LONG REACH EDFA/DRA HYBRID AMPLIFIER BASED WDM-PON

A dissertation submitted towards the partial fulfilment of the requirement for the award of the degree of

Master of Technology
in
Microwave & Optical Communication Engineering

by

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CERTIFICATE

This is to certify that the thesis report entitled, "**Long Reach EDFA/DRA Hybrid Amplifier based WDM-PON**" being submitted by **Abhishek kumar singh** to the *Department of Electronics and Communication Engineering and Applied Physics, Delhi Technological University, Delhi* in partial fulfilment of the requirement for award of Master of Technology degree in ***Microwave and Optical Communication*** is a record of bona fide work carried out by him under the supervision and guidance of Prof. R. K. Sinha. The matter embodied in this report has not been submitted for the award of any other degree.

Prof. R. K. Sinha	**Prof. S C. Sharma**	**Prof. Rajiv Kapoor**
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DECLARATION

I hereby declare that all the information in these documents has been obtained and presented in accordance with academic rules and ethical conduct. It is being submitted for the degree of Master of Technology in Microwave and Optical Communication Engineering at Delhi Technological University, Delhi. It has not been submitted before for any degree or examination in any other university.

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With all praises to the almighty and by His blessings I have finally completed this thesis.

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ABSTRACT

A Passive Optical Network (PON) is a single, shared optical fiber that uses inexpensive optical splitters to divide the single fiber into separate strands feeding individual subscribers. PONS are called "passive" because, other than at the CO and subscriber endpoints, there are no active electronics within the access network.

With the growing inability to meet electricity demands and due to other environmental concerns, low-power design of network equipment has attracted significant research attention. Among access technologies, the Passive Optical Network (PON) technology consumes less power.

A WDM-PON solution provides scalability because it can support multiple wavelengths over the same fiber infrastructure, is inherently transparent to the channel bit rate, and it does not suffer power-splitting losses. In the WDM-PON, each ONU can operate at a rate up to the full bit rate of a wavelength channel.

Recently, the long reach wavelength division multiplexing passive optical network (WDM-PON) have attracted more attention. However, the long reach optical fiber links must suffer from the limitation of nonlinear distortion. Furthermore, the wavelength-specific laser source in each ONU will increase capital expenditures of system. In this study, the hybrid amplifier (HA) is designed to enhance the signal power and compensate the fiber dispersion over a wide wavelength range.

This paper describes the design of a narrowband hybrid amplifier composed of a distributed Raman amplifier and Erbium doped fiber amplifiers for the C-band, using the same pump lasers to estimate the noise figure of configuration. In our proposed approach, the power budget and sensitivity will be improved. In our work we have shown the simulation results of a hybrid amplifier consisting of Erbium doped fiber amplifiers EDFAs and a distributed Raman amplifier in the C-band. We characterize the design by numerical simulation based on the Optisystem 7.0 of an ordinary single mode fiber transmission line.

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LIST OF ABBREVIATIONS

ASE	Amplified spontaneous emission
BER	Bit error rate
CD	Chromatic dispersion
CNR	Carrier-to-noise ratio
DCF	Dispersion compensated fiber
DFA	Doped fiber amplifier
DFB	Distributed feedback
DRA	Distributed raman amplifier
DS	Dispersion shifted
EDFA	Erbium-doped fiber amplifiers
FRA	Fiber raman amplifier
FWM	Four-wave mixing
GVD	Group velocity dispersion
HA	hybrid amplilifier
ISI	Inter symbol interference
LD	Laser Source/ Modulator
NB-HA	Narrow band hybrid amplifier
NDS	Normal dispersion shifted
NF	Noise figure
OADM	Optical add drop multiplexer
OAMP	Optical amplifier
OC	Optical Combiner
OFA	Optical fiber amplifier
ONU	Optical Network Unit
OS	Optical Wavelength Splitter
OXC	Optical cross connect
OXS	Optical cross switch
PMD	Polarization-mode dispersion
PON	Passive optical network
PS	Power splitter

PRBS	Pseudo random bit sequence generator
RA	Raman Amplifier
RF	Radio frequency
RN	Remote Node
RWA	Routing and wavelength assignment
SBS	Stimulated Brillouin scattering
SMF	Single-mode fibers
SNR	Signal-to-noise ratio
SOA	Semiconductor optical amplifier
SPM	Self-phase modulation
SRS	Stimulated Raman scattering
SSF	Split step fourier
SWB-HA	Seamless wide band hybrid amplifier
TDM	Time Domain Multiplexing
WDM	Wavelength-division multiplexing
MUX	Multiplexer
WLAN	Wireless local area networks
XPM	Cross-phase modulation

Chapter 1

Introduction

1.1 Overview

Local loops using optical fiber for access connections are called fiber-in-the loop (FITL) systems [1–2]. Optical fiber has the advantage of high bandwidth, low loss, and low noise. Compared to the coaxial cable plant, which usually requires many cascaded RF amplifiers, fiber plants are in general much cleaner and require very little maintenance.

Studies for FITL started in the 1980s [3–4]. Fiber access systems are also referred to as fiber-to-the-x (FTTx) system, where ‘‘x’’ can be ‘‘home,’’ ‘‘curb,’’ ‘‘premises,’’ ‘‘neighbourhood,’’ etc., depending on how deep in the field fiber is deployed or how close it is to the user. In a fiber-to-the-home (FTTH) system, fiber is connected all the way from the service provider to household users. In an FTTC system, fiber is connected to the curb of a community where the optical signal is converted into the electrical domain and distributed to end users through twisted pairs. Therefore, an FTTC system can also be regarded as a hybrid fiber twisted pair system.

Nowadays, most people think of FTTx as the P2MP power-splitting PONs (PS-PONs). In reality, fiber access systems can be point-to-point (P2P) or P2MP. Moreover, they can use an active remote distribution node such as an Ethernet switch or a simple passive splitter as the remote distribution node used in PSPONs. In fact, NTT adopted P2P architectures in some early FTTH trials [5]. Another type of PON called WDM-PON uses a wavelength multiplexer as the remote distribution node [4].

Wavelength division multiplexing (WDM) increases system capacity by transmitting multiple wavelengths on a single fiber. Coarse WDM techniques have already been applied in PON systems to separate upstream and downstream signals, and provide analog video overlay [6]. An important advantage of the optical fiber is its virtually unlimited bandwidth from an access viewpoint.

Coarse WDM overlay on a power-splitting PON is an obvious way to provide different services and increase system capacity. For example, one can segregate the optical spectrum into different coarse WDM bands and engineer a G-PON system in one wavelength band and an EPON in a different band, doubling the value of the costly fiber plant [7]. All the PON systems mentioned so far use a power coupler to distribute the signal from OLT to users at different ONUs. In a WDM-PON system, a WDM coupler is used to distribute signals to different users. Each ONU is allocated with its own wavelengths. Such a system has the advantage of high capacity, privacy, and protocol transparency.

As the demand for higher transmission capacity in wavelength division multiplexing WDM systems increases, the channel speed, channel number, and spectral efficiency need to be upgraded [8]. To this end, Raman amplifiers have become essential in overcoming the limitations of the bandwidth, noise figure NF, and output power of conventional doped fiber amplifiers [9]- [11]. Recently, great attention has been paid to the Raman amplifiers used in conjunction with Erbium-doped fiber amplifiers EDFAs to form hybrid amplifiers, especially when the system capacity needs to be upgraded by raising channel speed and spectral efficiency without bandwidth expansion [10]-[12].

Hybrid EDFA/Raman amplifiers are also attractive in optical communications because of their abilities of tailoring gain profile, compensating fiber dispersion and loss, enhancing the optical signal-to-noise ratio [12]. These amplifiers are designed in order to maximize the span length and/or to minimize the impairments of fiber nonlinearities, and to enhance the bandwidth of EDFAs [13]. Recently, hybrid amplifiers known as Raman-assisted fiber optical parametric amplifiers RA-FOPAs have attracted much attention because of their flexibility in selecting parametric pump wavelengths and full utilization of the C+L band in addition to the inherent advantages of hybrid amplifiers [14]. The gain profile in WDM systems must be carefully equalized during propagation or after short distances, which typically requires the use of additional gain flattening filters of multiple wavelengths Raman pumps, adding to the cost of a fiber optic link. However, for applications in which a smaller channel bandwidth is sufficient, the gain equalization can be done using a simplified arrangement of an EDFA and single-pump distributed Raman amplification [15], as will be done in this report.

1.2 Motivation and Problem Statement

The motivation for project came while under taking course on OFC. The main issue with optical communication is the losses which signal suffer while travelling through the fiber via splitters joints and fiber itself. Thus, to achieve the long distance communication via fiber we need significant amount of gain and noise figure as low as possible. So an idea came to improve the gain of optical amplifiers by using different combination of signal wavelength and with help of some modulation scheme.

1.3 Goals/Scope of present work

The main goals of this project are to get acquainted with passive optical network designing using optisystem 7 software and improve the gain and noise figure. The present work consists of designing of wavelength division multiplexed passive optical network and provide gain using combination of EDFA and DRA. The scope of this project lies on designing and implementation of hybrid amplifier based WDM-PON and further improve gain with help of different modulation technique.

The next section describes the organization of chapters in the thesis.

1.4 Report Organization

The thesis report is divided into seven chapters, each having ample information for comprehending the concepts of this project.

Chapter 1: presents introduction to project, design and introduction to WDM-PON, discusses the motivation and problem statement, goal and scope of present work.

Chapter 2: literature review and the theory involved in the research work of this project have been presented. In this chapter we discussed various optical amplifiers their advantages and disadvantages. Different types of hybrid amplifiers and their experimental setup.

Chapter 3: the detailed designing of proposed hybrid amplifier (EDFA/DRA) based WDM-PON experimental setup in optisystem 7, their simulation at different channel wavelength and simulation results.

Chapter 4: introduction of different modulation schemes (e.g. phase modulation, Differential Phase Shift Keying). Simulation result with introduction of modulation scheme.

Chapter 5: Analysis of variation of Gain and Noise Figure with variation of different parameters (e.g. signal wavelength, pump signal power, pump signal wavelength,)

Chapter 6: summarizes detailed results of simulation analysis.

The Final chapter of the thesis (Chapter 7) presents the conclusions and future aspects of this project. The significance and contribution of this work is summarized.

Chapter 2

Literature Review

2.1 Introduction

This chapter reviews several basic but important concepts that are necessary to comprehend the contents of this report. Here general information about passive optical network, wavelength Division multiplexing and different optical amplifiers are introduced.

2.2 Passive optical Network

The general structure of a modern telecommunication network consists of three main portions: backbone (or core) network, metro/regional network, and access network. On a very high level, core backbone networks are used for long-distance transport and metro/regional networks are responsible for traffic grooming and multiplexing functions. Structures of backbone and metro networks are usually more uniform than access networks and their costs are shared among large numbers of users. These networks are built with state-of-the-art fiber optics and wavelength division multiplexing (WDM) technologies to provide high-capacity connections.

Access networks provide end-user connectivity. They are placed in close proximity to end users and deployed in large volumes. Access networks exist in many different forms for various practical reasons. In an environment where legacy systems already exist, carriers tend to minimize their capital investment by retrofitting existing infrastructure with incremental changes, whereas in a green-field environment, it often makes more sense to deploy future proof new technologies which might be revolutionary and disruptive.

Compared to traditional copper-based access loops, optical fiber has virtually unlimited bandwidth (in the range of tera-hertz or THz of usable bandwidth). Deploying fiber all the way to the home therefore serves the purpose of future proofing capital investment. A passive optical network (PON) is a form of fiber optic access network. Most people nowadays use PON as a synonym of FTTx, despite the fact that the latter carries a much broader sense. Figure 2.1 shows the alternatives of FTTx [1]. As seen from the figure, in the simplest case, individual optical fibers can be run directly from the central office (CO) to end users in a single star architecture.

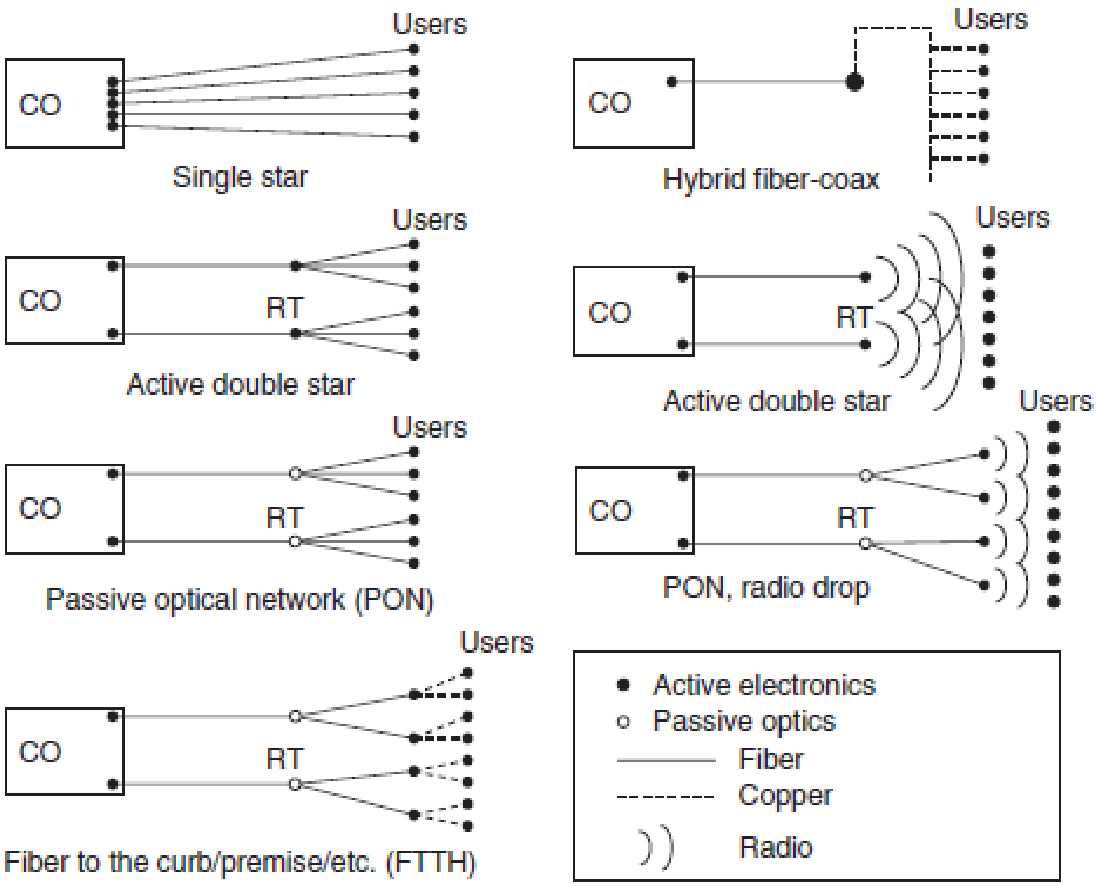


Figure 2.1 FTTx alternatives (from [1] copyright [2004] by IEEE)

A TDM-PON uses a passive power splitter as the remote terminal. The same signal from the OLT is broadcast to different ONUs by the power splitter. Signals for different ONUs are multiplexed in the time domain. ONUs recognizes their own data through the address labels embedded in the signal. Most of the commercial PONs (including BPON, G-PON, and EPON) fall into this category.

A WDM-PON uses a passive WDM coupler as the remote terminal. Signals for different ONUs are carried on different wavelengths and routed by the WDM coupler to the proper ONU. Since each ONU only receives its own wavelength, WDM-PON has better privacy and better scalability. Each wavelength behave as a different channel, this quality of WDM-PON is very useful.

Figure 2.2[17] given below shows the general architecture of TDM-PON and WDM-PON.

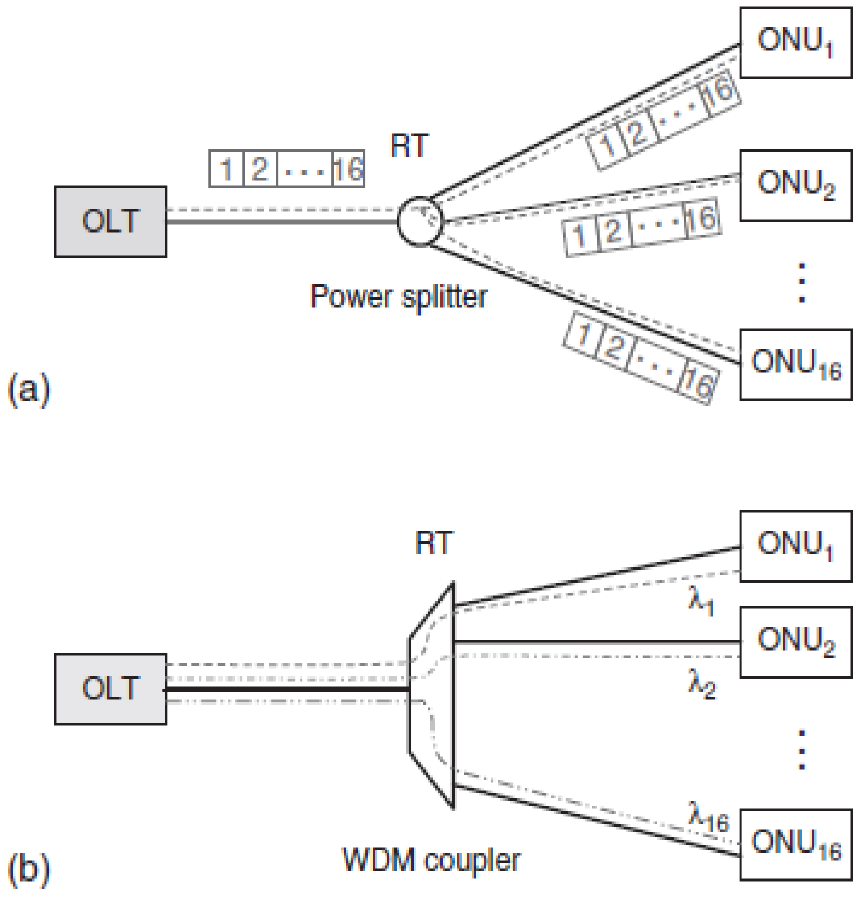


Figure 2.2 Architecture of (a) TDM-PON and (b) WDM-PON[17].

2.3 Optical Amplifiers

Optical amplifiers, as their name implies, operate solely in the optical domain with no inter conversion of photons to electrons. Therefore, instead of using regenerative repeaters which require optoelectronic devices for source and detector, together with substantial electronic circuitry for pulse slicing, retiming and shaping, optical amplifiers are placed at intervals along a fiber link to provide linear amplification of the transmitted optical signal. The optical amplifier, in principle, provides a much simpler solution in that it is a single in-line component which can be used for any kind of modulation at virtually any transmission rate. Moreover, such a device can be bidirectional and if it is sufficiently linear it may allow multiplex operation of several signals at different optical wavelengths (i.e. wavelength division multiplexing)

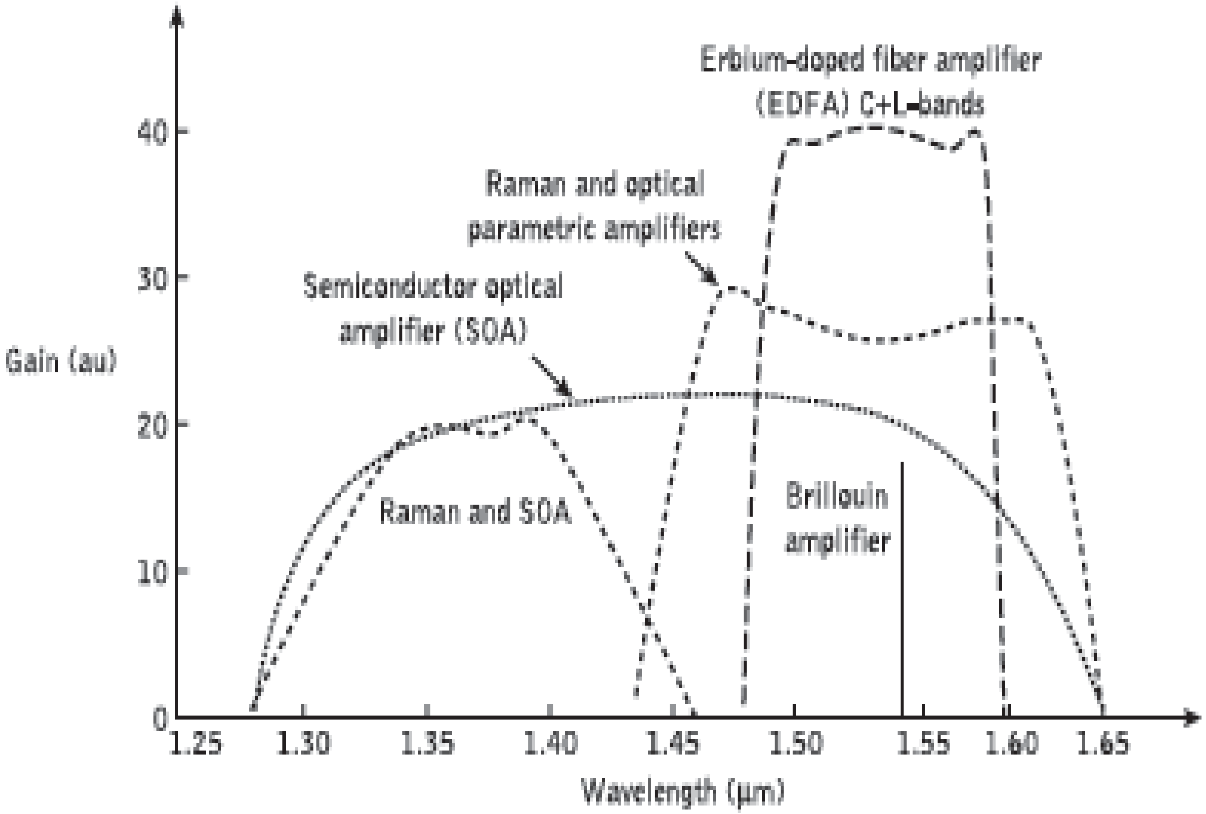


Figure 2.3 Gain–bandwidth characteristics of different optical amplifiers [19]

In particular with single-mode fiber systems, the effects of signal dispersion can be small and hence the major limitation on repeater spacing becomes attenuation due to fiber losses. Such systems do not require full regeneration of the transmitted digital signal at each repeater, and optical amplification of the signal proves sufficient. Hence over recent years optical amplifiers have emerged as promising network elements not just for use as linear repeaters but as optical gain blocks, wavelength converters, optical receiver preamplifiers and, when used in a nonlinear mode, as optical gates, pulse shapers and routing switches [18]. The two main approaches to optical amplification to date have concentrated on semiconductor optical amplifiers which utilize stimulated emission from injected carriers and fiber amplifiers in which gain is provided by either stimulated Raman or Brillouin scattering or by rare earth dopants. Both amplifier types (i.e. semiconductor and fiber; specifically rare earth and Raman) have the ability to provide high gain over wide spectral bandwidths, making them eminently suitable for optical fiber system applications. Semiconductor optical amplifiers, however, offer an advantage due to their smaller size and also because they can be integrated to produce subsystems which are an essential element of current optical communication systems and networks.

Different amplifiers work in different wavelength range approximate window of operation is given below in fig 2.4

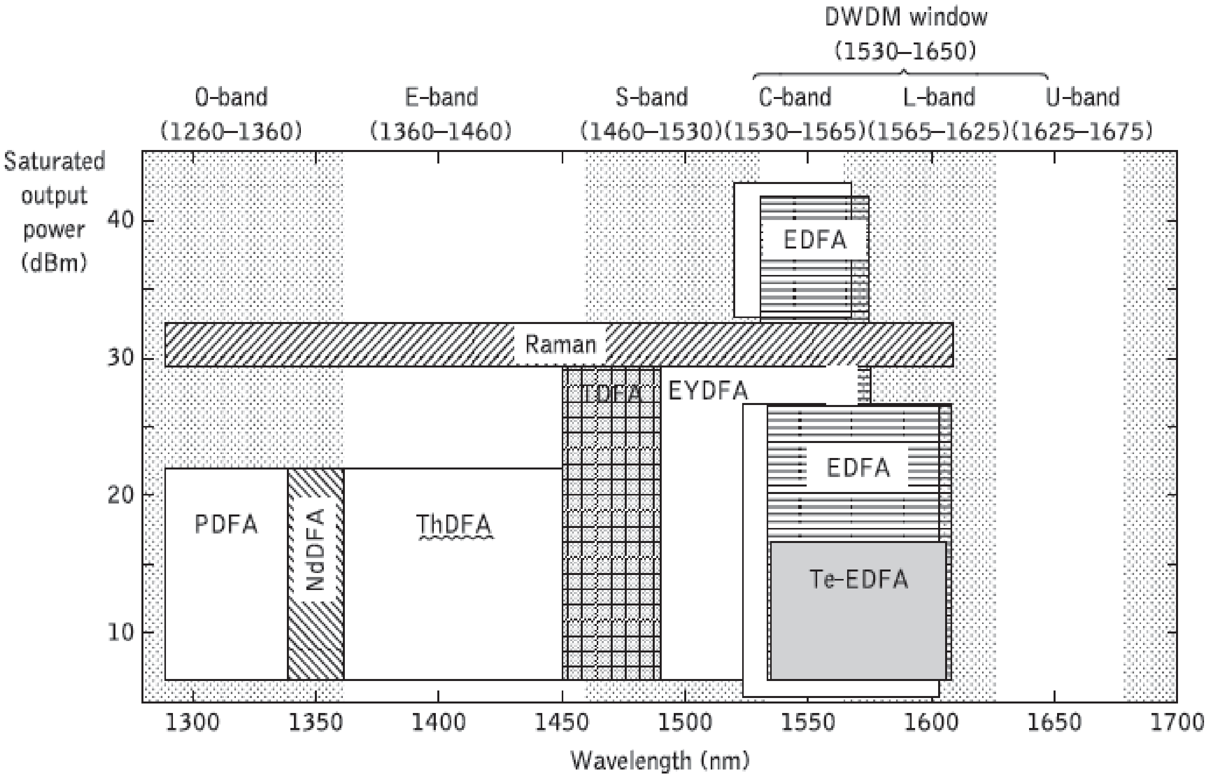


Figure 2.4 Optical amplification wavelength range for different fiber amplifiers [19]

The typical gain profiles for various optical amplifier types based around the 1.3 and 1.5 μm wavelength regions are illustrated in Figure 10.1. It may be observed that the semiconductor optical amplifier (SOA), the erbium-doped fiber amplifier (EDFA) and the Raman fiber amplifier all provide wide spectral bandwidths. Hence these optical amplifier types lend themselves to applications involving wavelength division multiplexing [21]. By contrast, the Brillouin fiber amplifier has a very narrow spectral bandwidth, possibly around 50 MHz, and therefore cannot be employed for wideband amplification. It could, however, be used for channel selection within a WDM system by allowing amplification of a particular channel without boosting other nearby channels.

Whereas SOAs exhibit low power consumption and their single-mode waveguide structures make them particularly appropriate for use with single-mode fiber, it is fiber amplifiers which present fewer problems of compatibility for in-line interconnection within optical fiber links [22]. At present, SOAs are the most developed optical amplifier generic type but research into fiber amplifiers has also made rapid progress towards commercial products over the last few years.

The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the Fiber amplifiers (e.g. EDFA, Raman amplifier) and can be integrated with semiconductor lasers, modulators, etc. However, the performance is still not comparable with the Fiber amplifiers. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time. High optical nonlinearity makes semiconductor amplifiers attractive for all optical signal processing like all-optical switching and wavelength conversion.

2.3.1 EDFA

The erbium-doped fiber amplifier is emerging as a major enabler in the development of worldwide fiber-optic networks. The purpose of this chapter is to present an introduction to the history of the erbium-doped fiber amplifier, as well as the context within which fiber amplifiers are having a very significant commercial impact. The emergence of the fiber amplifier foreshadows the invention and development of further guided wave devices that should play a major role in the continuing increase in transmission capacity and functionality of fiber networks.

Doped fibre amplifiers (DFAs) are optical amplifiers that use a doped optical fibre as a gain medium to amplify an optical signal. They are related to fibre lasers. The signal to be amplified and a pump laser are multiplexed into the doped fibre, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fibre Amplifier (EDFA), where the core of a silica fibre is doped with trivalent erbium ions and can be efficiently pumped with a laser at a wavelength of 980 nm or 1,480 nm, and exhibits gain in the 1,550 nm region.

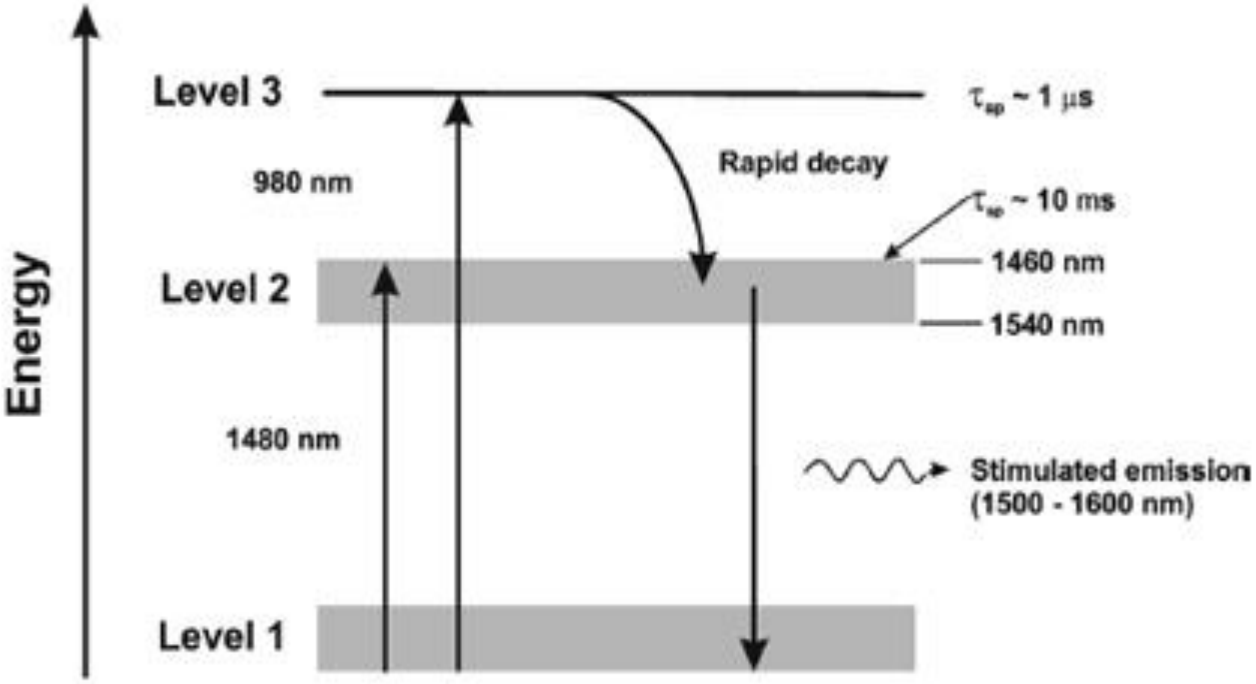


Fig 2.5 Energy band Diagram of Erbium ion [19]

Amplification is achieved by stimulated emission of photons from dopant ions in the doped fibre. The pump laser excites ions into a higher energy from where they can decay via stimulated emission of a photon at the signal wavelength back to a lower energy level. The excited ions can also decay spontaneously (spontaneous emission) or even through non-radiative processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification.

The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fibre, and the wavelength and power of the pump laser.

Set up for an EDFA amplifier in the network is show below in the figure 2.6.

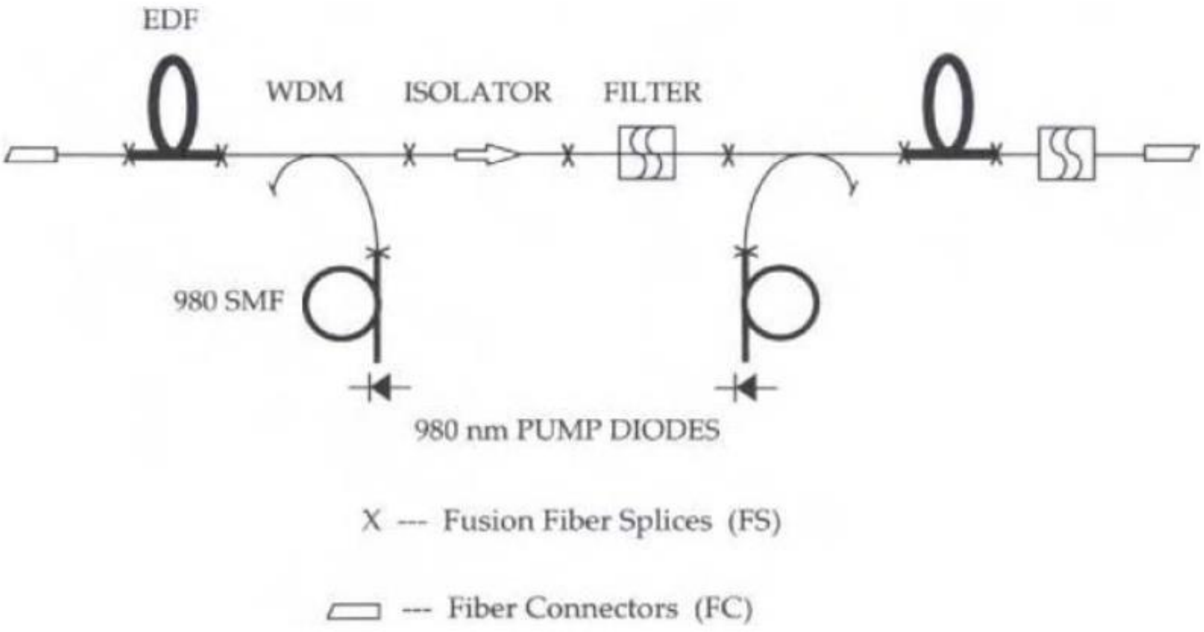


Figure 2.6: Typical two-stage erbium-doped fiber amplifier. The various components needed are pump lasers, isolators, wavelength division multiplexers (WDM), filters, connectors, and various types of transmission fiber[23].

The principal source of noise in DFAs is Amplified Spontaneous Emission (ASE), which has a spectrum approximately the same as the gain spectrum of the amplifier. Noise figure in an ideal DFA is 3 dB, while practical amplifiers can have noise figure as large as 6–8 dB.

As well as decaying via stimulated emission, electrons in the upper energy level can also decay by spontaneous emission, which occurs at random, depending upon the glass structure and inversion level. Photons are emitted spontaneously in all directions, but a proportion of those will be emitted in a direction that falls within the numerical aperture of the fibre and are thus captured and guided by the fibre. Those photons captured may then interact with other dopant ions, and are thus amplified by stimulated emission. The initial spontaneous emission is therefore amplified in the same manner as the signals, hence the term Amplified Spontaneous Emission. ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE is a direct concern to system performance since that noise will co-propagate with the signal to the receiver where it degrades system performance.

Counter-propagating ASE can, however, lead to degradation of the amplifier's performance since the ASE can deplete the inversion level and thereby reduce the gain of amplifier.

2.3.2 Raman Amplifier

Raman gain arises from the transfer of power from one optical beam to another that is downshifted in frequency by the energy of an optical phonon (a vibrational mode of the medium), as shown in Fig. 1.1. Figure 1.2 shows that Raman amplifiers utilize pumps to impart a transfer of energy from the pumps to the transmission signals through the Raman effect mechanisms. In particular, counter propagating pump geometry is illustrated. As discussed below, this is commonly used to avoid coupling of pump fluctuations to the signal. Also shown are isolators that can be used around the amplifiers to avoid the amplification of spurious reflections and control of double Rayleigh scattering. The Raman gain spectrum in fused silica fibers is illustrated in Fig. 2.7 [24, 25].

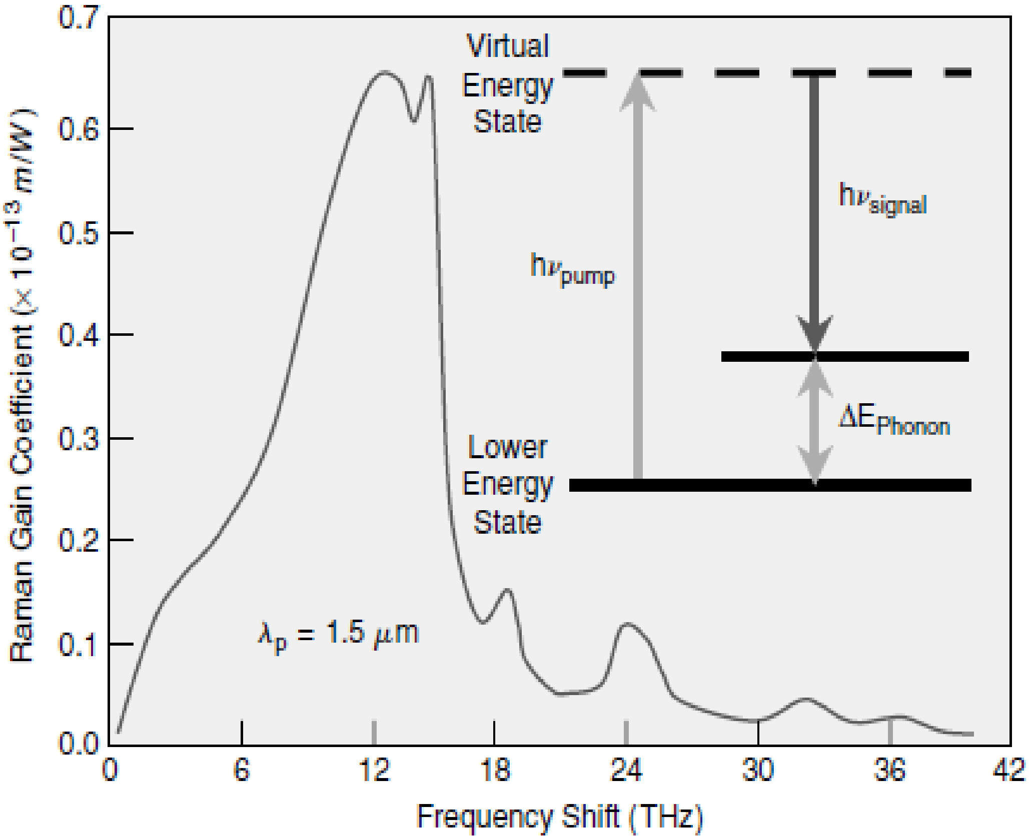


Fig. 2.7. Raman gain curve in fused silica fiber for copolarized pump and signal beams [24, 25]. Inset shows an energy level diagram representative of the Raman process, which takes a higherenergy pump photon and splits it into a lower-energy signal photon and a phonon.

The gain bandwidth is over 40 THz wide, with the dominant peak near 13.2 THz. The gain band shifts with the pump spectrum, and the peak value of the gain coefficient is inversely proportional to the pump wavelength. In the telecommunications bands around 1500 nm, 13.2 THz corresponds to approximately 100 nm. For example, if the pump is near 1450 nm, then the gain band will be around 1550 nm.

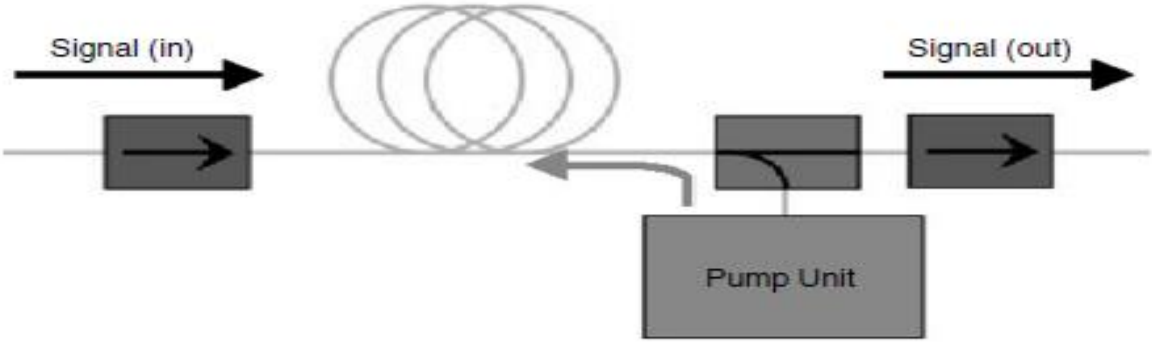


Fig. 2.8. Raman amplifiers transfer energy from the pump beam to the signal beam. The configuration shown has a counter propagating pump and signal beam[26].

Because a long fiber length with small core size is required for Raman amplifiers, it is possible to combine the amplification process with the required chromatic dispersion compensation. To achieve the most efficient gain due to Raman, gain fiber with the smallest effective area is best utilized. Of the various fiber types commercially available, dispersion-compensating fiber, or DCF, exhibits the smallest effective area resulting in the highest Raman gain efficiency. The resulting, chromatic dispersion compensation can be achieved simultaneously within the discrete Raman amplifier portion of an “all-Raman” system. External, per band, DCF units, along with their associated attenuation of the signal wavelengths, need not be engineered into the total system span budget. In current systems such as those based on EDFAs, the loss of the DCF is minimized by placing the DCF in the midstage of a two- or more stage amplifier. Even so, some amount of margin must be allocated for the DCF loss, or alternately the additional gain and associated noise required to compensate this loss. With Raman, the DCF provides gain, not loss. Some of the Raman fundamental properties would appear to be drawbacks for telecommunications applications. However, many of these drawbacks can be overcome by proper design of the amplifier architecture. For example, Fig. 1.3 illustrates the polarization dependence of Raman gain [24].

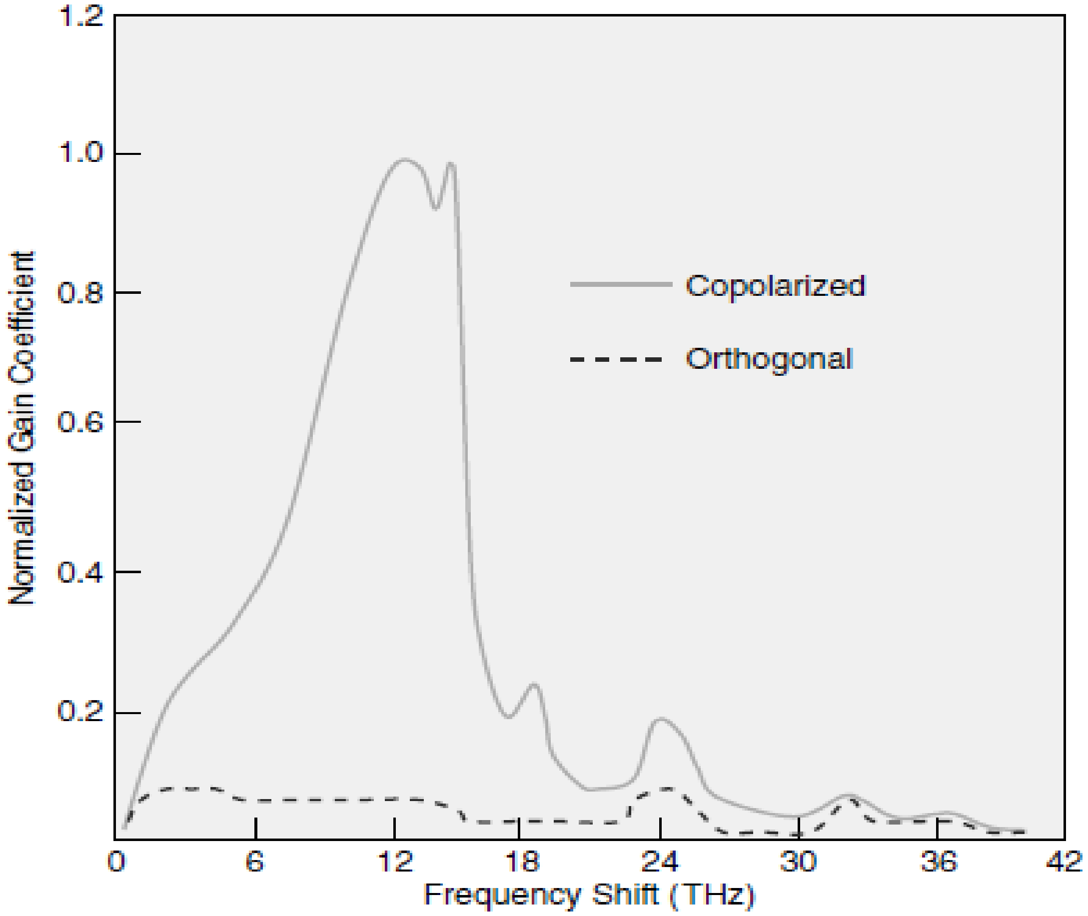


Fig. 2.9. Normalized Raman gain coefficient for copolarized and orthogonally polarized pump and signal beams [24]. Source: R.H. Stolen and E.P. Ippen "Raman Gain in Glass Optical Waveguides" Applied Physics Letters Vol 22 (©1973 AIP)

The copolarized gain is almost an order of magnitude larger than the orthogonal polarization gain near the peak of the Raman curve. Nonetheless, a polarization-independent Raman amplifier can be made by using polarization diversity pumping to avoid polarization-dependent loss. Furthermore, the mixture of modes in a non-polarization-maintaining fiber helps to scramble the polarization dependence.

Based on the above physics, some of the advantages of Raman amplifiers become clear. First, Raman gain exists in every fiber: this means, for example, that existing links can be upgraded even though they are already installed. This provides a cost effective means of upgrading, inasmuch as the upgrade can be done from the terminal ends. Second, the gain is non-resonant, which means that gain is available over the entire transparency region of the fiber ranging from approximately 0.3 microns to 2 microns. To illustrate, Fig. 2.10 shows the attenuation versus wavelength for a typical fused silica fiber [27]. For wavelengths below 1310 nm, loss rises from Rayleigh scattering. For wavelengths above about 1620 nm, the loss rises from bend-induced losses as well as infrared absorption. This still provides a window from about 1250 to 1650 nm, or a window of about 50 THz optical bandwidth. Most systems today use erbium-doped fiber amplifiers and operate in the C-band, which stretches between about 1530 and 1565 nm. Extended band amplifiers are beginning to open up the long wavelength L-band, which is between approximately 1570 and 1610 nm. Therefore, less than half of the low-loss window in the optical fiber is used with current amplifier technology based on EDFAs.

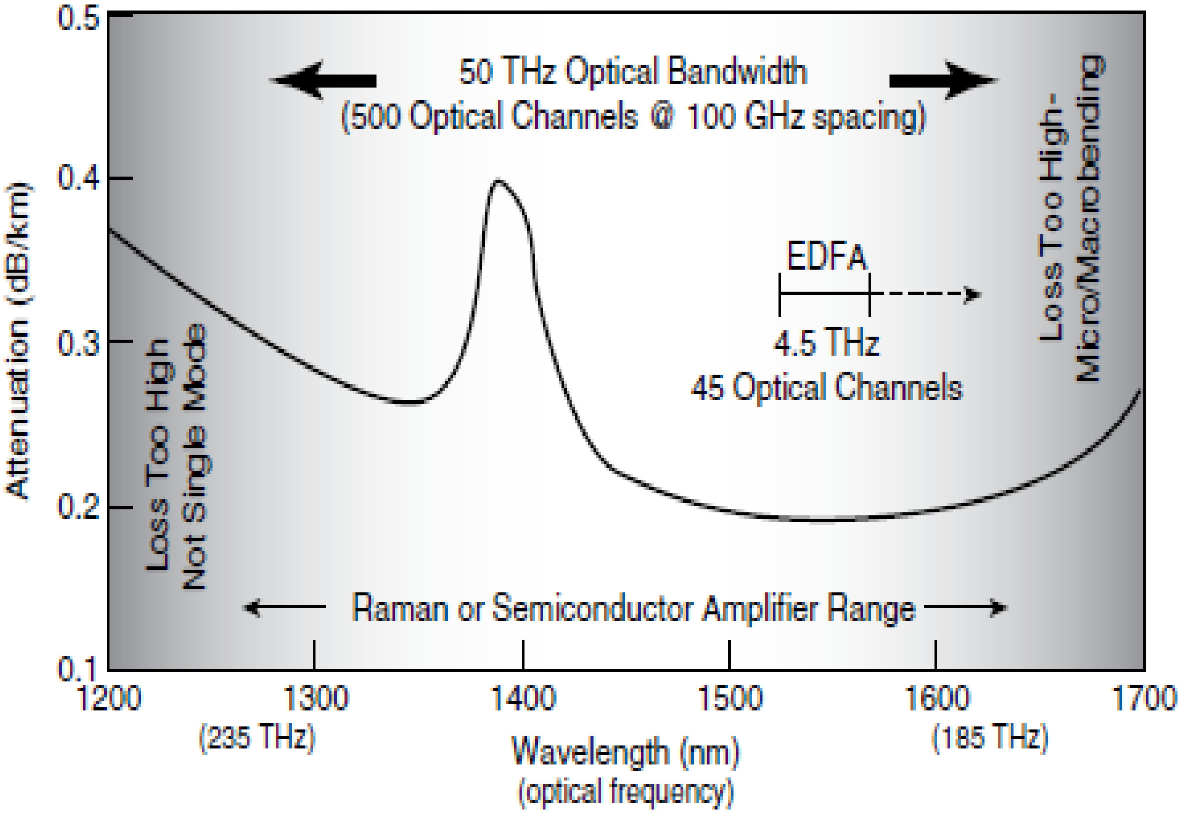


Fig. 2.10. Attenuation versus wavelength for a typical fused silica fiber [27]. Source: R.B.Kummer “Fiber Issues for NontraditionalWavelength Bands” OFCTechnical Digest, pg ThR1-1 (©2000 OSA)

A third advantage of Raman amplifiers is that the gain spectrum can be tailoredby adjusting the pump wavelengths. For instance, multiple pump lines can be used to increase the optical bandwidth, and the pump distribution determines the gain flatness. As an example of tailoring of the Raman gain spectrum. Fig. 2.11 shows the gain spectrum using one or two pump wavelengths [28, 29].

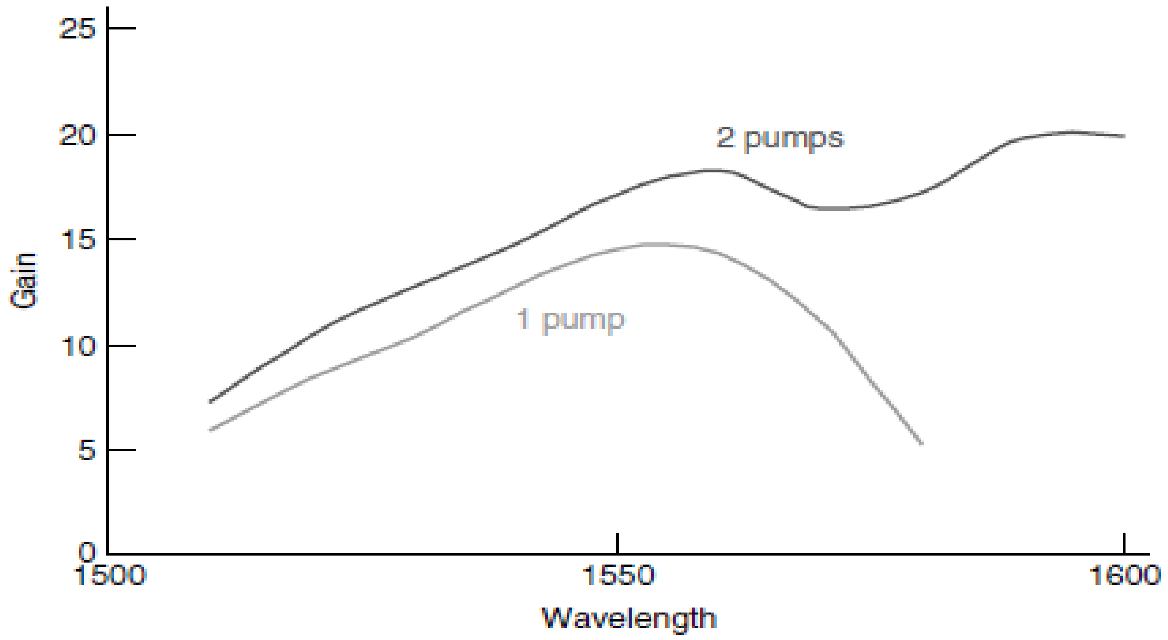


Fig. 2.11. Raman gain spectrum using one or two pump wavelengths [28, 29].

2.3.3 Hybrid Amplifier

This chapter describes the technologies needed for cascading an erbium-doped fiber amplifier (EDFA) and a fiber Raman amplifier (FRA or RA) to create a hybrid amplifier (HA), the EDFA/Raman HA. Two kinds of HA are defined the narrowband HA (NB-HA) and the seamless and wideband HA (SWB-HA). The NB-HA employs distributed Raman amplification in the transmission fiber together with an EDFA and provides low noise transmission in the C- or L-band. The noise figure of the transmission line is lower than it would be if only an EDFA were used. The SWB-HA, on the other hand, employs distributed or discrete Raman amplification together with an EDFA, and provides a low-noise and wideband transmission line or a low-noise and wideband discrete amplifier for the C- and L-bands. The typical gain bandwidth of the NB-HA is ~30 to 40 nm, whereas that of the SWB-HA is ~70 to 80 nm.

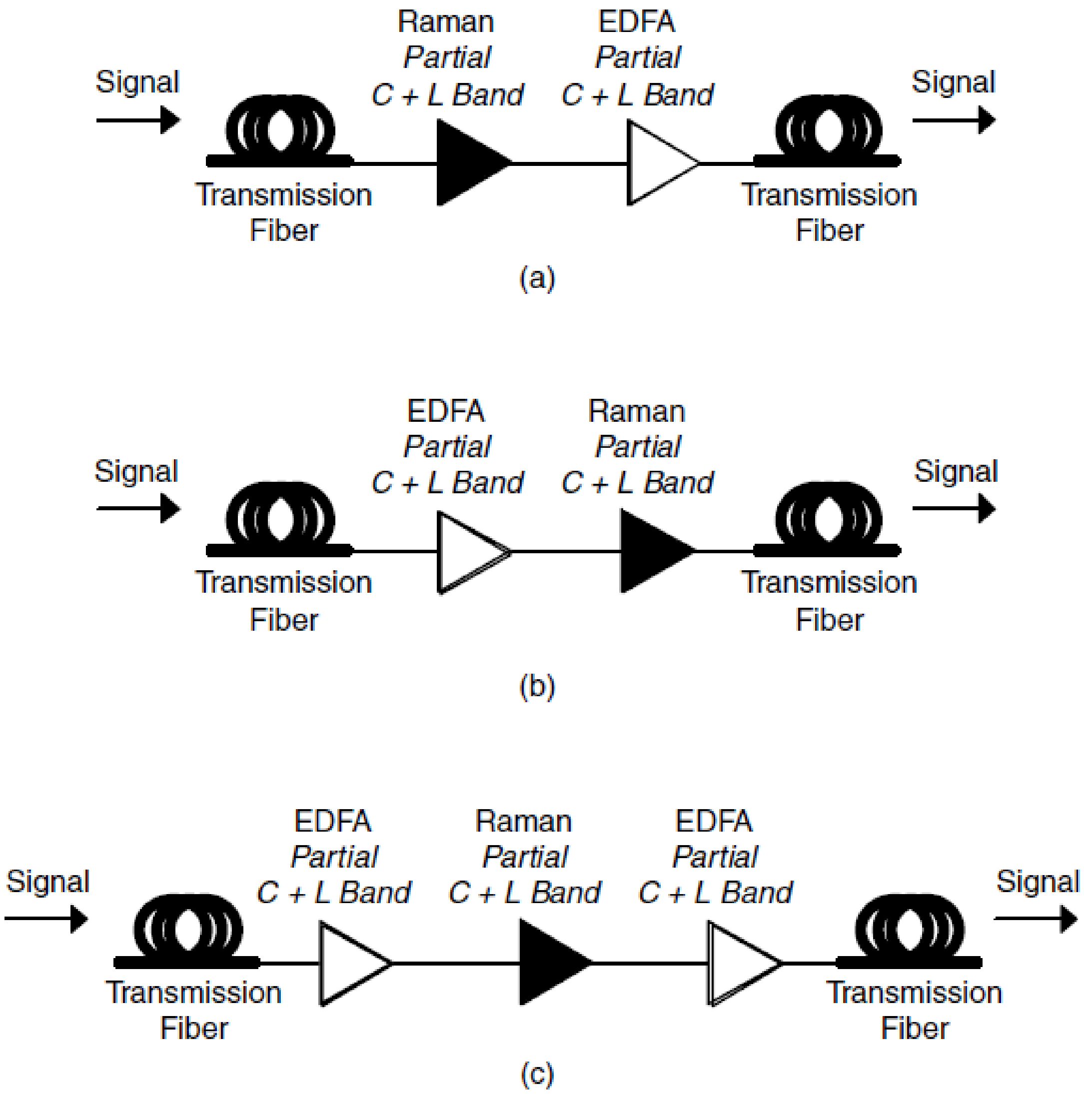


Fig. 2.12. Basic configurations of a transmission line with a seamless wideband hybrid EDFA/Raman amplifier. Each of the EDFA and Raman amplifiers covers a partial C- and L-band with different gain slopes. The EDFA and Raman amplifier are serially connected. The hybrid amplifiers are: (a) a discrete Raman amplifier followed by an EDFA; (b) an EDFA followed by a discrete Raman amplifier; (c) pre- and post-EDFAs and an intermediate discrete Raman amplifier[30].

Another example of an EDFA/DRA hybrid amplifier is NB-HAs (narrowband hybrid EDFA/Raman amplifiers). Figure 13.10 shows the configuration of the L-band NB-HA of [5].

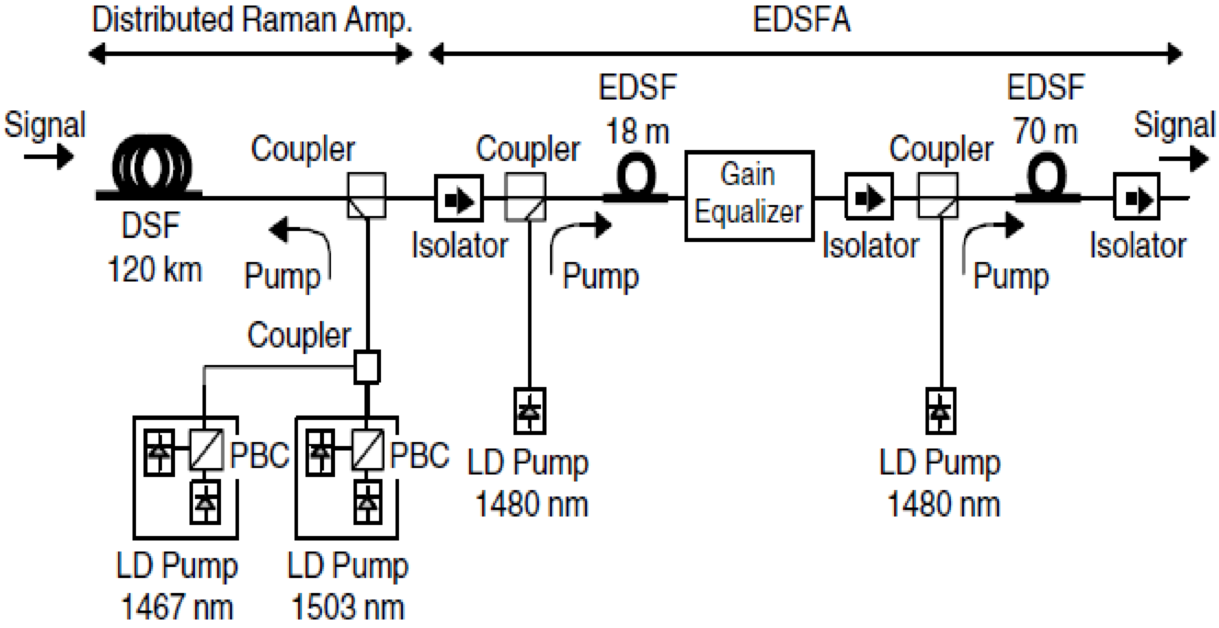


Fig. 2.13. Configuration of a narrowband hybrid EDFA/Raman amplifier (PBC: polarization beam combiner). (After Ref. [32]. © 1999 IEE)

The HA consists of a DRA and an EDSFA. Several experiments have been reported on the NB-HA [31–34], including NB-HAs in the L-band with DSFs. The improvements in the OSNR and the transmission distance with a fixed inline repeater spacing [32] and a repeater spacing upgrade [4] with the NB-HAs were confirmed. Moreover, reports on NB-HAs in the C-band with DSFs have confirmed the significant suppression of nonlinear impairments and the improvement of the transmission distance [33, 34, 35].

Due to these factors in our research we consider the NB-HAs (narrowband hybrid EDFA/Raman amplifiers).

Chapter 3

Hybrid amplifier (EDFA/DRA) based WDM-PON

The focus of this chapter is the designing of Wavelength Division multiplexing based Passive Optical Network. Here, we design the circuit with help of Optisysten 7 and get the simulation result in different spectrum.

3.1 Introduction

The experimental setup of hybrid amplifier (EDFA/DRA) based WDM-PON is shown in the fig. here we have used pump laser array as an optical source of different wave length, to multiplex these signals we have used a WDM-multiplexer followed by a 100 km long single mode optical Fiber. now to overcome the losses we have used a distributed raman amplifier of 10 km length followed by two Erbium doped fiber amplifiers each of 5 meter length. To analyse the overall gain, noise figure and signal to noise ratio we are using dual port WDM analyser and to observe signal and noise spectrum we are using optical spectrum analyser.

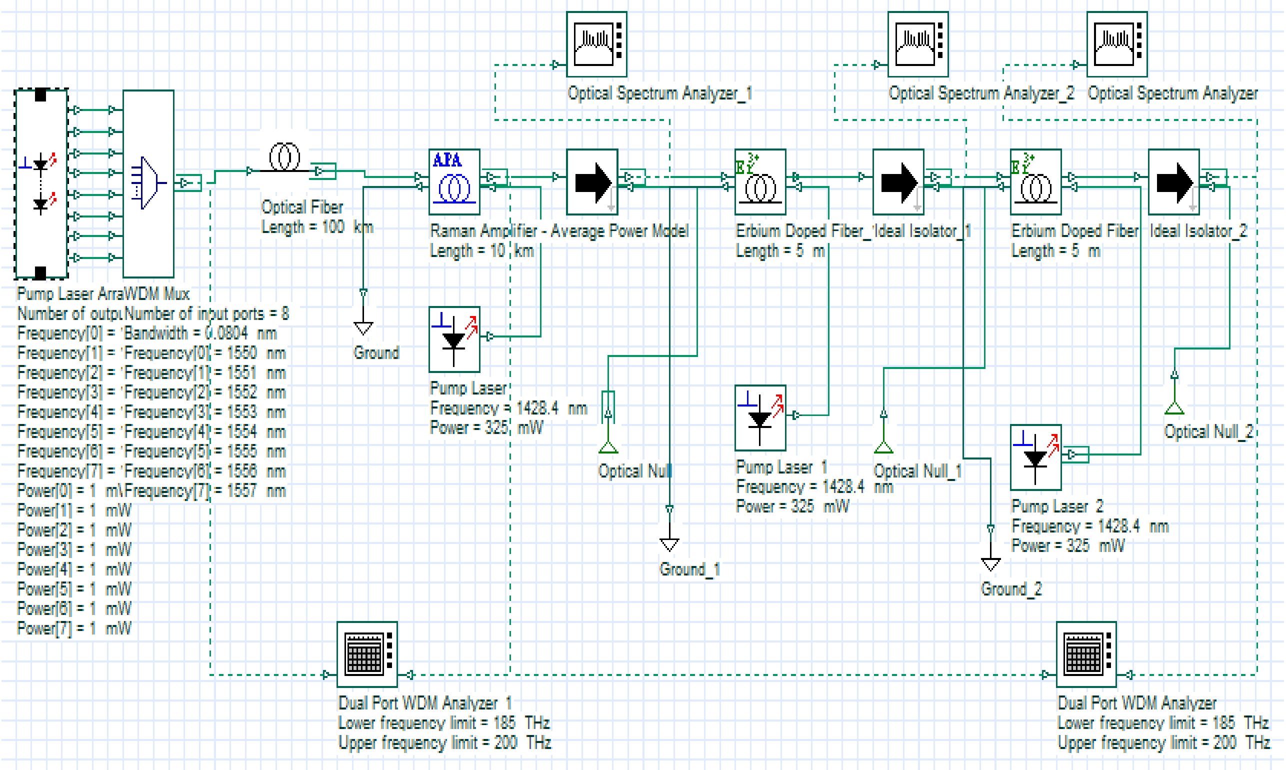
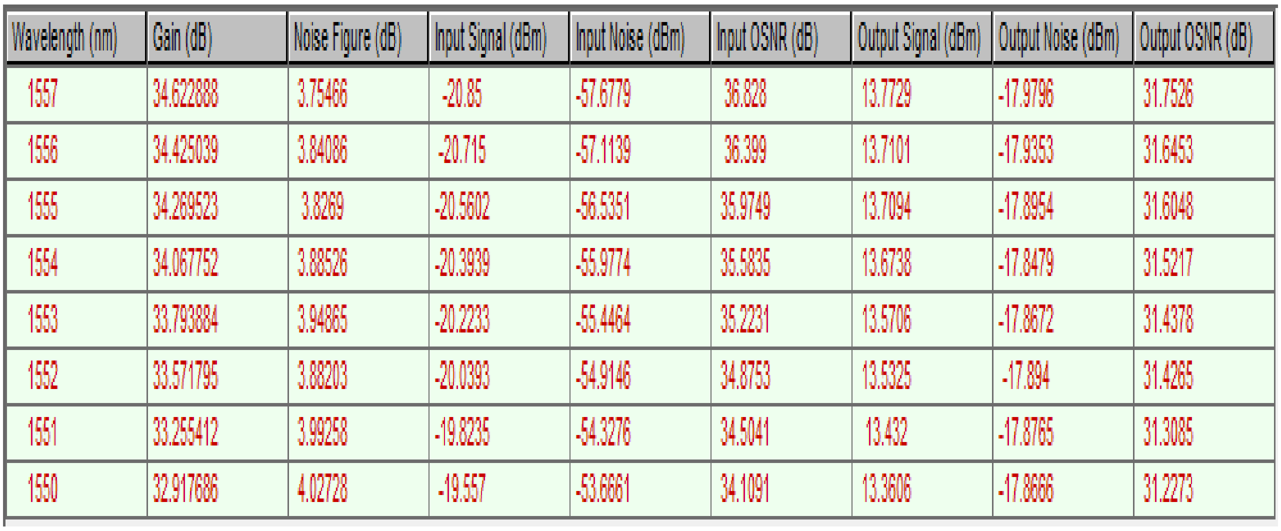


Fig 3.1 Experimental setup of EDFA/DRA based WDM-PON with 8 channels in optisystem 7

3.2 Simulation results with 8 channels

Now we are going to analyse the optical network in different wavelength window. The Simulation results of WDM-PON shown in fig 3.1 with 8 multiplexed channels each spaced at 1 nm in different spectrum is given below.

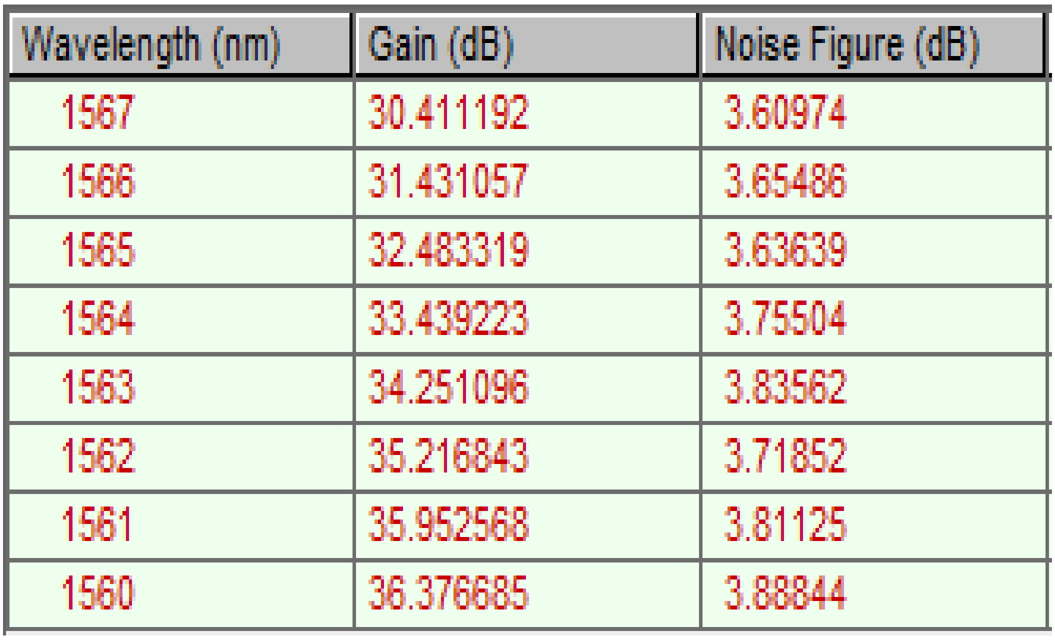
Table 3.1 different parameters (e.g. gain, Noise figure, OSNR etc.) with 8 multiplexed channels (1550-1557 nm)



Wavelength (nm)	Gain (dB)	Noise Figure (dB)	Input Signal (dBm)	Input Noise (dBm)	Input OSNR (dB)	Output Signal (dBm)	Output Noise (dBm)	Output OSNR (dB)
1557	34.622888	3.75466	-20.85	-57.6779	36.828	13.7729	-17.9796	31.7526
1556	34.425039	3.84086	-20.715	-57.1139	36.399	13.7101	-17.9353	31.6453
1555	34.269523	3.8269	-20.5602	-56.5351	35.9749	13.7094	-17.8954	31.6048
1554	34.067752	3.88526	-20.3939	-55.9774	35.5835	13.6738	-17.8479	31.5217
1553	33.793884	3.94865	-20.2233	-55.4464	35.2231	13.5706	-17.8672	31.4378
1552	33.571795	3.88203	-20.0393	-54.9146	34.8753	13.5325	-17.894	31.4265
1551	33.255412	3.99258	-19.8235	-54.3276	34.5041	13.432	-17.8765	31.3085
1550	32.917686	4.02728	-19.557	-53.6661	34.1091	13.3606	-17.8666	31.2273

If we vary the wavelength window gain and noise figure varies with it. In the tables given below are few simulation reults in different window.

Table 3.2 Gain and Noise Figure in late C and early L band with 8 channels (1560-1567 nm)



Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1567	30.411192	3.60974
1566	31.431057	3.65486
1565	32.483319	3.63639
1564	33.439223	3.75504
1563	34.251096	3.83562
1562	35.216843	3.71852
1561	35.952568	3.81125
1560	36.376685	3.88844

The signal and noise strength variation could be analysed by the spectrum analyser is show in the fig 3.2

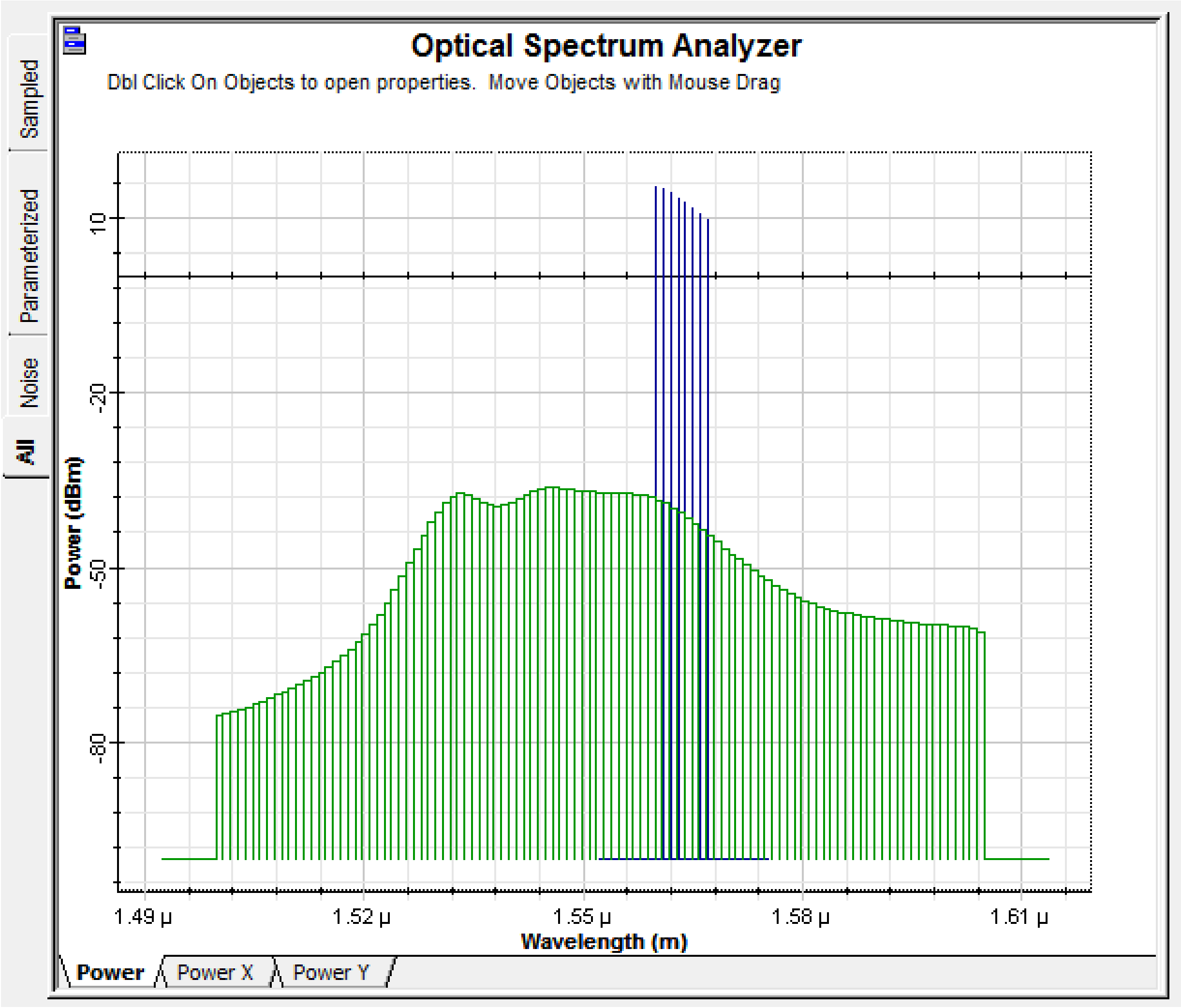


Fig 3.2 Signal and Noise spectrum with 8 channels (1560-1567 nm)

As we can see with only 8 multiplexed channels we are getting gain as high as 34.62 dB but it is not very cost effective so we are going to increase the no. of channels up to 16 and then analyse the results.

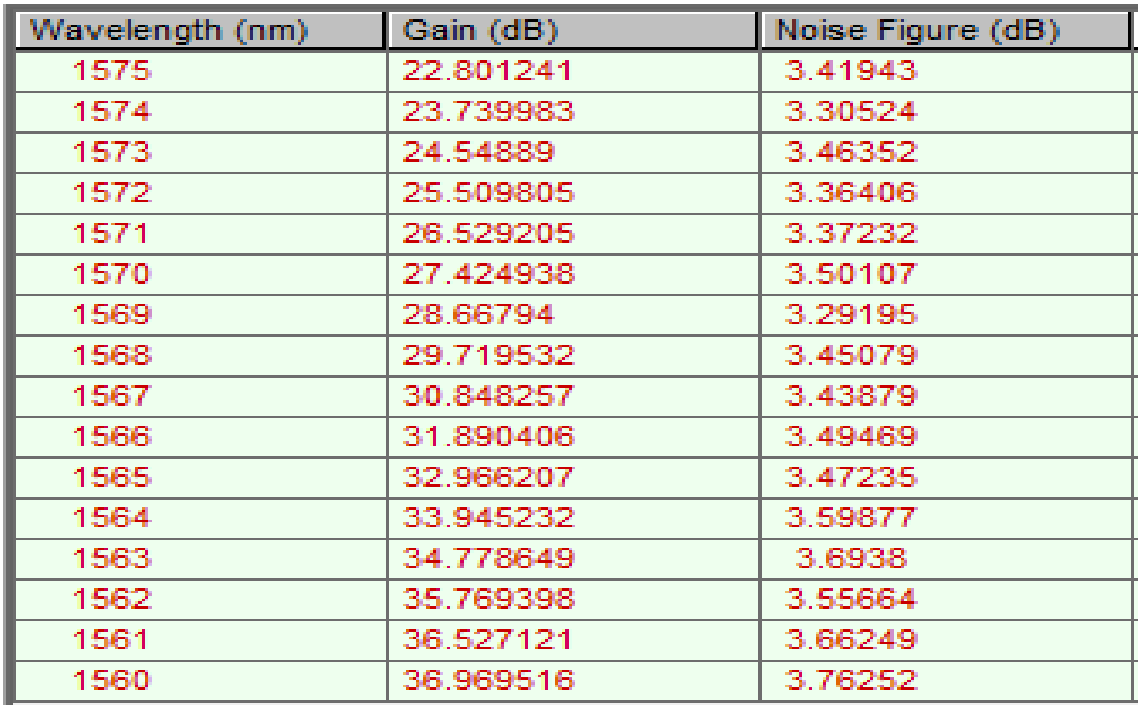
3.3 Simulation results with 16 channels

Now we are going to analyse the overall gain and noise figure with hybrid EDFA/DRA amplifier with different 16 channels window each channel spaced at 1nm channel spacing, in lower C band and early L band.

Table 3.3 Gain and Noise figure with 16 multiplexed channels in late C band (1550-1565 nm)

Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1565	26.291701	3.52186
1564	26.95114	3.62348
1563	27.486776	3.67646
1562	28.131935	3.5266
1561	28.585618	3.59781
1560	28.775364	3.71227
1559	29.019389	3.60242
1558	29.011975	3.71572
1557	28.903889	3.76839
1556	28.604319	3.96061
1555	28.336536	3.97014
1554	28.024801	4.08571
1553	27.647409	4.268
1552	27.303295	4.26765
1551	26.877616	4.5709
1550	26.425	4.70204

Table 3.4 Gain and noise figure with 16 multiplexes channels (1560-1575 nm)



Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1575	22.801241	3.41943
1574	23.739983	3.30524
1573	24.54889	3.46352
1572	25.509805	3.36406
1571	26.529205	3.37232
1570	27.424938	3.50107
1569	28.66794	3.29195
1568	29.719532	3.45079
1567	30.848257	3.43879
1566	31.890406	3.49469
1565	32.966207	3.47235
1564	33.945232	3.59877
1563	34.778649	3.6938
1562	35.769398	3.55664
1561	36.527121	3.66249
1560	36.969516	3.76252

As we can see with variation of wavelength gain and noise Figure of our optical network varies significantly. In 1550-1565 nm window maximum gain was 29 dB only, whereas in 1560-1575 nm window the maximum gain was increased up to around 37 dB but there was a huge variation in gain with wavelength in this window.

To see the variation of gain with wavelength the amplitude and noise spectrum is plotted in fig 3.3 given below

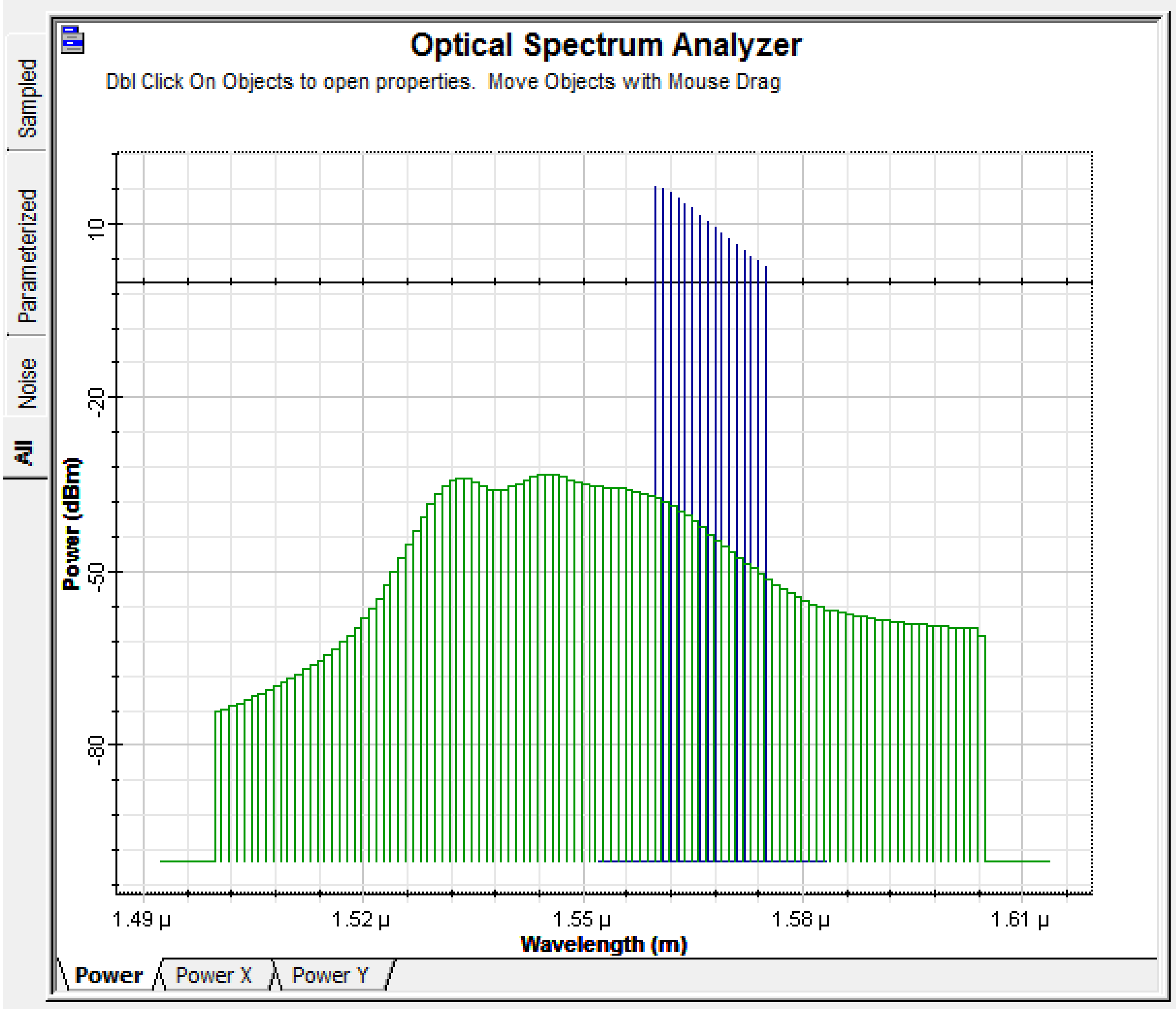
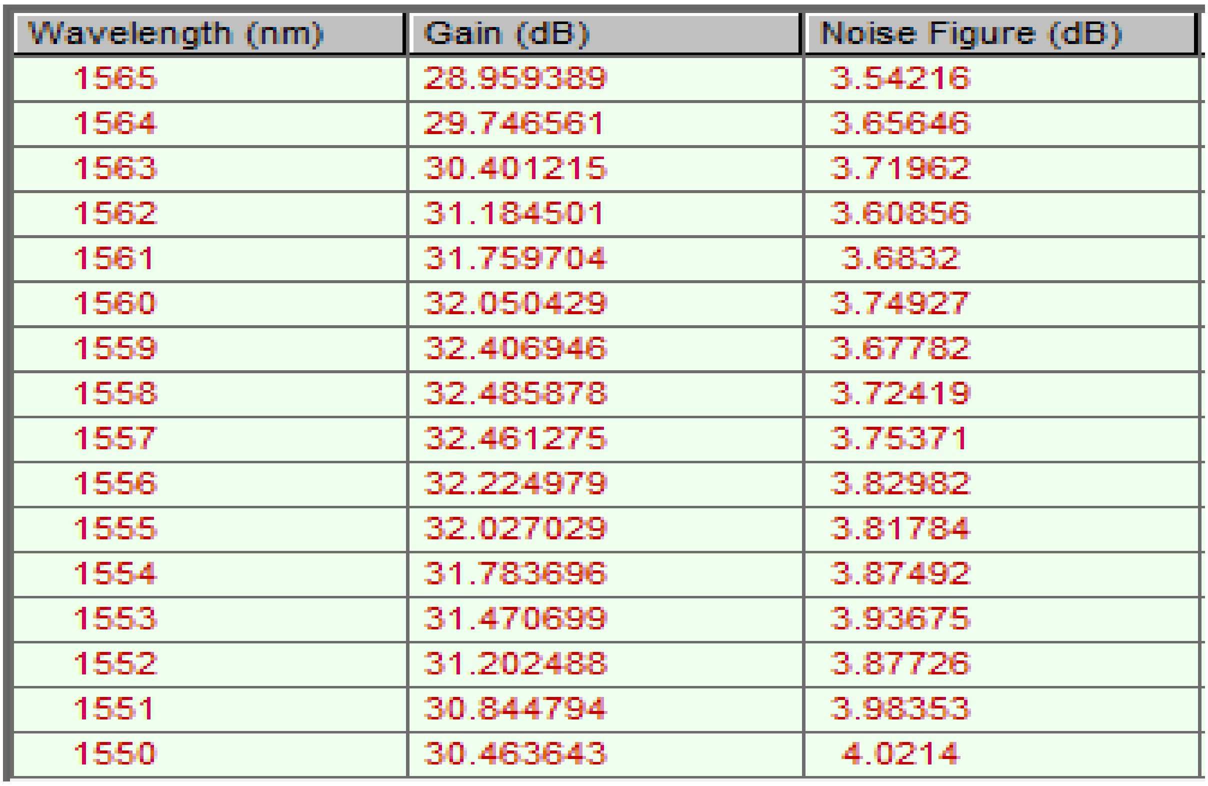


Fig 3.3 Signal and noise spectrum with 16 multiplexed channel (1560-1575 nm)

As we can see the gain is dropped with 16 multiplexed channel as compare to 8 multiplexed channel but it can be further improved with variation of amplifier pump power and pumping signal wave length. The best combination is achieved at pump power of 325 mW and pump signal wavelength of 1428.4 nm. Gain and noise figure at these values are given in table 3.5.

Table 3.5 Gain and Noise Figure with 16 multiplexed channels (1550-1565 nm)



Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1565	28.959389	3.54216
1564	29.746561	3.65646
1563	30.401215	3.71962
1562	31.184501	3.60856
1561	31.759704	3.6832
1560	32.050429	3.74927
1559	32.406946	3.67782
1558	32.485878	3.72419
1557	32.461275	3.75371
1556	32.224979	3.82982
1555	32.027029	3.81784
1554	31.783696	3.87492
1553	31.470699	3.93675
1552	31.202488	3.87726
1551	30.844794	3.98353
1550	30.463643	4.0214

These all results were without use any modulation scheme now we are going to analyse the effect of different modulation scheme on our passive optical network.

Chapter 4

Effect of modulation on gain and noise figure

4.1 Introduction

We know that in digital communication system different modulation scheme improve the communication range reliability of system. Different modulation scheme have different probability of error in this chapter we are going to analyse the effect of these modulation scheme on our passive optical network.

4.2 Effect of phase modulation

Now before transmission we have phase modulated each channel (wavelength), the experimental setup of phase modulated 16 channel multiplexed WDM-PON is given below in fig. 4.1

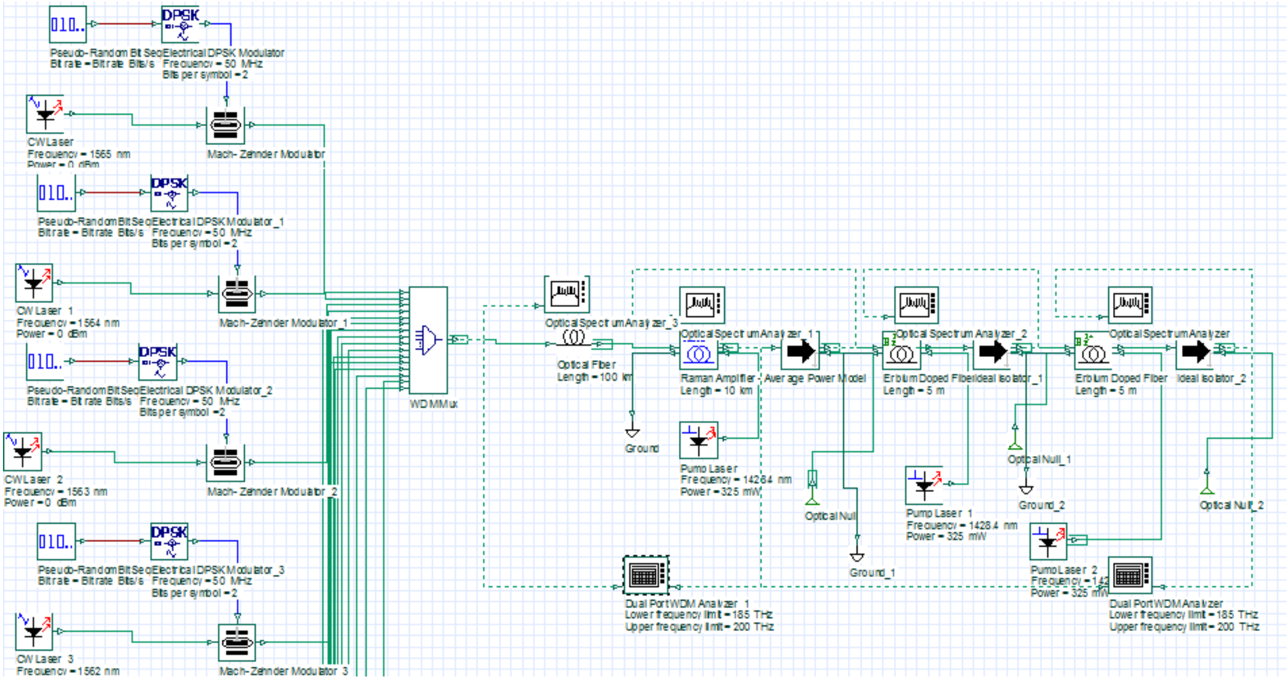
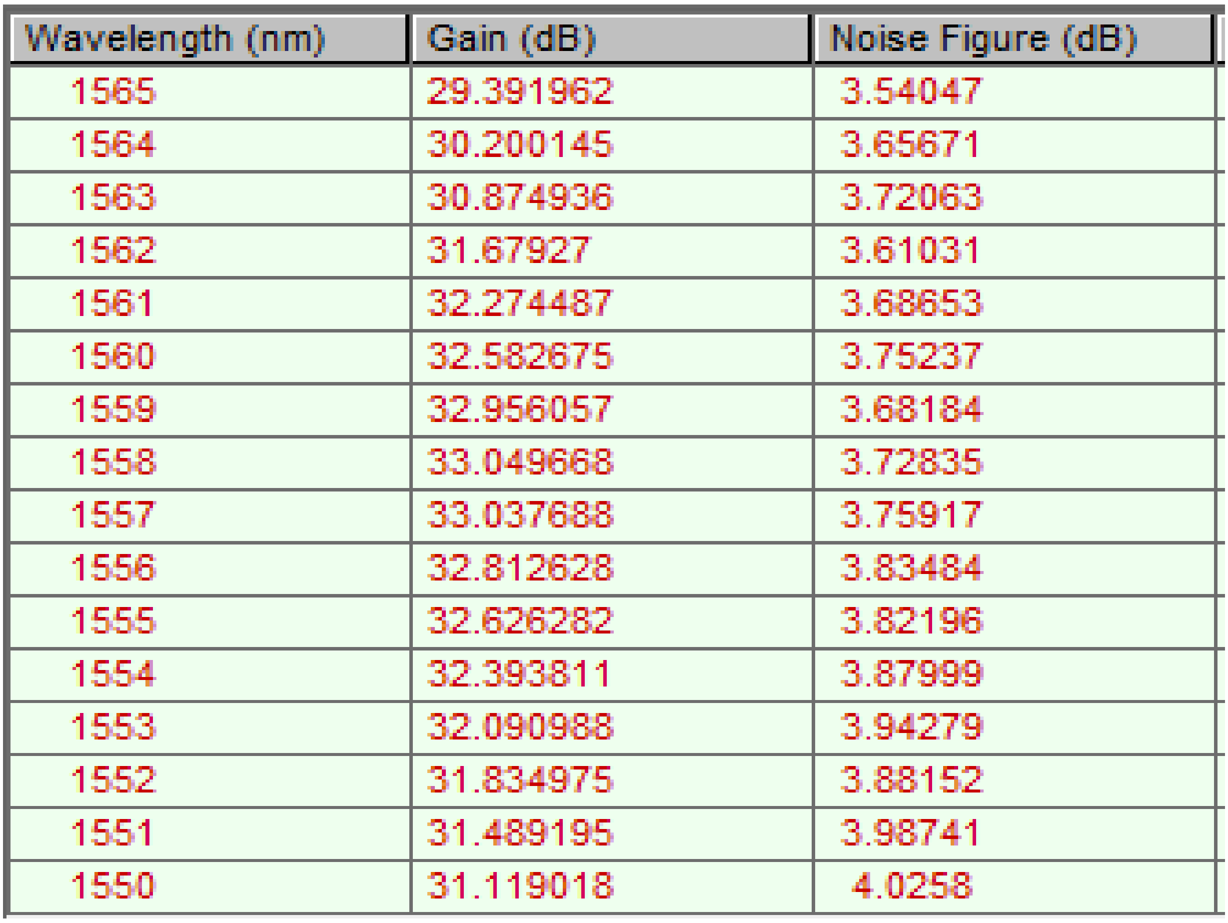


Fig 4.1 Phase modulated 16 channel multiplexed WDM-PON

The simulation results of phase modulated 16 channel multiplexed signal is given below in table 4.1

Table 4.1 Gain and noise figure of phase modulated 16 channels (1550-1565 nm) PON.



Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1565	29.391962	3.54047
1564	30.200145	3.65671
1563	30.874936	3.72063
1562	31.67927	3.61031
1561	32.274487	3.68653
1560	32.582675	3.75237
1559	32.956057	3.68184
1558	33.049668	3.72835
1557	33.037688	3.75917
1556	32.812628	3.83484
1555	32.626282	3.82196
1554	32.393811	3.87999
1553	32.090988	3.94279
1552	31.834975	3.88152
1551	31.489195	3.98741
1550	31.119018	4.0258

As we can see gain with phase modulation is increased around 0.5 dB with respect to 16 channels no modulation WDM-PON. But noise figure isn’t affected much so now we are going to use another modulation scheme.

4.3 Effect of DPSK

Earlier we realized that with help of PSK gain is improved as much as 0.5 db. But as we know DPSK(Differential Pulse Shift Keying) is better modulation scheme so now we are going to analyse our WDM-PON with DPSK. The experimental set up for DPSK based 16 channels WDM-PON in optisystem 7 is given below in fig 4.2

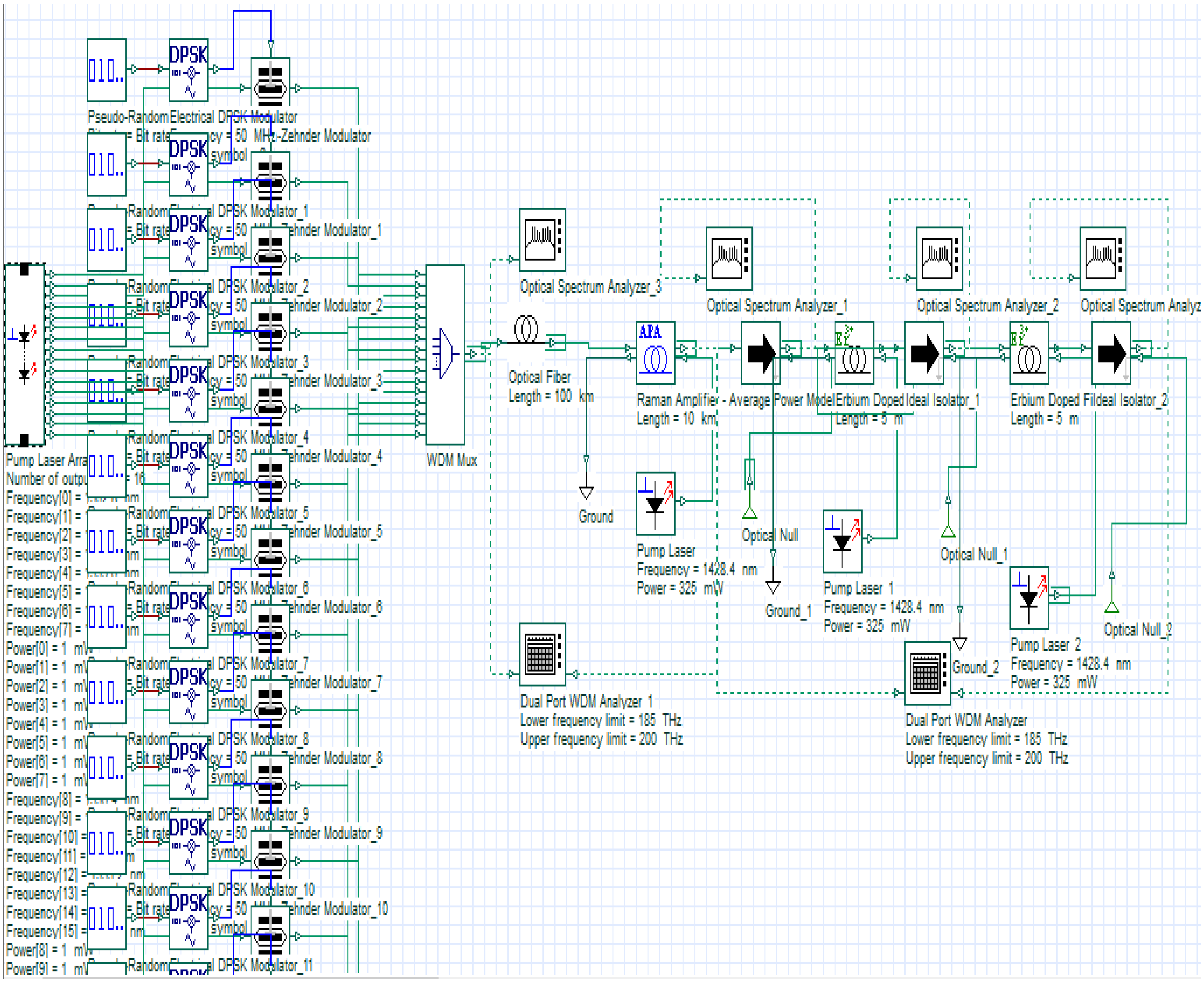


Fig 4.2 Experimental set up for DPSK based 16 channels WDM-PON

Here we have used a pump laser array as variable optical source, a PRBS generator, a differential phase shift keying and after that a mach zehnder modulator. Then these modulate 16 signals are multiplexed with a WDM multiplexer and then passed on to the 100 km single mode fiber. After which we have set up of our hybrid (EDFA/DRA) amplifier. To analyse the gain we are using dual port WDM-analyser

The simulation result for DPSK based 16 channels (1550-1565 nm) WDM-PON from the WDM analyser (e.g. their gain and noise figure) is given below in table 4.2

Table 4.2 Gain and Noise Figure for DPSK based 16 channel (1550-1565 nm) WDM-PON

Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1565	31.025885	3.55132
1564	31.912089	3.67664
1563	32.659069	3.74894
1562	33.548993	3.63346
1561	34.218455	3.71768
1560	34.5878	3.78955
1559	35.031074	3.71452
1558	35.176965	3.76646
1557	35.216652	3.7968
1556	35.029748	3.87756
1555	34.885985	3.86381
1554	34.695619	3.92413
1553	34.432342	3.98907
1552	34.222905	3.92089
1551	33.918216	4.03294
1550	33.592262	4.0684

Signal and noise strength of various frequency component is given below in fig. 4.3.

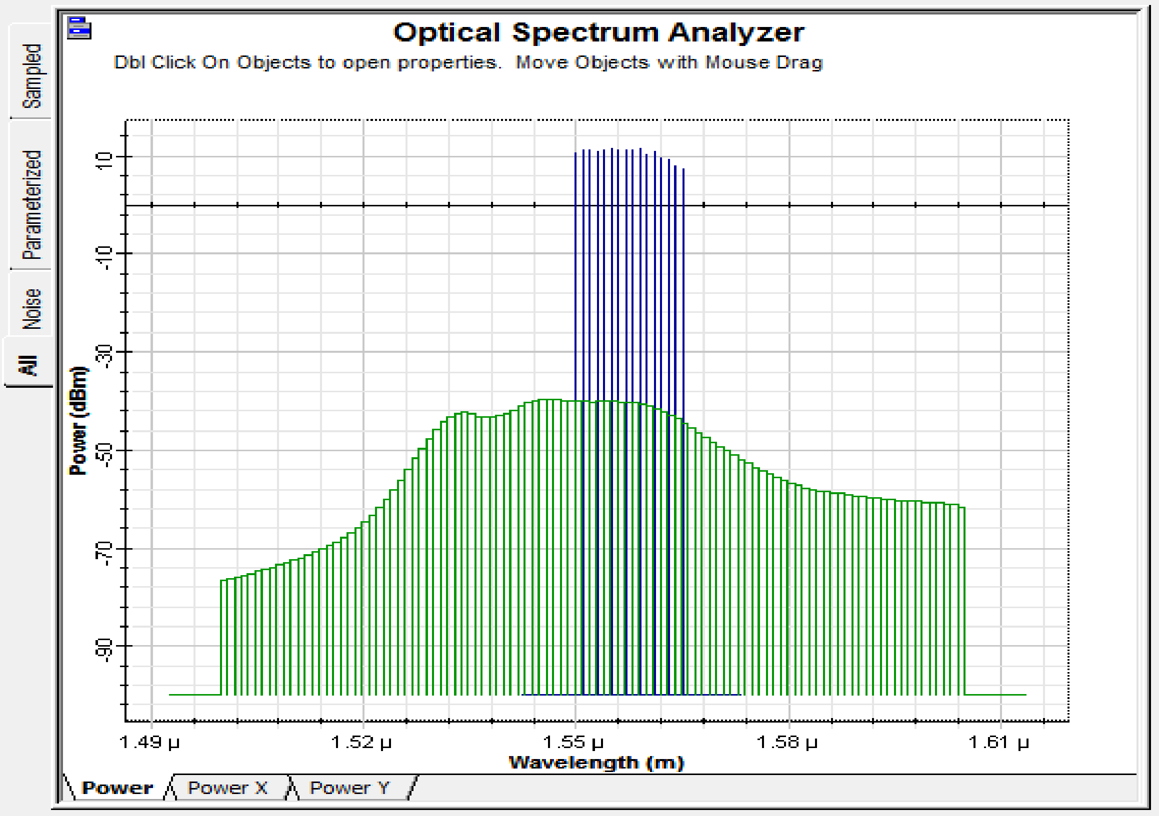
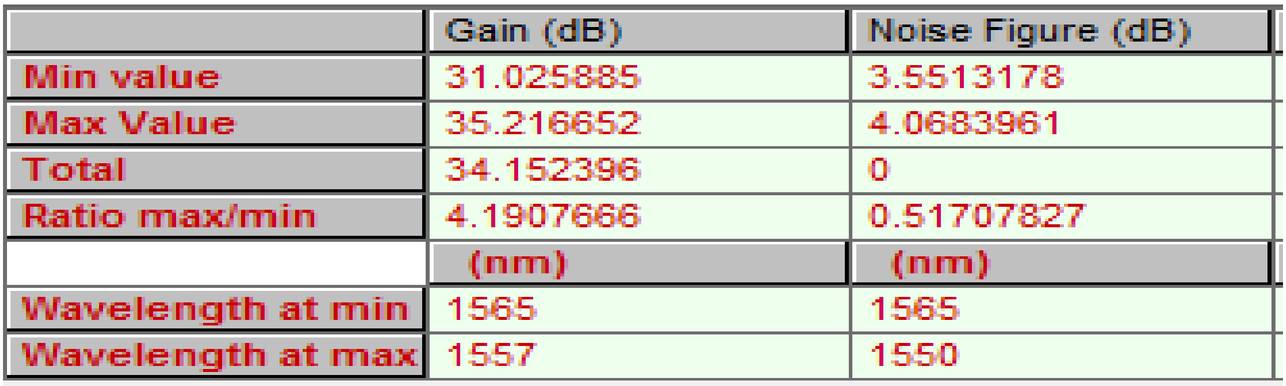


Fig 4.3 Signal and Noise Spectrum for DPSK based 16 channel (1550-1565 nm) WDM-PON

As we can see that the gain of our hybrid amplifier (EDFA/DRA) based WDM-PON is improved more than 3 dB with help of DPSK compared to no modulation WDM-PON.

But gain is varying a lot with wavelength as shown in table 4.4 given below

Table 4.3 Variation of gain and noise figure at different wavelength

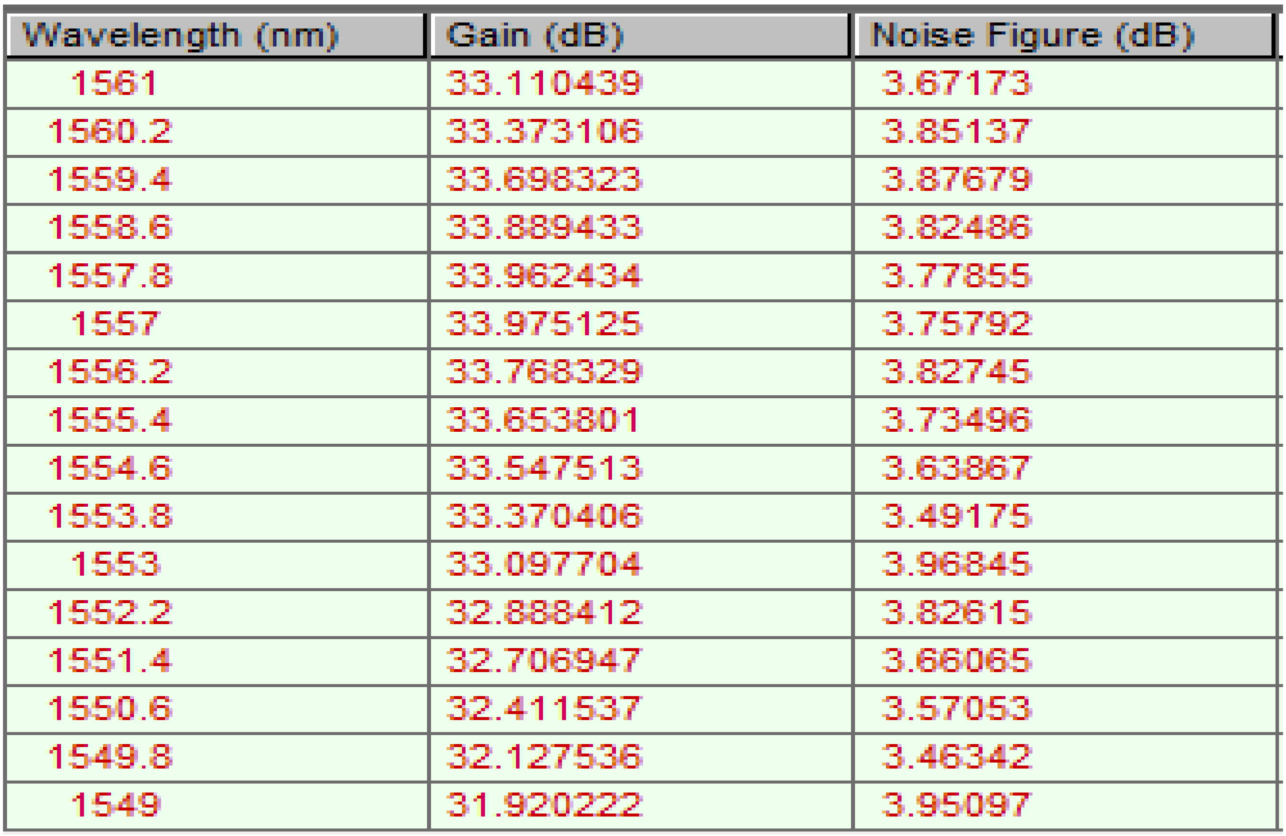


	Gain (dB)	Noise Figure (dB)
Min value	31.025885	3.5513178
Max Value	35.216652	4.0683961
Total	34.152396	0
Ratio max/min	4.1907666	0.51707827
	(nm)	(nm)
Wavelength at min	1565	1565
Wavelength at max	1557	1550

In all our previous calculations we were using either 8 or 16 channels each spaced at 1 nm meters. We analysed the gain in different operating window later C band, later C and early L band and also in early L band. We found the gain was highest in later C band with 8 channels. But with increasing the number of channels we reduce cost per channel and we optimized the gain up to significant value. But as we can see from table above still the ratio of maximum and minimum gain is quite large.

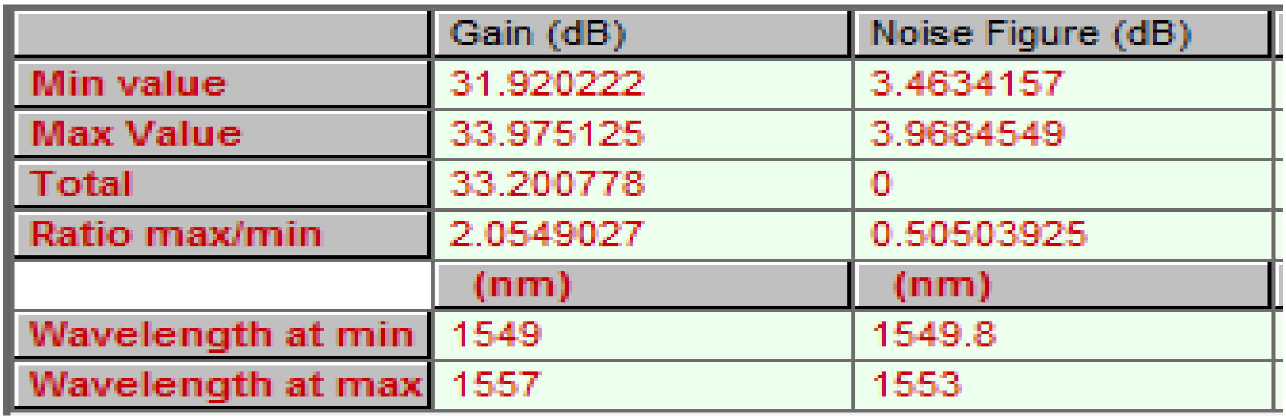
Now these results could be further improved by varying the operational wavelength window and channel spacing. During the simulation it was observed that the best outcome was achieved with channel spacing of 0.8 nm and channel wavelength of late C band few of simulation results are given below

Table 4.4 Gain and Noise figure of 16 multiplexed channel (each at 0.8nm spacing)



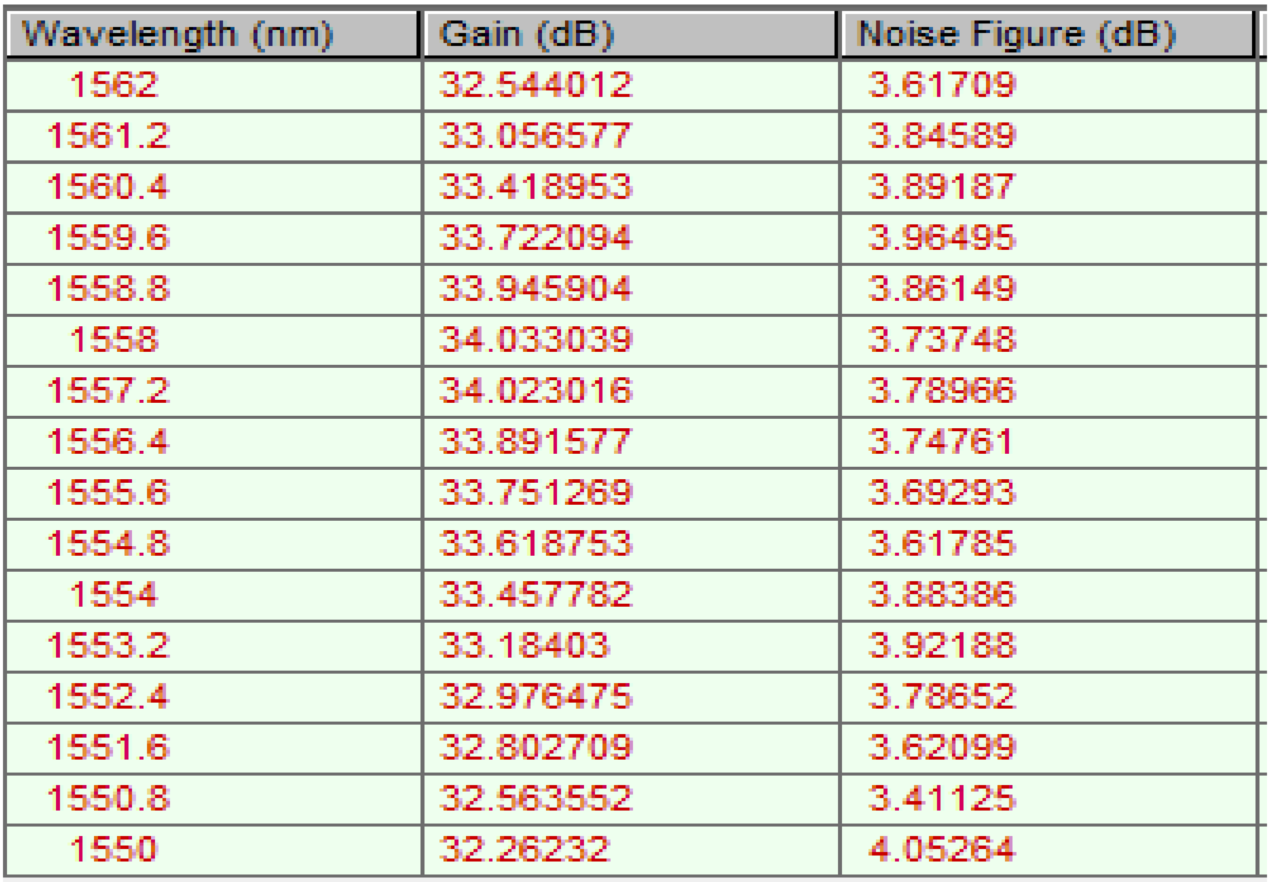
Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1561	33.110439	3.67173
1560.2	33.373106	3.85137
1559.4	33.698323	3.87679
1558.6	33.889433	3.82486
1557.8	33.962434	3.77855
1557	33.975125	3.75792
1556.2	33.768329	3.82745
1555.4	33.653801	3.73496
1554.6	33.547513	3.63867
1553.8	33.370406	3.49175
1553	33.097704	3.96845
1552.2	32.888412	3.82615
1551.4	32.706947	3.66065
1550.6	32.411537	3.57053
1549.8	32.127536	3.46342
1549	31.920222	3.95097

Table 4.5 Min and max gain and noise figure and their respective wavelength



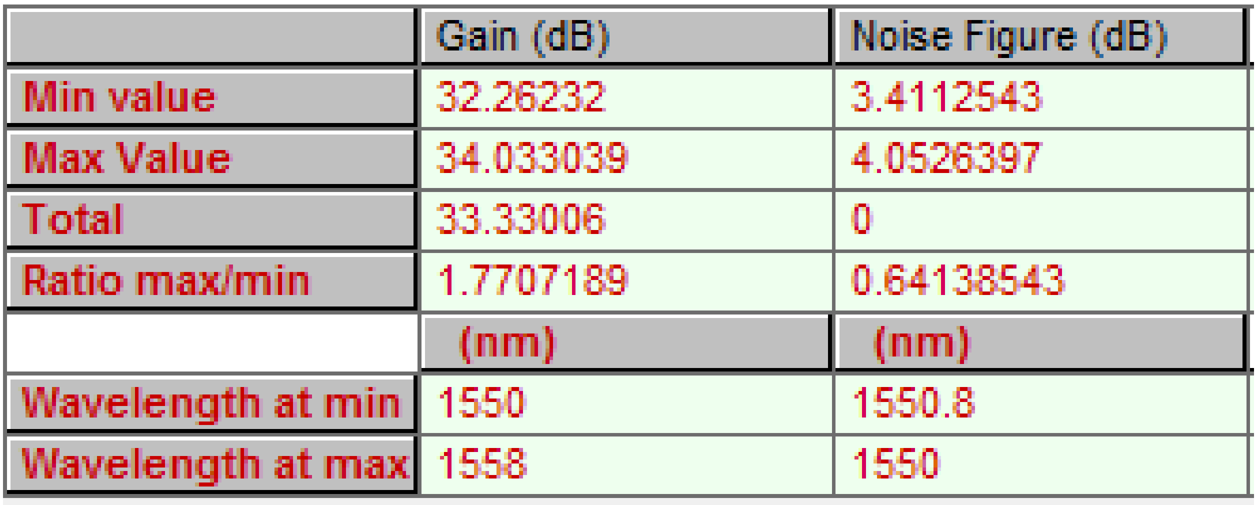
	Gain (dB)	Noise Figure (dB)
Min value	31.920222	3.4634157
Max Value	33.975125	3.9684549
Total	33.200778	0
Ratio max/min	2.0549027	0.50503925
	(nm)	(nm)
Wavelength at min	1549	1549.8
Wavelength at max	1557	1553

Table 4.6 Gain and noise figure 16 channel (1550-1562 nm each at 0.8 nm spacing)



Wavelength (nm)	Gain (dB)	Noise Figure (dB)
1562	32.544012	3.61709
1561.2	33.056577	3.84589
1560.4	33.418953	3.89187
1559.6	33.722094	3.96495
1558.8	33.945904	3.86149
1558	34.033039	3.73748
1557.2	34.023016	3.78966
1556.4	33.891577	3.74761
1555.6	33.751269	3.69293
1554.8	33.618753	3.61785
1554	33.457782	3.88386
1553.2	33.18403	3.92188
1552.4	32.976475	3.78652
1551.6	32.802709	3.62099
1550.8	32.563552	3.41125
1550	32.26232	4.05264

Table 4.7 Min and max gain and noise figure and their respective wavelength



	Gain (dB)	Noise Figure (dB)
Min value	32.26232	3.4112543
Max Value	34.033039	4.0526397
Total	33.33006	0
Ratio max/min	1.7707189	0.64138543
	(nm)	(nm)
Wavelength at min	1550	1550.8
Wavelength at max	1558	1550

As we can see we have optimized result as much as that the maximum and minimum gain ratio is dropped upto 1.77 and maximum noise figure as low as 4 dB.

The distribution of gain can analysed by signal and noise distribution as shown in fig 4.6 given below

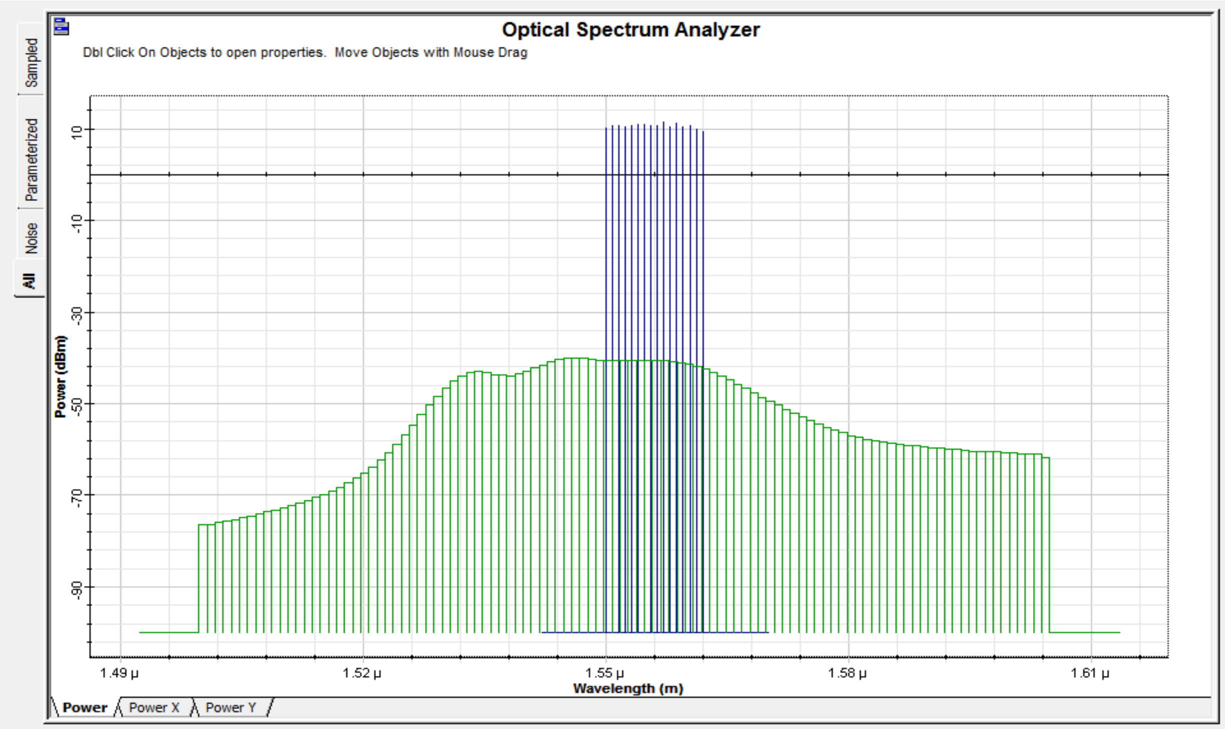


Fig 4.4 Signal and Noise Spectrum for DPSK based 16 channel (1550-1562 nm) WDM-PON

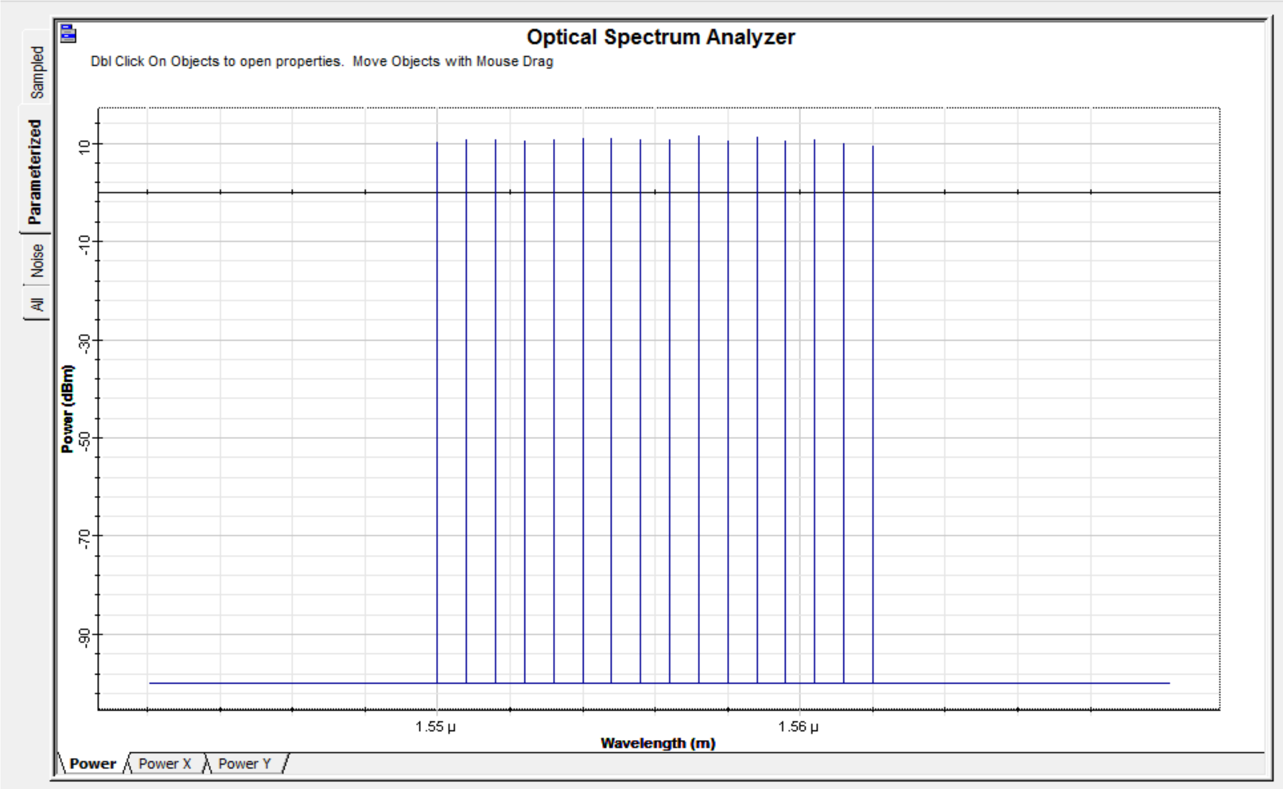


Fig 4.5 Signal Spectrum for DPSK based 16 channel (1550-1562 nm each at 0.8 nm) WDM-PON

From fig. 4.4, fig. 4.5 and table 4.7 it can be observed that variation of gain (i.e. difference between maximum and minimum gain) is reduced to a great extent by optimizing the parameters like channel spacing and pump signal wavelength.

These parameters effect the overall gain and Noise Figure of our optical network in various ways to understand their exact effect we are going to analyse their behaviour in detail in next chapter.

Chapter 5

Effect of variation of parameter

5.1 Introduction

This chapter illustrates the effect of variation of different parameter of wavelength division multiplexed passive optical network. In the optimized experimental setup which we designed on optisystem 7, we are going to vary different parameter like wavelength, pump power, pump signal wavelength etc. and going to observe the result via different graph plotted.

5.2 Gain vs wavelength

Variation of gain with wavelength of optimized setup of 16 channel (1550-1562 each spaced 0.8 nm apart) WDM-PON is given below

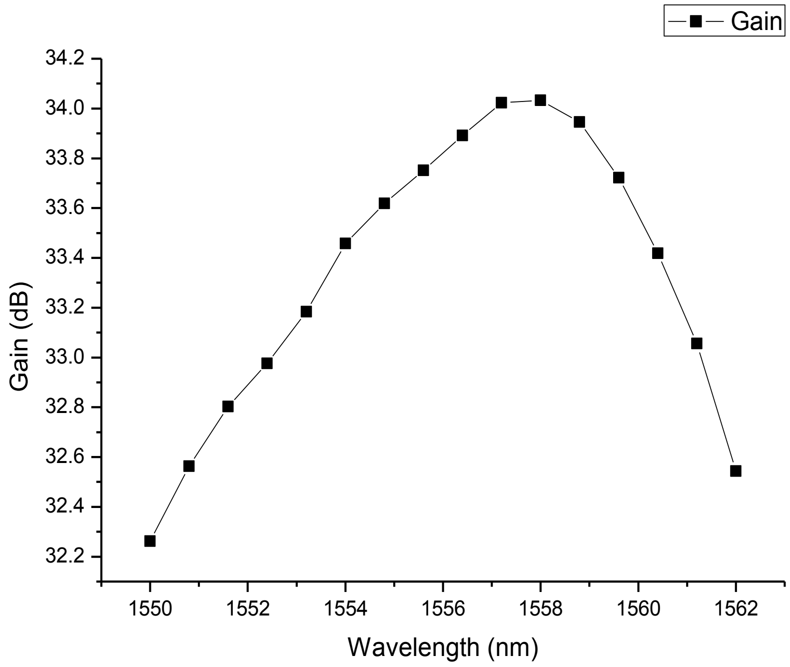


Fig 5.1 Variation of gain with wavelength

These observations of gain variation with wavelength are taken at some constant parameters like pump power of 325 mw, pump signal wavelength of 1428.4 nm.

5.3 Wavelength vs Noise Figure

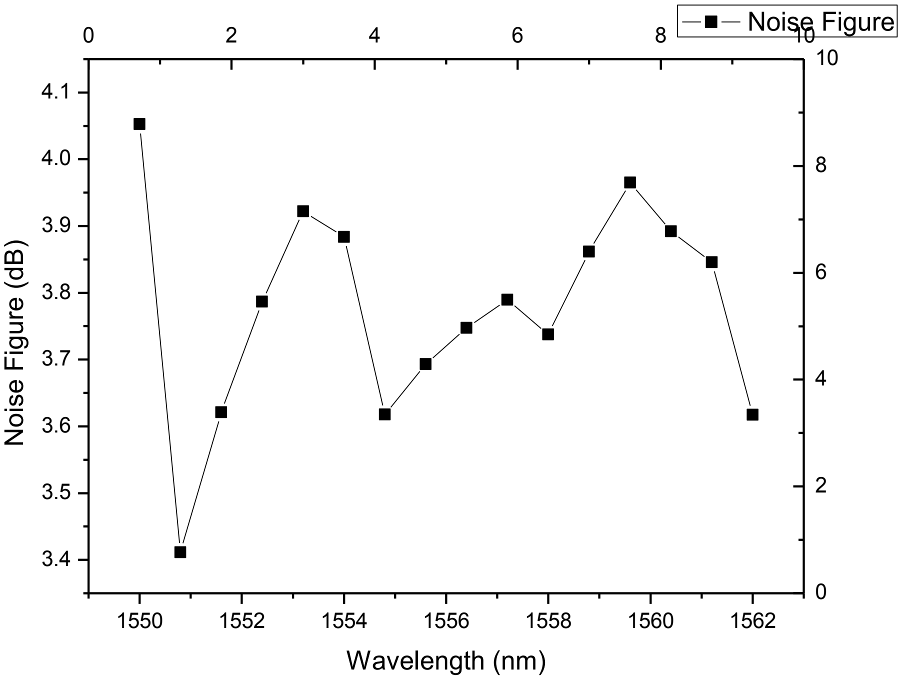


Fig 5.2 Wavelength vs Noise Figure

Noise Figure variations with wavelength is measured at constant pump power of 325 mw and pump signal wavelength of 1428.4 nm. As we can see overall Noise Figure is less than 4 dB.

5.4 Wavelength vs OSNR

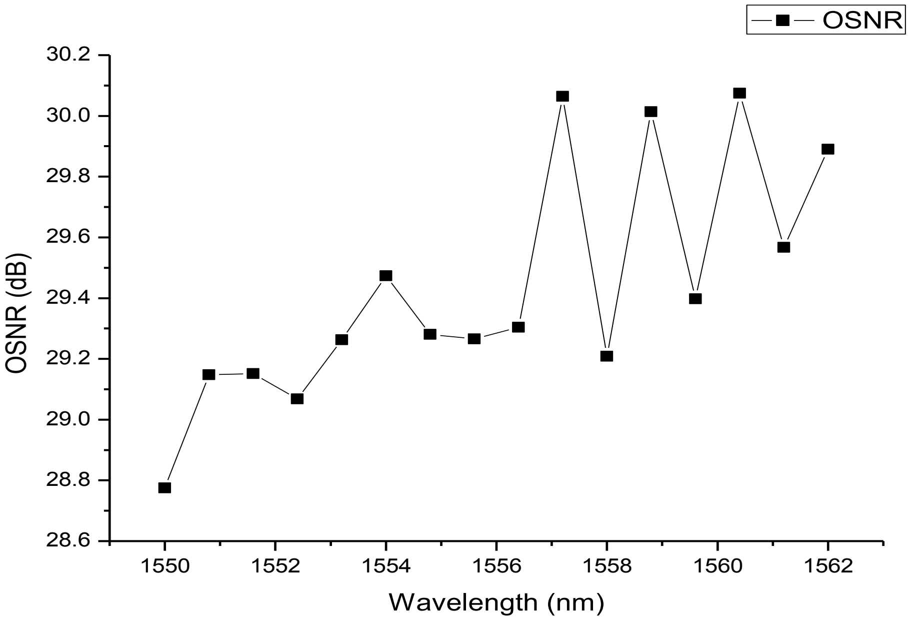


Fig 5.3 Wavelength vs OSNR

5.5 Variation of Pump power

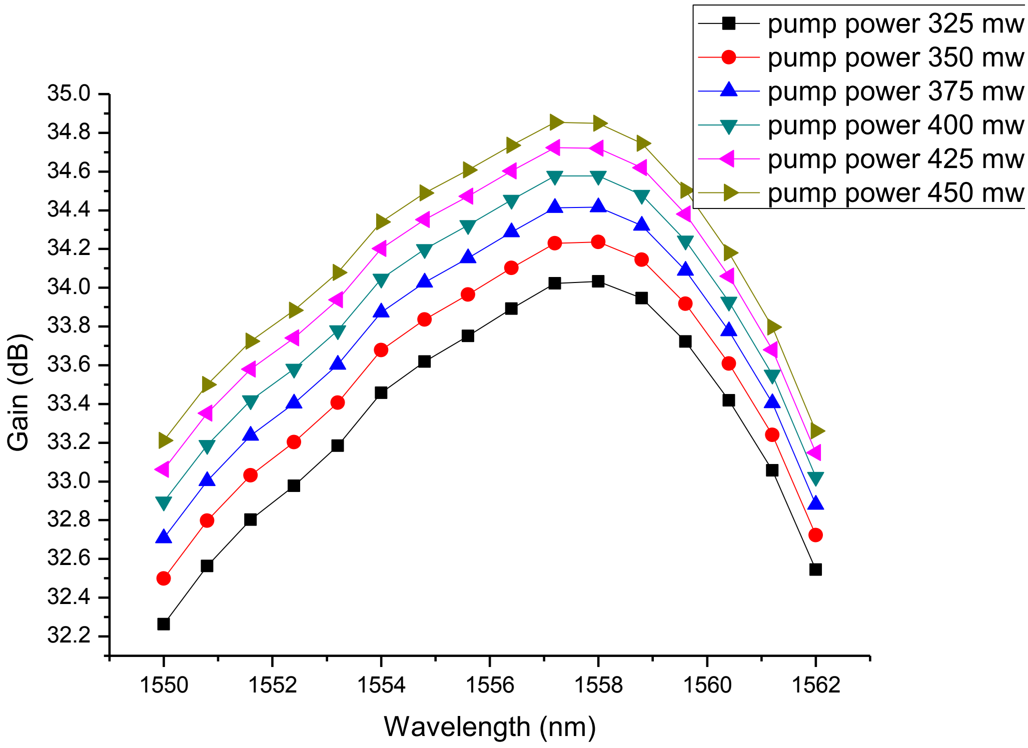


Fig 5.4 Wavelength vs gain at diffrent pump power

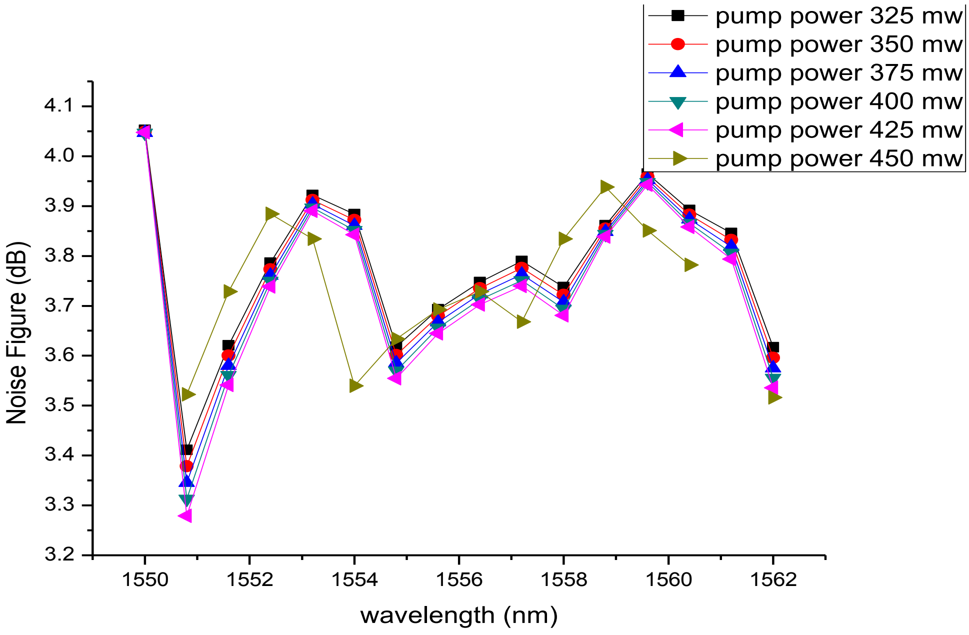


Fig 5.5 Wavelength vs Noise Figure at different pump power

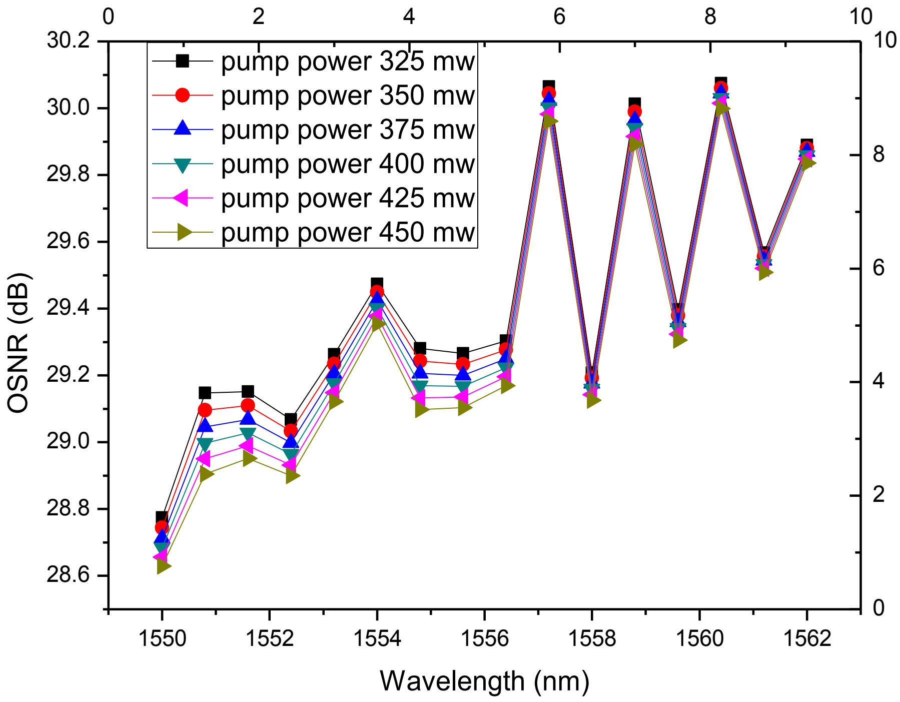


Fig 5.6 Wavelength vs OSNR at different pump power

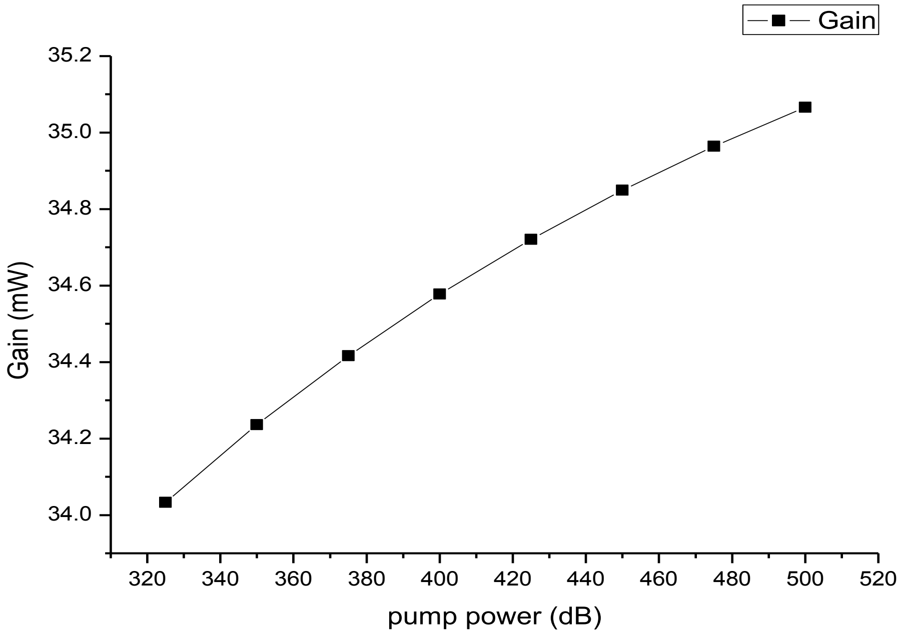


Fig 5.7 Gain vs pump power

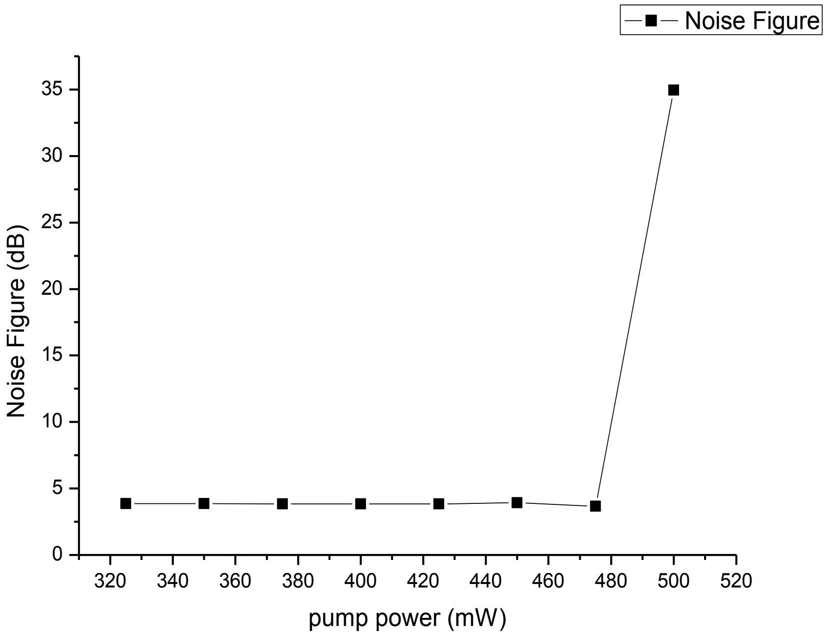


Fig 5.8 Pump power vs Noise Figure

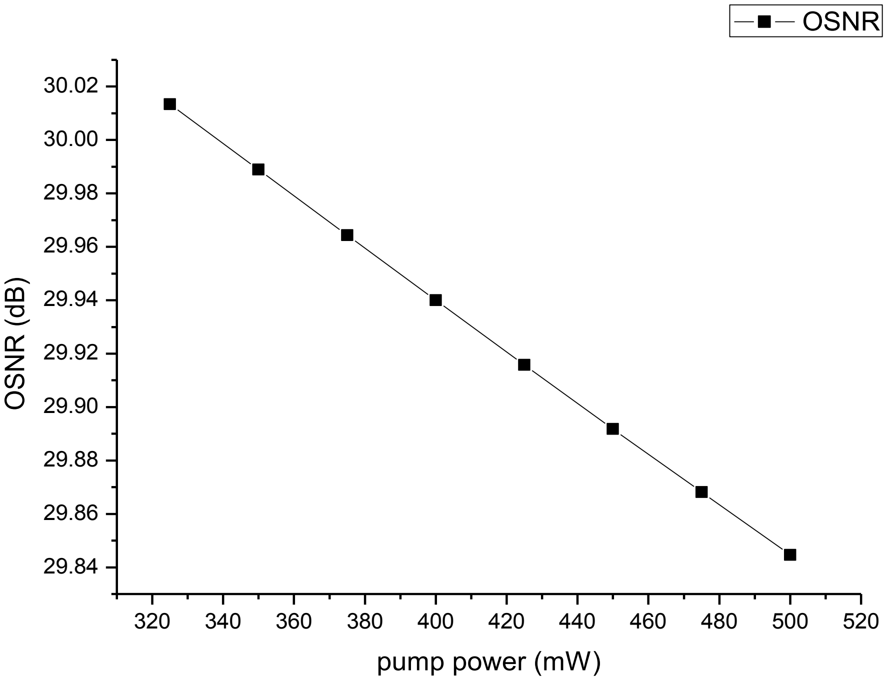


Fig 5.9 pump power vs OSNR

The graphs plotted above shows the variatios of Gain, Noise Figure and Output Signal to Noise Ratio with variation of pump power. It is clear that gain is increasing with pump power but OSNR is decreasing with increasein pump power. Thus we have to choose the value according to our need of high gain or low noise.

5.6 Variation of pump signal wavelength

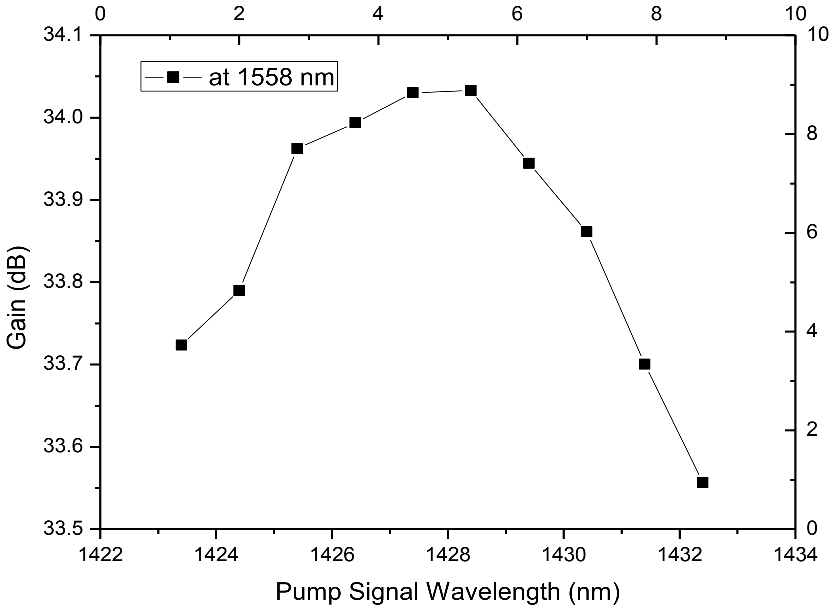


Fig 5.10 Variation in gain with pump signal wavelength variation

These observations are taken at constant pump power of 325 mw and at signal wavelength of 1558 nm. As we can see maximum gain is attained at pump signal wave length of 1428.4 nm.

Chapter 6

Results

- We Implemented Wavelength Division multiplexing based Passive Optical Network in which we used one Distributed Raman Amplifier followed by two Erbium Doped Fiber Amplifier, all three are pumped with same pumping power and same pump signal wavelength.
- It has been shown that result is optimum when we are using pump power of 325 mW and pump signal wavelength of 1428.4 nm.
- Although by increasing pump power we can increase the gain further (i.e. with pump powers of 425, 525 and 575 mw we get gains of 34.72, 35.17, and 35.33 dB respectively) but OSNR decreases with increase in pump power so we have to make a compromise.
- Without any modulation scheme with 8 multiplexed signals gain was as high as 36 dB and maximum Noise Figure as low as 3.8 dB. But when we increased no. of channels to 16 gain was dropped up to 29 dB and maximum Noise Figure is increased up to 4.75.
- The gain and Noise Figure is further improved by variation of signal wavelength, pump power, pump signal wavelength.
- In late C band with help of phase modulation gain can be improved further 0.5 dB and with DPSK gain can be improved more than 3 dB.
- For 16 multiplexed channels each at spacing of 0.8 nm with help of DPSK we achieved maximum gain of 34 dB and maximum Noise Figure of 4 dB.

Chapter 7

Conclusions

6.1 Conclusions

The objective of this work has been to

- Improve the gain and Noise Figure of hybrid amplifier (EDFA/DRA) based WDM-PON with different number of channels.
- To further improve the result with help of different modulation scheme.
- Observe the effects of variation in different parameters (e.g. pump power, pump signal wavelength etc.) on gain, Noise Figure and OSNR.
- The analysis was done for each setup in optisystem 7. The effects were observed and were used to accurately arrive at the final design.

6.2 Future Scope

We have improved the gain and Noise Figure to a great extent but we can further analyse the variation with

- Using gain equalization filter to further flatten the gain for different wavelength
- The noise figure can be further improved by use of special noise reduction filters.

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