap silang pada bahagian
penurunan didapati pada 19.90 dB dan pada bahagian keluaran adalah 20.32 dB.
Ujian bagi kehilangan kembali pula adalah sangat rendah iaitu sebanyak 4.93 dB.
P_OADM boleh di perbaiki dari segi kehilangan sesipan dengan menggunakan
“circulator” atau “combiner” tetapi dengan kadar harga yang lebih tinggi.
ACKNOWLEDGMENTS

I would like to take this opportunity to express my gratitude to my supervisor Dr Borhanuddin Muhammad Ali who gave me guidance throughout the course. My deepest thank is to Dr. Malay Mukeerje who always put me back into track. I also would like to say thank you to Dr. Nejim Ali Al-Asedi who made it possible for me to use optical equipment from MIMOS Bhd. I also would like to say thanks to Dr Harith Ahmad the director of Telekom Malaysia Photonic Research Center (TMPRC) who have allowed me undergo this program smoothly through the facilities at the Faculty of Science, University Malaya. My utmost gratitude that I would like to express is to Dr. Mohamad Khazani Abdullah from TMPRC for his supervision and guidance who has patiently and exuberantly helped me throughout the program. I am also very much obliged to all TMPRC staff and my colleagues at UPM whose friendship, support and help contribute to a large portion of this achievement. I also would like to say “alhamdullillah” to the “hidayah” from Allah and all the good is from Him and the defeat is from my weakness and I also would like to acquire a forgiveness from Him and the “Nur” as a guidance throughout my life.
I certify that an Examination Committee met on 1st February 2001 to conduct the final examination of Ruzita Abu Bakar on her Master of Science thesis entitled “A Passive Optical Add/Drop Multiplexer (P_OADM) for Wavelength Division Multiplexing (WDM) System” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Nor Kamariah Nordin,
Faculty of Engineering
Universiti Putra Malaysia
(Chairperson)

Borhanuddin Mohd. Ali, Ph.D.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd. Khazani Abdullah, Ph.D.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Nejim Al Asedi, Ph.D.
Manager Networking Lab,
MIMOS Bhd.
(Member)

MOHD. GHAZALI MOHAYIDIN, Ph.D.
Professor/Deputy Dean of Graduate School,
Universiti Putra Malaysia.

Date: 02 MAY 2001
This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of requirement for the degree of Master of Science.

AINI IDERIS, Ph.D.
Professor
Dean of Graduate School,
Universiti Putra Malaysia.

Date: 12 JUL 2001
DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

RUZITA ABU BAKAR
Date: 20/04/2001
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vii</td>
</tr>
<tr>
<td>APPROVAL SHEETS</td>
<td>viii</td>
</tr>
<tr>
<td>DECLARATION FORM</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xvi</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xvii</td>
</tr>
</tbody>
</table>

## CHAPTER

### I INTRODUCTION

1.1. Revolution of Optical Communication System and Devices 1
1.2. Thesis Overview 4

### II OVERVIEW OF OADM AND NETWORK ARCHITECTURE

2.1. TDM and WDM System 7
2.1.1. TDM 8
2.1.2. WDM 8
2.2. Elements for WDM System and Devices 9
2.2.1. Multiplexer and Demultiplexer 10
2.2.2. Tunable Optical Filter 10
2.2.3. Broadcast Star Coupler 10
2.2.4. Wavelength Routers 11
2.2.5. Optical Cross-Connect 11
2.2.6. Wavelength Converters 11
2.2.7. Optical Add/Drop Multiplexer 11
2.3. Optical Add Drop Multiplexer 12
2.3.1. Market Survey 12
2.3.2. Advantages 13
2.3.3. Types of OADM 14
2.3.3.1. Preplanned OADM 15
2.3.3.2. Dynamic Reconfiguration OADM 15
2.4. Current Designs of OADM 16
2.4.1. OADM with Intrinsic Bragg Grating 16
2.4.2. Double Bragg Grating OADM 17
2.4.3. Provisionable Optical ADM 19
2.5. Application of OADM 20
2.5.1. Linear Network 20
2.5.2. Ring Network 21
2.5.2.1. Uni-directional Patch Switched Ring
2.5.2.2. Bi-directional Lined Switched Ring
2.5.3. Mesh Network
2.6. Conclusion

III THEORY AND WORKING PRINCIPLE OF OADM
3.1. Components of the OADM
3.1.1. Bragg Grating
3.1.2. Isolator
3.1.3. Directional Coupler
3.1.4. Variable Coupler
3.1.5. Pigtail/Patchcord
3.1.6. Connectors
3.2. Performance Characteristics of OADM
3.2.1. Interchannel Crosstalk
3.2.2. Insertion Loss
3.2.3. Return Loss
3.3. Fibre Loss Measurement
3.3.1. Attenuation Coefficient
3.3.1.1. Material Absorption
3.3.1.2. Rayleigh Scattering
3.3.2. Waveguide Imperfections
3.4. Conclusion

IV LOSS DEPENDENCY ON VARIOUS COUPLING RATIOS OF OADM
4.1. Theoretical Evaluation of Varying the Coupling Ratios to the P_OADM
4.2. Test Evaluation of Varying the Coupling Ratios to the P_OADM
4.3. Conclusion

V CHARACTERIZATION OF COMPONENTS AND SYSTEM DEVELOPMENT OF P_OADM
5.1. Characterization of Components
5.1.1. Bragg Grating
5.1.1.1. Back-Reflection Testing
5.1.1.2. Insertion Loss
5.1.2. Isolator
5.1.2.1. Insertion Loss of Isolator
5.1.3. Coupler
5.1.3.1. Coupling Ratio and Insertion Lost Test
CHARACTERIZATION OF THE NOVEL PASSIVE OPTICAL ADD/DROP MULTIPLEXER (P_OADM) SYSTEM

6.1. P_OADM with a Single Channel Dropped (P_OADM 1)
6.1.1. A Single Input Channel Testing
6.1.1.1. Functional Test
6.1.1.2. Insertion Loss of Drop and Output Port of the P_OADM 1
6.1.1.3. Insertion Loss of the P_OADM 1
6.1.2. Two Input Channels with a Different Power Input Test
6.1.2.1. Functional and Insertion Lost Test
6.1.2.2. Crosstalk Test
6.1.3. Two Input Channels with the Same Power Input Test
6.1.3.1. Functional and Insertion Loss Test
6.1.3.2. Return Lost
6.1.4. Three Different Input Channels Test
6.1.4.1. Functional and Insertion Loss test
6.1.5. Add Channel Test
6.2. Passive P_OADM with Dual Channel Dropped (P_OADM 2)
6.2.1. Functional and Insertion Lost Testing
6.2.2. Crosstalk
6.3. Conclusion

VII CONCLUSION & RECOMMENDATION FOR FURTHER WORKS

REFERENCE

APPENDICES
I Theory of Distributed Feedback
II OADM A Paper for Patent Filling
<table>
<thead>
<tr>
<th>III</th>
<th>Patent and Publication</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BIODATA OF AUTHOR</td>
<td>121</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The evolution of optical communication networks</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>A wavelength division multiplexed (WDM) fibre optic link</td>
<td>3</td>
</tr>
<tr>
<td>1.3</td>
<td>Block diagram of OADM</td>
<td>3</td>
</tr>
<tr>
<td>2.1</td>
<td>Schematic Diagram of Wavelength Division Multiplexer</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>Graph of the estimates in U.S OADM Market 1998 – 2002</td>
<td>13</td>
</tr>
<tr>
<td>2.3</td>
<td>Generic add/drop multiplexer using optical switches</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>Schematic Diagram Preplanned OADM</td>
<td>15</td>
</tr>
<tr>
<td>2.5</td>
<td>Schematic Diagram of Dynamic Reconfiguration OADM</td>
<td>16</td>
</tr>
<tr>
<td>2.6</td>
<td>OADM making use of intrinsically written Bragg grating on a fibre coupler</td>
<td>17</td>
</tr>
<tr>
<td>2.7</td>
<td>Schematic Diagram of Double Bragg grating OADM</td>
<td>18</td>
</tr>
<tr>
<td>2.8</td>
<td>Schematic Diagram of a Provisionable Optical ADMs</td>
<td>20</td>
</tr>
<tr>
<td>2.9</td>
<td>WADM Requirements in Linear Homing Network</td>
<td>21</td>
</tr>
<tr>
<td>2.10</td>
<td>Ring Topology Connecting Nodes A and Nodes B</td>
<td>23</td>
</tr>
<tr>
<td>3.1</td>
<td>The working principle of an isolator</td>
<td>28</td>
</tr>
<tr>
<td>3.2</td>
<td>Examples of optical couplers : (a) Splitter (b) directional coupler and (c)multiplexer and demultiplexer</td>
<td>30</td>
</tr>
<tr>
<td>3.3</td>
<td>Illustrate the cross section of the tunable Optical Fibre Coupler</td>
<td>32</td>
</tr>
<tr>
<td>3.4</td>
<td>Crosstalk measured path of OADM</td>
<td>33</td>
</tr>
<tr>
<td>3.5</td>
<td>A schematic diagram of the OADM to mitigate the crosstalk due to Fresnel reflection</td>
<td>35</td>
</tr>
</tbody>
</table>
3.6 Block Diagram of an OADM defining insertion loss parameters

4.1 Schematic diagram of OADM showing the coupling ratio of the directional couplers

4.2 Theoretical results of $P_{\text{drop}}$ vs coupling ratio for power level at the drop port

4.3 Theoretical results of $P_{\text{out}}$ Coupling ratio $V_s$; for $Y_6$ not equal to $Y_3$ and $Y_6$ equal to $Y_3$

4.4 Experimental set-up for OADM loss dependency on various coupling ratios

4.5 Experimental results on power drop vs coupling ratio measured at the drop port of the OADM

4.6 Experimental results on power output vs coupling ratios measured at the output port of the OADM

5.1 Measurement for back-reflected wavelength comprising of a tunable laser source, an optical spectrum analyzer, connectors, patchcords, couplers, isolator and the Bragg grating.

5.2 The spectra measured by Optical Spectrum Analyzer (OSA) at the back reflection port of the Bragg grating of the NP_OADM

5.3: Measurement set up for the insertion loss of Isolator;
(a) Measurement of $P_1$ consisting of power source, patchcord 1 and power meter.
(b) Measurement of $P_2$ consisting of power source, patchcord 1 and 2 as well as power meter and the isolator

5.4: Measurement of insertion loss of the directional coupler consist of light source at 1550 and 1320 nm, optical power meter at leg 1, directional coupler and index matching gel at leg 2

5.5 The experimental result of coupling ratio coupler versus insertion loss of the coupler at 1550 nm and 1310 nm showing exact match

5.6 The positioning of the directional coupler legs
5.7 Measurement of excess loss for directional coupler consisting of light source at 1550 nm and 1320 nm, optical power meter, directional coupler and index matching gel 58

5.8 The experimental result on the excess loss versus coupling ratio at 1330 nm and 1550 nm 59

5.9 The percentage of coupling ratio against uniformity for couplers at 1550 nm and 1310 nm 61

5.10 Insertion loss measurement of a connector pair.
(a) Measurement of P1 consisting of power source, PC1 and power meter.
(b) Measurement of P2 consisting of power source, PC1, PC2, connector and power meter 63

5.11 Variation of connector loss with input power level at 1303.2 nm and 1533.3 nm wavelength, respectively 64

5.12 Effect of insertion loss with numerous times of cleaning 66

5.13 Measurement set-up to determine the insertion loss of connectors consist of light source, patchcord, coupled module and optical power meter 67

5.14 The measurement of actual splice loss 69
(a) Measurement for P1 consist of power source, two pigtails, two splices and optical power meter
(b) Measurement of P2 consisting of power source, two pigtails, three splices and optical power meter

5.15 Splice loss versus attenuation for machine loss of 0.01 dB compare with actual loss 70

5.16 Splice loss versus attenuation for machine loss of 0.4 dB compared with actual loss 70

6.1 The schematic diagram of Passive NP_OADM with a single channel dropped 74

6.2 Superimposed trace of power input, powers drop and power out with wavelength for functional test of NP_OADM 75

6.3 Insertion-loss vs wavelength for Path 1 and Path 2 of the NP_OADM 77
6.4 Power versus wavelength for power add, power out and insertion loss measured at the add port of NP_OADM 1

6.5 The two channels used for the Two Input Channels with a different Power Input Test of NP_OADM#1 are at 1538.75 nm (Channel 1) and 1541.80 nm (Channel 2) with the input power of -28.27 dBm and -13.43 dBm, respectively.

6.6 Hybrid Brillouin-Erbium fibre laser (HBFL) system configuration in a ring used to originate multi-channel for NP_OADM test.

6.7 Power measured at the drop port Channel 1 at -5.45 dBm and Channel 2 at -23.73 dBm of NP_OADM 1.

6.8 Power measured at the output port with Channel 1 at -37.84 dBm and Channel 2 at -71.10 dBm of NP_OADM 1.

6.9 The power spectrum of the two input channels with the same power input test at -11.80 dBm.

6.10 The power spectrum measured at the drop port of two channels; Channel 1 at -40.01 dBm and Channel 2 at -21.10 dBm, at equal power.

6.11: Power spectrum measured at the output port for Channel 1 is -18.08 dBm and Channel 2 is zero.

6.12 Measurement for return loss of OADM system consisting of a laser source, detector, tapper and OADM.

6.13 Power spectrum of three different input channels test for NP_OADM; Channel 1 at -0.009 dBm, Channel 2 at 1.25 dBm and Channel 3 at -1.22 dBm.

6.14 The superimposition channels of input power, output power and dropped power. Input power for Channel 1,2 and 3 are -0.009 dBm, 1.25 dBm and -1.22 dBm. Output power for Channel 1,2 and 3 are -5.0 dBm, -77.55 dBm and -8.00 dBm. Drop power for Channel 1,2, and 3 are -26.00 dBm, -8.13 dBm and -30 dBm.

6.15 Power spectrum of NP_OADM 1 measured at the output port indicating a decrease of power at Channel 2.

6.16 Power spectrum for NP_OADM 1 at Channel 1,2 and 3 measured at the drop port at -8.50 dBm, -8.0 dBm and -38.3 dBm, respectively.
6.17 Power spectrum of NP_OADM 1 for Channel 1, 2, and 3 measure at the output port at -3.65 dBm, -59.3 dBm and -19.93 dBm

6.18 The schematic diagram of NP_OADM 2

6.19 Test set-up for functional and insertion loss test for NP_OADM 2
# LIST OF TABLE

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Typical specification for Bragg grating with the centre wavelength at 1460nm – 1490nm</td>
<td>27</td>
</tr>
<tr>
<td>3.2</td>
<td>The typical specifications of the isolators used in this study</td>
<td>28</td>
</tr>
<tr>
<td>3.3</td>
<td>The typical specification of 3dB couplers</td>
<td>30</td>
</tr>
<tr>
<td>3.4</td>
<td>The typical specifications of the connectors used in the experiments</td>
<td>33</td>
</tr>
<tr>
<td>5.1</td>
<td>Test result of the power taken for the power input, power reflected and power out</td>
<td>53</td>
</tr>
<tr>
<td>5.2</td>
<td>Test result of $P_1$ and $P_o$</td>
<td>55</td>
</tr>
<tr>
<td>5.3</td>
<td>Excess loss test result at 1320 nm and 1550 nm</td>
<td>59</td>
</tr>
<tr>
<td>5.4</td>
<td>Uniformity test result at 1320 nm and 1550 nm</td>
<td>61</td>
</tr>
<tr>
<td>5.5</td>
<td>Test result of power measurement of $P_1$ and $P_2$ at 1310 nm and 1550 nm for connector lost</td>
<td>64</td>
</tr>
<tr>
<td>5.6</td>
<td>Four set of result for connector lost</td>
<td>65</td>
</tr>
<tr>
<td>5.7</td>
<td>The test result measuring the pathcord insertion lost for the power input and power output</td>
<td>68</td>
</tr>
<tr>
<td>6.1</td>
<td>The average value of crosstalk for path 1 determined during the test</td>
<td>83</td>
</tr>
<tr>
<td>6.2</td>
<td>The average value of crosstalk for path 2</td>
<td>84</td>
</tr>
<tr>
<td>6.3</td>
<td>The average value of return loss of NP_OADM 1</td>
<td>88</td>
</tr>
<tr>
<td>6.4</td>
<td>Dropped channel detected at the drop port of the NP_OADM 2</td>
<td>95</td>
</tr>
<tr>
<td>6.5</td>
<td>Crosstalk measured at Path 1 with four different conditions</td>
<td>98</td>
</tr>
</tbody>
</table>
LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>Beam Splitters</td>
</tr>
<tr>
<td>BLSR</td>
<td>Bi-Directional Line Switched Ring</td>
</tr>
<tr>
<td>DEMUX</td>
<td>Demultiplexer</td>
</tr>
<tr>
<td>EDFA</td>
<td>Erbium Doped Fibre Amplifiers</td>
</tr>
<tr>
<td>E-ADM</td>
<td>Electronic Add Drop Multiplexer</td>
</tr>
<tr>
<td>EXC</td>
<td>Electrical Cross Connect of Electrical Terminal</td>
</tr>
<tr>
<td>FBG</td>
<td>Fibre Bragg Grating</td>
</tr>
<tr>
<td>FTTH</td>
<td>Fibre To The Home</td>
</tr>
<tr>
<td>FDM</td>
<td>Frequency Division Multiplexing</td>
</tr>
<tr>
<td>PMD</td>
<td>Polarization Mode Dispersion</td>
</tr>
<tr>
<td>PC</td>
<td>Polarization Controllers</td>
</tr>
<tr>
<td>MUX</td>
<td>Multiplexer</td>
</tr>
<tr>
<td>P_OADM</td>
<td>Passive Optical Add/Drop Multiplexer</td>
</tr>
<tr>
<td>OADM</td>
<td>Optical Add/Drop Multiplexers</td>
</tr>
<tr>
<td>OXC</td>
<td>Optical Cross Connect</td>
</tr>
<tr>
<td>OSNR</td>
<td>Optical Signal Noise Ratio</td>
</tr>
<tr>
<td>TDM</td>
<td>Time Domain Multiplexer</td>
</tr>
<tr>
<td>TSA</td>
<td>Time Slot Assignment</td>
</tr>
<tr>
<td>TSI</td>
<td>Time Slot Interchange</td>
</tr>
<tr>
<td>WDM</td>
<td>Wavelength Division Multiplexer</td>
</tr>
<tr>
<td>WP</td>
<td>Wavelength Paths</td>
</tr>
<tr>
<td>UPSR</td>
<td>Uni-directional Path Switched Ring</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

1.1 Revolution of Optical Communication System and Devices

Optical networks are high-capacity telecommunications systems based on optical technologies and components that provide routing, grooming and restoration at the wavelength level as well as wavelength-based services. The system can be improved further by use of system, which provide additional capacity on existing fibers. In the modern day world, the optical layer has been supplemented with more functionality, which were once in the higher layers. The optical network is proposed to provide end-to-end services completely in the optical domain, without having to convert the signal to the electrical domain. Transmitting IP directly over WDM has become a reality and is able to support bit-rates of OC-192. It holds the key to the bandwidth surplus and opens the frontier of high-speed telecommunication in the new century.

Optical communication systems have reached its sixth generation, with the employment of optical amplifiers [1]. The evolution of optical communications networks is as shown in Figure 1.1. From 1990 to 1997 the data rates have increased four-fold with each upgrade from 155 to 622 Mb/s; then from 622 Mb/s to 2.48 Gb/s. From 1995 to 2005, the transmission capacity has and is expected to increase to 10Gb/s to cover the boom in the network traffic. Carriers can choose whether to transmit 10 Gb/s in a single fibre using Time Domain Multiplexer (TDM) or
alternatively using Wavelength Division Multiplexer (WDM) to transmit four 2.5 Gb/s channels on a single fibre [2].

WDM is currently gaining popular supports all over the world as it offers many advantages over traditional TDM systems that transmit only a single channel [3]. Among others, the advantages include a much higher channel capacity, less fibres to be installed, and channel management flexibility. To implement and realize the WDM technology for fibre-optic communication systems, several new optical components are also being researched and developed extensively [4]. Among the important components in the WDM system are multiplexers and demultiplexers, tunable optical filters, wavelength routers, optical cross-connects, wavelength converters, WDM transmitter and receiver and Optical Add/Drop Multiplexers (OADM).

Figure 1.1: The evolution of optical communication networks