INVESTIGATION ON METROPOLITAN AREA NETWORKS AND OPTICAL NETWORKS BASED ON FTTH

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MEHAK GILL

CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled, "**Investigation On Metropolitan Area Networks And Optical Networks Based On FTTH**", in partial fulfillment of the requirements for the award of degree of **Master in Engineering** in **Electronics & Communication Engineering** at **Thapar University**, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. R. S. Kaler (Professor)** and refers other researcher's work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted for the award of any other degree to any other university.

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ABSTRACT

Optical networks will change the paradigms possible for tomorrow's information systems designers by increasing the viability of network-reliant applications. It will effectively eliminate the limitations imposed by geographical boundaries. Optoelectronic technology and optical networking will become the key enablers of the future communications infrastructure through the elimination of the severe restrictions of bandwidth and bit-error rate inherent in traditional electromagnetic signal-based communications. The ability to deploy distributed data-intensive and compute intensive applications will make tomorrow's information systems effectively seamless, and will facilitate the deployment of applications utilizing advanced voice, data, image, and video communications components. The objective of this thesis to investigate the metropolitan area networks comprising optical components such as optical cross connects, arrayed waveguide grating multiplexers, demultiplexers and the performance analysis of the Broadband Passive Optical Network (BPON) based on FTTH.

The Arrayed waveguide gratings based multiplexers and demultiplexers for WDM applications prove to be capable of precise multiplexing and demultiplexing of a large number of channels with relatively low losses. The performance and feasibility for the metropolitan area network based on arrayed waveguide grating (AWG) multiplexers and arrayed waveguide grating (AWG) demultiplexers operating at the bitrate of 10 Gb/s is demonstrated. The comparative investigation and suitability of various data formats is also presented. It has been reported that RZ Raised cosine is the most suitable data format for optical network based on arrayed waveguide grating (AWG) multiplexers and arrayed waveguide grating (AWG) demultiplexers.

The quality-of-service offered by the metropolitan area network which is based on optical cross connect (OXC) and arrayed waveguide grating (AWG) demultiplexer operating at 10 Gb/s with 0.1 nm channel spacing for NRZ signal transmission is demonstrated. The OXC and AWG Demultiplexers in the proposed architecture allow incremental expansion in terms of the number of wavelength channels to be transmitted. Dispersion and crosstalk are

the main signal-degrading factors arising from the operation of the OXC and the effectiveness of each factor is individually investigated.

The network architecture based on FTTH systems with broadband PON (passive optical networks) access is presented. The architecture targets the delivery of very high speed, end to end optical communications between the edge nodes connecting the end users. Transmission allows the simultaneous delivery of real-time applications (Voice over IP, Video) and other data-oriented applications (Internet, peer-to-peer). To optimize the bandwidth in BPON the CWDM technique for the transmission through the optical fiber path is employed. The comparative investigation and suitability of various data formats for internet and the voice over IP transmission is also presented and the three different modulations such as QAM, PSK and offset PSK for the video signal transmission are studied. It has been observed that the most suitable data format for data transmission is RZ Rectangular when QAM and PSK modulation is used for video signal modulation whereas for offset PSK modulated video signal most suitable data format is NRZ rectangular. It is demonstrated that the most suitable modulation technique is PSK modulation technique. Passive Optical Network (PON)-based Fiber-To-The-Home (FTTH) is a promising solution that can break through the economic barrier of traditional point-to-point solutions. Hence, the thesis investigates the metropolitan area networks based on optical cross connects and AWG multiplexers and demultiplexers and broadband passive optical networks based on FTTH.

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LIST OF ABBREVIATIONS

AWG	ARRAYED WAVEGUIDE GRATING
BER	BIT ERROR RATE
BPON	BROADBAND PASSIVE OPTICAL NETWORK
CWDM	COARSE WAVELENGTH DIVISION MULTIPLEXING
DWDM	DENSE WAVELENGTH DIVISION MULTIPLEXING
EDFA	ERBIUM DOPED FIBER AMPLIFIER
FTTH	FIBER TO THE HOME
IP	INTERNET PROTOCOL
LAN	LOCAL AREA NETWORK
MAN	METROPOLITAN AREA NETWORK
NRZ	NON RETURN TO ZERO
OLT	OPTIACAL LINE TERMINATION
ONT	OPTICAL NETWORK TERMINATION
OXC	OPTICAL CROSS CONNECTS
PON	PASSIVE OPTICAL NETWORKS
PSK	PHASE SHIFT KEYING
QAM	QUADRATURE AMPLITUDE MODULATION
QoS	QUALITY OF SERVICE
RN	REMOTE NODE
RZ	RETURN TO ZERO
TDM	TIME DIVISION MULTIPLEXING
WAN	WIDE AREA NRTWORKS
WDM	WAVELENGTH DIVISION MULTIPLEXING

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Today, telecommunication networks are at the hearth of the information society, allowing billions of people to stay in touch with each other in every part of the world, exchanging data at ever growing speeds. Over the last ten years, the amount of traffic carried by the Internet has been growing at a rate of approximately 70 to 150% per year. The growth can be expected to continue at this rate till at least the end of this decade. In analogy to Moore's Law for semiconductors, which states that the processing power and the number of transistors in a microprocessor approximately doubles every 18 months, this trend is often referred to as 'Moore's Law for Internet traffic'. Although Moore's Law is not a natural law, but results from a complex interaction between technology, sociology, and economics, it has still held with remarkable regularity and for various technologies over many decades. Starting from the seventies, the Internet technology started spreading to a growing number of Universities and companies, as soon as they gained access to computational and networking resources [1]. WDM technology enables network operators to continuously increase the capacity of their networks. (With WDM multiple data channels are transmitted over a single optical fiber enabling network operators to multiply the capacity of their existing infrastructure without installing new fiber which would be very costly.) The additional capacity in turn stimulates innovation of new applications which further increase the demand for more bandwidth [2]. Clearly, WDM will remain the key technology to satisfy the ever increasing demand for more bandwidth within the next years. However, a closer look at the infrastructure of today's Internet reveals that it consists of different domains that, besides the need for more bandwidth, all face different limitations and challenges [3]. Most of the metropolitan area networks are based on the Wavelength Division Multiplexing. Metropolitan networks play a critical role in the overall expansion of network services.

1.2 NEED FOR SPEED

The limited capacity of telecommunication networks, and the fixed nature of the services they support, has allowed them to smoothly evolve into efficient carriers of their respective services. The last decade has shown that this situation is no longer stable. Although services such as fax and Internet can be delivered over telephone lines today, it is clear that this is patchwork adaptation. Even high-speed cable modems will not permanently solve the problem of telecommunications for access in future decades, since the rapid advances of personal computer processing power has changed the likely trajectory of telecommunications evolution [2]. WDM offers an attractive solution to increasing LAN bandwidth without disturbing the existing embedded fiber, which is present in most buildings and campuses, and continue to be the cable of choice for the near future. By multiplexing several relatively coarsely spaced wavelengths over a single, installed multimode network, the aggregate bandwidth can be increased by the multiplexing factor [3].

1.3 REQUIREMENTS FOR NEXT GENERATION METROPOLITAN AREA NETWORK (MAN):

Next generation MANs must meet following requirements

1. **SCALABILITY**-ability to scale to high bandwidths and large number of network nodes.
2. **LOW COST**-Low installation and output costs as well as low cost per Gbps.
3. **SUPPORT FOR NEXT GENERATION DIFFERENTIAL SERVICES**-the network must be able to provide differing level of services by defining and maintaining service level agreements (SLA).
4. **POWERFUL AND EASY TO USE NETWORK MANAGEMENT**-network management must provide protection against misconfigurations; network management must provide extensive control and monitoring facilities.
5. **ROBUSTNESS-**Redundant hardware and fiber protection restoration **[3].**

1.4 CONSIDERATIONS IN BUILDING MAN

We make a number of assertions about the right way to build MAN

1. **OPTIMIZED FOR IP TRANSPORT**-IP is increasingly becoming most dominant part in today's networks and its presence is only expected to increase further in next generation MANS. Optimizing for IP transport enables flexibility in service and minimizes equipment and operating costs.
2. **PACKET SWITCHED-**packet switched technology provides efficiency and gain through statistical multiplexing and thus is effective, flexible and scalable.
3. **QoS-** In order to provide acceptable QoS guarantees it is necessary to integrate intelligent traffic planning.
4. **PROVIDE RESTORATION FUNCTIONALITIES**-fault detection and rerouting [3].

1.5 OPTICAL NETWORKING

Only an optical communications backbone would have enabled the Internet to scale as it has, and only an optical communications backbone will allow it to continue to grow at the astonishing rate of the past decade. The Internet infrastructure utilizes optical communications links (also known as photonic links) to transfer user data from node to node in the Internet backbone. Figure 1.1 shows a hypothetical example of an Internet backbone in which photonic links interconnect the nodes. Additionally, photonic links are used in ring networks to interconnect nodes in the metropolitan area. In some rare cases, photonic links are used in residential areas to connect homes and small offices to the Internet [2]. Optical network can also be divided into two types. They are single-channel and multi-channel optical networks. Single-channel optical networks only use up a narrow portion of the low-loss bandwidth for data transmission. Its data rate is limited by the speed of electronic circuits. Multi-channel optical networks allow several light sources having disjointed spectral bands to transmit signals through different wavelength channels in the same fiber simultaneously. Each channel can be operated at a peak electronic speed, say a few Gb/s. As a single fiber can accommodate up to 10^4 electronic-grade channels **[4]**, different

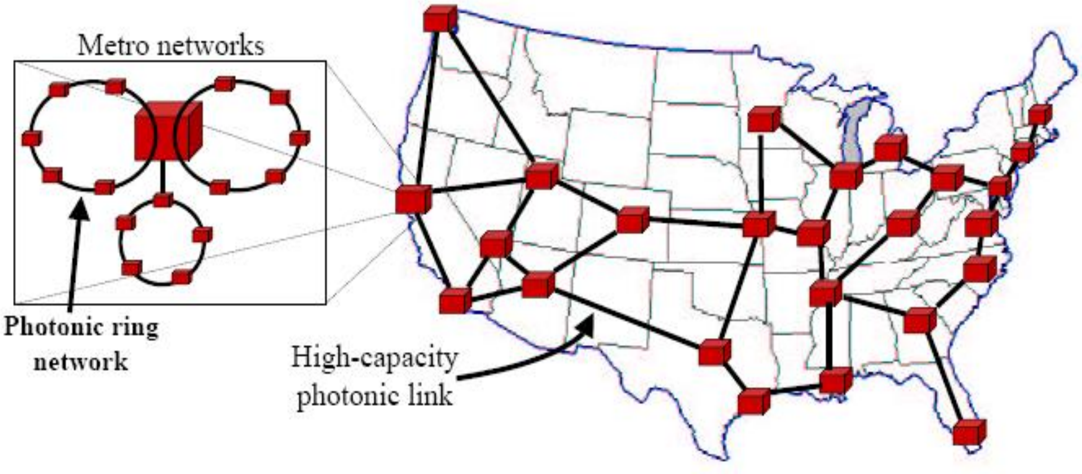

Figure 1.1: A hypothetical example of an Internet backbone [3]

wavelengths can use one of the channels for transmission. It is called as Wavelength Division Multiplexing (WDM).

1.6 WAVELENGTH DIVISION MULTIPLEXING

As demand for bandwidth in the Internet continues to grow, the capacity of the photonic infrastructure must scale to stay ahead of the demand. Two common means for increasing the capacity of photonic links have been employed. The first technique is to increase the bit rate of the signal transmitted by the semiconductor laser. During the last decade, transmission bit rates have increased from 622 Mb/s to 2.5 Gb/s to 10 Gb/s [3]. The technique for increasing the capacity of a photonic link is wavelength division multiplexing (WDM). Figure 1.2 illustrates a WDM link. In a WDM system multiple semiconductor lasers, each at a unique wavelength, are combined onto the fiber optic cable using a wavelength multiplexer. The multiple optical signals propagate through the fiber cable together until they are demultiplexed at the destination and received by photodetectors [3]. With today’s technology, the wavelength values of the optical signals are typically spaced apart by 100 GHz, or in some cases 50 GHz, as specified by the International Telecommunications Union (ITU). Some newer systems are even using 25 GHz wavelength spacing. In the first years of WDM, the typical transmission wavelength region was between approximately 1530 nm and 1565 nm. This enables about 40wavelengths with 100 GHz

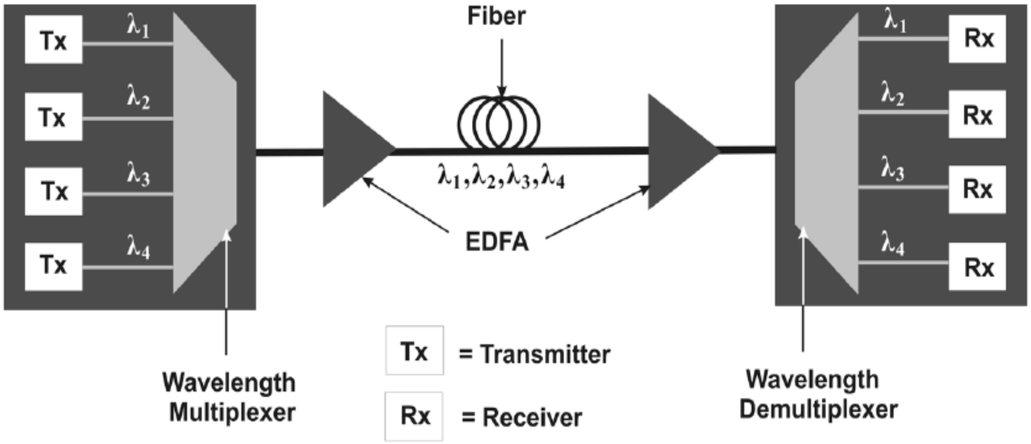

Figure 1.2: WDM system [3]

spacing (this equates to 0.8 nm spacing in the 1550 nm region). It is no coincidence that this region is the amplification region for conventional EDFAs [5]. The 1530-1565 nm wavelength region is often referred to as the C-band, or conventional wavelength band. Remember, however, that the low-loss region of typical fiber optic cable is much wider than this region**.** To exploit other regions of the transmission window, EDFAs that amplify in the long wavelength band (L-band) were later developed. It should be no surprise that in recent years researchers have been attempting to develop and to perfect technologies to amplify in the short wavelength band (S-band) as well. Ultimately, the new amplifier technologies will open up the entire 25 THz bandwidth of standard fiber optic cables. Researchers in recent years attempting to harvest the entire bandwidth potential of a photonic link have produced tremendously impressive results.

1.6.1 BASIC OPERATION

WDM enables the utilization of a significant portion of the available fiber bandwidth by allowing many independent signals to be transmitted simultaneously on one fiber, with each signal located at a different wavelength. Routing and detection of these signals can be accomplished independently, with the wavelength determining the communication path by acting as the signature address of the origin, destination or routing. Components are therefore required that are wavelength selective, allowing for the transmission, recovery, or routing of specific wavelengths [1]. In a simple WDM system, each laser must emit light at a different wavelength, with all the lasers' light multiplexed together onto a single optical fiber. After being transmitted through a high-bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter. Each laser is modulated at a given speed, and the total aggregate capacity being transmitted along the high-bandwidth fiber is the sum total of the bit rates of the individual lasers. An example of the system capacity enhancement is the situation in which ten 2.5-Gbps signals can be transmitted on one fiber, producing a system capacity of 25 Gbps. This wavelength-parallelism circumvents the problem of typical optoelectronic devices, which do not have bandwidths exceeding a few gigahertz unless they are exotic and expensive. The speed requirements for the individual optoelectronic components are, therefore, relaxed, even though a significant amount of total fiber bandwidth is still being utilized [2].

1.7 METRPOLITAN AREA NETWORKS – A REVIEW

Metropolitan networks play a critical role in the overall expansion of network services. They not only provide for services within individual metropolitan areas, but they also serve as the gateways for wide-area national- and international-scale networks [6]. A metropolitan area network of the near future will be characterized by the quantity and diversity of its end users, by the high percentage of randomly fluctuating packet-based data traffic, and by the incredible load placed on the network at peak usage times. World-Wide Web suggests that as soon as subscribers view images, they desire video clips. Hyperlinks and low cost memory suggest that many of us will become servers, and video sources are likely to be practically available in our backyard. Thus, the demand for a variety of service options require the networks to be upgraded far beyond today’s capabilities. Today, the tendency is towards optical communications. One key difficulty is that the most commonly installed fiber in local area networks does not support this bandwidth over distances of 500 meters due to modal dispersion, which limits the effective bandwidth distance product [7]. It is no longer unthinkable for over a million users to simultaneously access the same metro network in the near future. With this many users, it is reasonable to believe that metro networks will be forced to support capacities of up to and beyond 1 Tb/s [8]. So the next-generation metro networks will likely be as follows. There will be millions of end users simultaneously accessing the network, resulting in more than 1 Tb/s of load on the network. Traffic will be composed primarily of randomly fluctuating, bursty, packet-based data traffic, much of which may be intra-network traffic. Additionally, the market for metro network operators is much more competitive than that of Internet backbone operators, and hence the cost-effectiveness and efficiency of a network are crucial. Thus, network architecture for next generation metropolitan area networks should cost-effectively support more than 1 Tb/s of bursty, packet-based data traffic with randomly distributed source and destination node pairs [8]. Currently, metropolitan area networks are based on a quite restricted number of technologies and standards, each one with its strengths and weaknesses. This is the reason why more than one of these competing technologies can often be found within the same MAN, so that the best characteristics of each of them can be exploited thus increasing the flexibility of the network and the resulting quality of service. A plethora of metropolitan area networks have been proposed and examined in recent years with the aim to alleviate the bandwidth bottleneck between increasingly higher-speed local/access networks and high-speed backbone networks. Most of the considered metropolitan area networks are based on the Wavelength Division Multiplexing.

1.8 NETWORK TOPOLOGIES:

The topology of the network defines how the nodes of the network communicate with one another over physical media. Each is used in specific network types. There are five major topologies in use today: Bus, Star, Ring, Tree, and Mesh. Each topology has its own strengths and weaknesses [3].

- **Bus-** With the Bus topology, all workstations are connected directly to the main backbone that carries the data. Traffic generated by any computer will travel across the backbone and be received by all workstations. However the biggest drawback is that the entire network shuts down if there is a break in the main cable and it is difficult to identify the problem in such an event.
- **Star-** The Star or Hub topology is one of the most common network topologies found in most offices and home networks. It has become very popular in contrast to the bus type, because of the cost and the ease of troubleshooting. A star topology consists of a point-to-point connection to a central connection, generally a hub or a

switch. The disadvantage of using this topology is that because each computer is connected to a central hub or switch, if this device fails, the entire network fails.

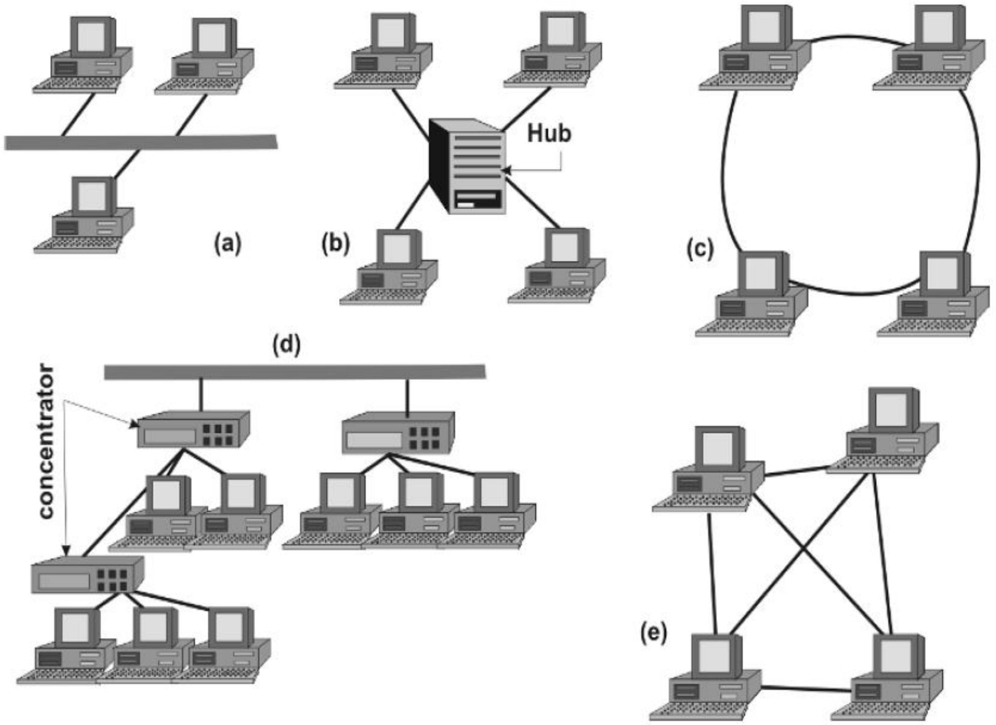

Figure 1.3 (a) Bus; (b) Star; (c) Ring; (d) Tree; (e) Mesh [3]

- **Ring-** In a ring network, every device has exactly two neighbors for communication purposes. All messages travel through a ring in the same direction (effectively either "clockwise" or "counterclockwise"). The ring topology has many of the same problems as the bus topology, in that it can be difficult to troubleshoot and a single break can disable the whole network. Rings are found in some office buildings or school campuses and in MANs.
- **Tree-** A tree topology combines characteristics of linear bus and star topologies. It consists of groups of star-configured workstations connected to a linear bus backbone cable. Tree topologies allow for the expansion of an existing network. Its main drawback is that if the backbone line breaks, the entire segment goes down. A

Passive Optical Network (PON) is the best example of a network with a tree topology. Trees can also be multihop if splitting nodes process the signal.

- **Mesh-** Mesh topologies involve the concept of routes. Unlike each of the previous topologies, messages sent on a mesh network can take any of several possible paths from source to destination. This provides a great improvement in performance and reliability, however the complexity and difficulty of implementation increases geometrically as the number of nodes on the network increases. For example, a three or four node mesh network is relatively easy to realize, whereas it is impractical to set up a full mesh network of 100 nodes — the number of interconnections would be so high and expensive that it is not practical. Mesh networks are not used much in LANs but are used in Wide Area Networks (WANs) where reliability is important and the number of sites being connected together is fairly small. A mesh may also be logically configured to be a concatenation of rings.

1.9 CHALLENGES FOR FUTURE WDM BASED OPTICAL ACCESS NETWORKS

Optical access networks draw much attention from the research community for their potential to solve the bandwidth bottleneck in the last mile. For first-generation optical access networks, the major thrust in research and development has been economical deployment, so both Academia and Industry have focused on passive optical networks (PON) using a tree topology and a media access control (MAC) protocol based on time division multiple access (TDMA). Current TDM-PON standards specify the line rate up to 1 Gb/s and maximum link reach of 20 km or more. These capabilities support the high speed broadband access needs of current residential end-users [9]. As more broadband applications appear, however, demands from end-users will soon outgrow the capacity of first generation access networks. Therefore, upgrading TDM-based optical access networks will be a major challenge. WDM has been considered an ideal solution to extend the capacity of optical networks without drastically changing the currently deployed fiber infrastructure. WDM can provide a virtual point-to-point link to each end-user over a PON without complicated MAC protocols, which simplifies tasks of network management, protection, and security to the level of traditional point-to-point networks. The topology, for example, need not remain a strict tree. The fiber layout may be extended as pure ring or ring plus tree architectures to provide better resiliency. Best effort, data centric services are not likely to dominate the network bandwidth; the network must be versatile enough to provide value-added services, such as video streaming, video on demand, voice over IP, and virtual private networks (VPN), and may support storage area networks (SAN). Quality of service (QoS) guarantees will become a critical issue as well, since different services have different requirements for throughput, delay, delay variation, and bit-error rate (BER). It is practically impossible to satisfy all the QoS requirements by simple over provisioning. Smart bandwidth allocation needs to be implemented in the network layers [10].

1.10 DESIGN ISSUES AND ENABLING TECHNOLOGIES FOR WDM BASED OPTICAL ACCESS NETWORKS

Here we briefly review some of the design issues and enabling technologies for WDM based optical access networks.

Frame Formats and MAC Protocols

The choice of frame format and related protocol depends on several factors such as interfaces with LAN/MAN and kinds of services and applications to be supported [11]. For example, if Resilient Packet Ring (RPR) is used in a MAN and applications in access are mostly data-centric, Ethernet is a clear choice. Currently, the following three frame formats are most popular:

- Asynchronous Transfer Mode (ATM)
- Ethernet
- Generic framing procedure (GFP)

WDM is usually constructed as a fixed point-to-point link to each end-user, eliminating a need for complicated MAC protocols. If fast tunable lasers or receivers are to be used to reduce cost, however, wavelength- and time-domain MAC protocols are needed as in [12]. In such a case, proprietary frame formats and protocols will likely be implemented, initially.

CWDM vs. DWDM

CWDM (Coarse Wavelength Division Multiplexing) uses 18 wavelengths from 1270 nm to 1610 nm with a channel bandwidth of 13 nm [13]. CWDM permits cheap components, such as athermal AWG and uncooled lasers in the network due to the wide channel spacing (20 nm): There is no need to (temperature-) stabilize laser sources or optical filters. On the other hand, DWDM (Dense Wavelength Division Multiplexing) achieves greater spectral efficiency and with commercially available fiber-based optical amplifiers, can provide longer reach, which makes it a better upgrade option in the long-term future.

Light Sources for WDM-PON (Passive Optical Network)

One key component for the successful deployment of WDM access networks is the laser diode. A laser diode can be expensive, especially if wavelength stabilization is required, as in DWDM networks [10].

Several approaches exist to achieve wavelength reconfigurability:

- Tunable laser diodes, ideally tunable Vertical Cavity Surface Emitting Diodes (VCSEL).
- Injection-locked Fabry-Perot lasers at ONUs.
- Broadband light source, such as LED, with spectral slicing.
- ONU contains only a modulator.

Video Broadcasting

Telephone companies and cable TV operators are attempting to offer innovative new services to their residential and small business customers. Thus telcos are going after video and Internet services while cable operators are providing data services over cable modems and are also exploring voice connections [14]. The near future promises to deliver exciting applications such as video-on-demand, interactive TV, distance learning, and electronic commerce. To provide such future services, both types of operators are currently upgrading their access infrastructure, often referred to as the “last mile.” Hybrid fiber-coax (HFC), fiber-to-the-curb (FTTC) and fiber-to-the-home (FTTH) are some of the planned access types. Optical networking has been identified as the key technology to bring such broadband services to the home.

Protection and Restoration

Protection and restoration for optical access networks is still a fairly un-developed field, since the number of users served by the network is relatively limited compared to WAN or MAN. The specifications for protection and restoration are not clearly defined yet. However, if the scale of access networks continues to grow and business users demand such qualities, protection and restoration will be indispensable. One way to protect a tree-topology PON is to connect ONUs with fiber links. The idea is to recover from a fiber cut between a remote node (RN) and an ONU [10].

1.11 WDM DEPLOYMENT CONSIDERATIONS

Even though WDM technology has only recently become commercially available, its deployment as a point-to-point transmission technology has been fast-paced. 8- and 16-channel systems are available today, and vendors are currently developing 32- and 40-channel WDM systems. Although transmission capacity on a link can be increased by adding more fibers i.e. by space division multiplexing (SDM) approach or increasing the transmission bit rate on the fiber by using time division multiplexing (TDM) approach but economic and reliability considerations make the case for WDM particularly compelling in situations where increased capacity is needed over long-distance links or where it may be cost-prohibitive to lay more fiber [15]. These considerations have led major long-distance network providers to employ WDM to upgrade transmission capacity in their backbone networks; WDM has been utilized for undersea networks; and the technology is beginning to emerge in metropolitan wide-area networks. Because significant challenges need to be overcome before all-optical networking can become a reality, over the next several years network operators will be faced with the need to integrate WDM with other complementary transport technologies into hybrid networks. Advances in optical network management and control capabilities are expected to facilitate the incorporation of both optical transport and optical switching technologies into larger segments of network infrastructures in the future [16].

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY

Diptish Dey et al. [3] demonstrated the concept for building a packet switched MAN with support for multicasting in the optical domain has been presented. The MAN comprises of interconnected all-optical rings. Slots transport data packets within each ring all-optically. This enables optical packet-switching at intermediate nodes on a ring. The nodes are capable of transmitting and receiving at all wavelengths. Problems such as slot-synchronization (chromatic dispersion), crosstalk accumulation and SNR degradation have been simulated, analyzed and/or experimentally demonstrated.

Slavisa Aleksic et al. [6] discussed that future metropolitan area networks (MANs) must be capable of providing high bandwidth, supporting multiple protocols, fast provisioning of different granularities of bandwidth, as well as good scalability and protection. All-optical packet switching, while combining high throughput with a large flexibility, might be a good candidate for next-generation MANs.

Greg Barish et al. [7] discussed that Web caching systems can lead to significant bandwidth savings, server load balancing, perceived network latency reduction, and higher content availability. The state of the art in caching designs, presenting taxonomy of architectures and variety of specific trends and techniques are described.

Biswanath Mukherjee et al. [26] demonstrated some of the architectural challenges involved in the design of all-optical packet switched networks, and it is shown that how future networks could be integrated with other network segments, to provide users end-to-end connectivity with performance and simplicity.

Martin Maier et al. [27] experimentally demonstrated comparison between slotted ring and AWG star networks. It is shown that the AWG star networks clearly outperform the ring networks in terms of throughput, delay, and packet loss for unicast traffic with the expense of the single point of failure which could be overcome by redundancy.

M. Reisslein et al. [28] studied WDM EPONs. It is shown that AWG based star network can supplement the existing metro networks and increase their capacity to overcome the metro gap.

Hyo-Sik Yang et al. [29] experimentally studied metro WDM star network based on an arrayed waveguide grating. The performance of this WDM star network based on an arrayed waveguide grating with a control channel, which exploits the broadband light source, i.e., an LED, has been investigated.

Hai Yuan et al. [38] experimentally studied FBG-Based Bidirectional optical cross connects. A new bidirectional optical cross connect (BOXC) using fiber Bragg gratings (FBGs) and optical circulators for bidirectional wavelength-division-multiplexing ring networks is proposed. Dynamic and independent wavelength routing is achieved by employing cascaded tunable FBGs.

A.Q.Liu et al. [39] experimentally demonstrated optical cross connects using drawbridge micromirrors. Factors such as optical cross connect architectures, insertion losses and mirror motion types have been investigated for the design of optical cross connects having large port numbers.

Chun Tung Chou et al. [40] presented a hybrid optical network architecture consisting of optical cross connects and optical burst switches. The architecture allows carriers to gradually migrate from an OXC-based network to an OBS-based network with improved network utilization. In addition; queuing analysis is used to study the performance of this new architecture.

Kyeong Soo Kim et al. [42] compared the current PON-based FTTH solutions, ATM-PON (APON), Ethernet PON (EPON) and provided a possible evolution scenario to future WDM PON. Once fibers are deployed with PON-based FTTH solutions, it becomes critical migrating to Wavelength Division Multiplexing (WDM)-PON from Time Division Multiplexing (TDM) used in current PON solutions.

Fu-Tai An et al. [10] investigated the key issues and reviewed enabling technologies for upgrading current-generation optical access networks with WDM techniques. It is studied that upgrading current-generation time division multiplexing (TDM)-based optical access networks will be a challenge in the future when end-user demand outgrows current network capacity.

Samir Chatterjee et al. [16] studied global infrastructures that are beginning to emerge and a host of broadband services appear and deliver economical service to users at offices and homes; optical networking will become a serious candidate for widespread implementation.

2.2 MOTIVATIONS

Many new applications and services have emerged amidst the rapid growth of the internet and telecommunications industry resulting in a surge of data on voice networks. This surge of data rendered the voice telecommunications infrastructure insufficient in the metropolitan area resulting in a metro gap. This dilemma provided us with a dire need to replace or upgrade the existing telecommunications infrastructure. So to cope with the changed realities and enable new applications and services to utilize huge bandwidths available in the long haul backbone networks, optical network based on AWG multiplexers and AWG demultiplexer can supplement the existing metro networks and increase their capacity to overcome the metro gap. The work over this network has not been done yet. Increasing demands for higher bit-rate are pushing the optical network to move closer to the end-users, and as a consequence the construction of the transparent all-optical dense wavelength-division multiplexing (DWDM) networks in a metropolitan or access area emerges gradually as a critical issue following the subject which focused mainly on establishing the long-haul all-optical DWDM networks in transport network areas. In the long-haul all-optical DWDM networks, the most significant function required to optical cross-connect (OXC) is the capability of processing a large number of different wavelength channels incoming simultaneously to a single node. OXCs will play a key role in metropolitan or access DWDM network. With the introduction of Optical Cross-connects (OXCs), end-to-end optical connections (also known as lightpaths) allow packets to be carried without optical-to-electronic conversion in the intermediate hops, thus overcoming the electronic conversion bottleneck. So to exploit the advantages of OXCs the network based on Optical cross connect and AWG demultiplexers can be designed and the work over this has not been done yet. Passive Optical Network (PON) based Fiber To The Home (FTTH) is a promising solution that can break through the economic barrier of traditional point-to-point solutions. TDM Multiplexing mostly used in current (Passive Optical networks) PON cannot exploit the huge bandwidth of the optical fibers and therefore will not be able to meet ever increasing demands for higher bandwidth by future network applications. To optimize the bandwidth in BPON (Broadband Passive optical network) based FTTH networks, CWDM (Coarse Wavelength Division Multiplexing) technique can be employed for the transmission through the optical fiber path. The work over this has not been done yet. This architecture targets the delivery of very high speed, end to end optical communications between the edge nodes connecting the end users. Transmission allows the simultaneous delivery of real-time applications (Voice over IP, Video) and other data-oriented applications (Internet, peer-to-peer).

2.3 THESIS OBJECTIVES

In this thesis the research is carried out keeping in view the following objectives

1) To investigate suitability of various data formats for 10 Gb/s optical network based on AWG (arrayed waveguide grating) multiplexers and AWG demultiplexers.
2) To investigate the performance of metro WDM network based on an optical cross connect and arrayed waveguide grating demultiplexers.
3) To investigate Broadband Passive Optical Network (BPON) based on FTTH.

2.4 THESIS ORGANIZATION

This thesis is divided into six chapters. The first chapter includes the introduction about the optical access networks, various network topologies and WDM technologies.

The second chapter includes the literature survey of various Metro Area Optical Networks based on WDM technologies.

The third chapter includes comparative investigation and suitability of the various data formats for 10 Gb/s optical network based on AWG multiplexers and AWG demultiplexers. The performance is based on the BER, Q Factor, Average eye opening and jitter characteristics.

The fourth chapter includes the performance analysis of metro WDM network based on an optical cross connect and arrayed waveguide grating demultiplexers. The performance is described in terms of the BER, Q Factor, Average eye opening and jitter characteristics.

The fifth chapter is based on the investigation of Broadband Passive Optical Network (BPON) based on FTTH.

Finally, the sixth chapter is includes the conclusion and the future scope.

CHAPTER 3

COMPARATIVE INVESTIGATION AND SUITABILITY OF VARIOUS DATA FORMATS FOR 10 Gb/S OPTICAL AWG MULTIPLEXER AND AWG DEMULTIPLEXER BASED TRANSMISSION LINKS

In this chapter, we have analyzed the performance and feasibility for the metropolitan area network based on arrayed waveguide grating (AWG) multiplexers and arrayed waveguide grating (AWG) demultiplexers operating at the bitrate of 10 Gb/s. In the network, the data is successfully transmitted to a distance of 50 km with a very low BER of 1 $x10^{-40}$ thus improving the performance over AWG star based networks. Here, we have observed that arrayed waveguide gratings based multiplexers and demultiplexers for WDM applications prove to be capable of precise multiplexing and demultiplexing of a large number of channels with relatively low losses. This chapter also presents the comparative investigation and suitability of various data formats like NRZ Rectangular, NRZ Raised cosine, RZ Rectangular, RZ raised cosine and RZ super Gaussian for optical transmission link. It has been shown that RZ Raised cosine yields the highest value of Q, good eye opening and lowest BER.

3.1. INTRODUCTION

Metropolitan networks have been attracting so much attention as they impose a bandwidth bottleneck. In today’s modern era, many new applications and services have emerged with the rapid growth of the internet and telecommunications industry resulting in a surge of data on voice networks [17]. This surge of data rendered the voice telecommunications infrastructure insufficient in the metropolitan area resulting in a metro gap. This dilemma provided us with a dire need to replace or upgrade the existing telecommunications infrastructure [18]. So to cope with the changed realities and enable new applications and services to utilize huge bandwidths available in the long haul backbone networks, a metro WDM network based on arrayed waveguide grating is proposed and evaluated in [19]. As the demand is increasing for capacity in long-haul light wave transmission systems, so to select which optical modulation format will be best is a main issue to ensure optimum system performance. Today as we know that long-haul transmission systems represent the fourth generation utilizing multiple carrier wavelengths, which has led to an explosion of channel capacity. At the same time, deregulation of telecommunication markets and global success of the internet has driven up the demand for higher and higher system capacity. Conventionally, non-return to zero (NRZ) modulation format has been used in long-haul transmission systems [20]. These systems are based on the fact that fiber dispersion and nonlinearities are detrimental effects. NRZ is used advantageously as it provides minimum optical bandwidth and minimum optical peak power per bit interval for given average power [21]. However, with increased bitrates, it has been shown that RZ modulation formats offer certain advantages over NRZ, as they tend to be more robust against distortions [22]. For instance, RZ modulation is more tolerant to non-optimized dispersion maps than NRZ schemes [23]. This can be explained by the fact that optimum balancing between fiber nonlinearities and dispersion is dependent on the pulse shape. A RZ-modulated signal stream consists of a sequence of similar pulse shapes, whereas an NRZ- modulated stream does not. From system designer's point of view, impairments in optical transmission need to be addressed. Moreover, how these affect the performance of the transmission link has to be investigated and ways to improve it have to be suggested. Therefore, it is important to investigate the robustness of various existing data formats on the performance of optical transmission link. For high-speed optical communication, the data transmission reliability is degraded by the system impairments like GVD and fiber non linearities. In recent years Arrayed Waveguide Gratings have become increasingly popular as wavelength (de)multiplexers for WDM applications. They have proven to be capable of precise demultiplexing of a large number of channels with relative low losses [24].The majority of the earlier presented WDM network architectures are either based on a physical ring topology or a physical star topology [25].

Biswanath Mukherjee et al. [26] demonstrated some of the architectural challenges involved in the design of all-optical packet switched networks, and it is shown that how future networks could be integrated with other network segments, to provide users end-to-end connectivity with performance and simplicity. Martin Maier et al. [27] experimentally demonstrated comparison between slotted ring and AWG star networks. It is shown that the AWG star networks clearly outperform the ring networks in terms of throughput, delay, and packet loss for unicast traffic with the expense of the single point of failure which could be overcome by redundancy.

M. Reisslein et al. [28] studied WDM EPONs. It is shown that AWG based star network can supplement the existing metro networks and increase their capacity to overcome the metro gap.

Hyo-Sik Yang et al. [29] experimentally studied metro WDM star network based on an arrayed waveguide grating. The performance of this WDM star network based on an arrayed waveguide grating with a control channel, which exploits the broadband light source, i.e., an LED, has been investigated.

Till now, the work is done on star based arrayed waveguide networks [26-29], but network based on AWG multiplexers and AWG demultiplexers have not been analyzed and no optimization has been done in this regard. Moreover, no work over comparative analysis for suitability of better data modulation format was done. Arrayed Waveguide Gratings multiplexers and demultiplexers for WDM applications have proven to be capable of precise multiplexing and demultiplexing of a large number of channels with relative low losses and with a very low BER of 1 $x10^{-40}$ for a transmission distance of 50 km compared with star AWG network [29] in which BER was reported to be 4.053 $x10^{-14}$ for transmission distance of 30 km. Thus network based on AWG multiplexers and demultiplexers discussed here clearly improving the performance over AWG star networks.

Thus, the architecture based on arrayed waveguide grating multiplexers and demultiplexers is discussed and comparative analysis of various data formats has also been done to find out the most suitable data format for transmission of data over this network taking in to account the ‘chirp’, which is in advertently present in all optical sources of short wavelength. The different data formats used by us present some notable differences in the context of data-rate/distance trade-offs and other device-related parameters that affect transmission performance. Data formats have been investigated for certain performance measures viz. Q factor, bit error rate (BER), eye opening, jitter, etc. The investigations have been carried out with chirp factors of 0, 0.5, 0.75, 0.85 and 1.0 at the optical source itself.

The chapter is organized as follows. Section 3.1 presents the introduction. Section 3.2 presents the descriptive model for the network based on AWG multiplexers and AWG demultiplexers. Section 3.3 describes the simulation model and the description of its components. Section 3.4 includes the discussion of the results. Section 3.5 presents the conclusion about the feasibility of the network.

3.2. DESCRIPTIVE MODEL

The basic architecture of the network based on an AWG multiplexers and AWG demultiplexers is shown in Fig.3.1. Each node is connected to the network via two fibers,

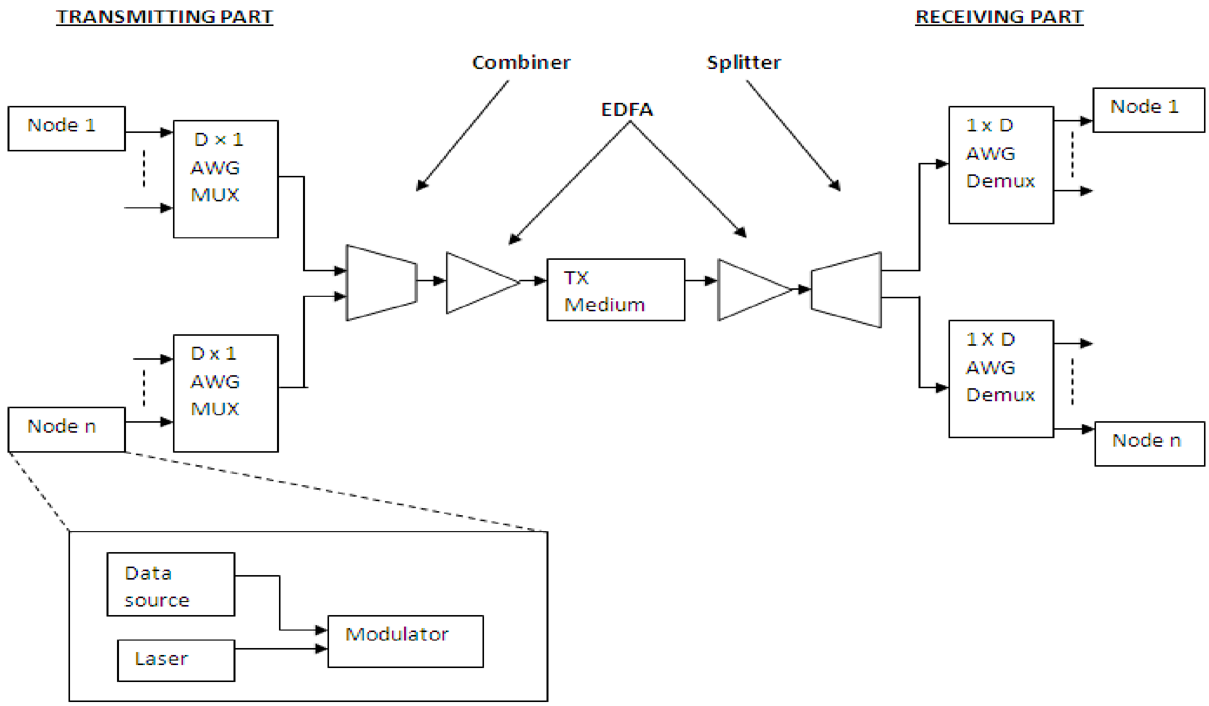

Figure 3.1 Block Diagram of the optical AWG multiplexer and AWG Demultiplexer based optical transmission model

i.e. one for transmission and the other for reception. At each AWG multiplexer input port data is collected from attached nodes. At each AWG multiplexer output port, a wavelength-insensitive combiner collects data from multiplexers out ports. After the amplification by EDFA the data is transmitted through single mode optical fiber. EDFA's gain is 5 dB. Similarly, after the transmission fiber data is amplified by the EDFA and the signals are distributed by a wavelength-insensitive splitter. After that the signal is distributed to nodes by AWG demultiplexers. Each node is equipped with a laser diode (LD) and a photodiode (PD) for data transmission and reception, respectively.

3.3. SIMULATION MODEL

The set up illustrates how to simulate optical network consisting of AWG multiplexers and AWG demultiplexers. The analysis is done by taking 8 nodes and the architecture is composed of two 4×1 AWG multiplexers indicated by component names awg_mux_1 and awg_mux_2, a 2×1 combiner indicated by b1, nine 1×2 splitters indicated by b2 –b9 and two 1x4 AWG demultiplexers indicated by component names awg_demux_1 and awg_demux_2 as shown in simulatin set up in Figure 3.4. The transmission medium consists of 50 km long standard single-mode fiber (SMF) and an optical amplifier (EDFA). SMF offers an attenuation α is 0.2 dB/km with dispersion D =0.2ps/km nm at 1553.3288 nm (193.0 THz). The central wavelength of the fiber is 193.0 THz. Each node is further composed of, one transmitter source and one receiver source. The analysis of results is made by means of measurement blocks inserted in the iterate block. The used frequencies in the optical network at the various nodes are, frequency f1 is equal to 192.65 THz, frequency f2 =192.75, f3 =192.85, f4 =192.95, f5 =193.05, f6 = 193.15, f7= 193.25, f8 =193.35, i.e. with the difference of 0.1 THz.

The transmitter as shown in Figure 3.2 is composed of data source, laser source indicated by component CW_Lorentzian, optical amplitude modulator indicated by component Sin2_MZ and optical link section.

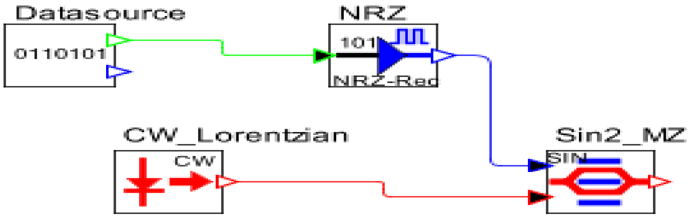

Figure3.2 Transmitter

Data source generates a binary sequence of data stream. Data source is customized by baud rate, sequence, logical signal level and the period length.

Laser block shows simplified continuous wave (CW) laser. In our model considered we have set 193.0 THz center emission frequency, 1553.32 nm wavelength, 1mw CW power, ideal laser noise bandwidth, 10 FWHM linewidth and laser random phase. The output from the driver and laser source is passed to the optical amplitude modulator.

Modulation driver generates different types of data formats such as NRZ Rectangular, NRZ Raised cosine, RZ Rectangular, RZ raised cosine and RZ super Gaussian.

The pulses are then modulated using MZ modulator at 10 Gb/s bitrate. Amplitude Dual-Arm Mach Zehnder Modulator is used to modulate optical signal of desired form at having the following parameters: offset voltage corresponding to the phase retardation in the absence of any (on both arms) electric field is 0.5V, extinction ratio =20 dB and average power reduction due to modulation is 3dB.

The optical signal from the EDFA i.e. after combiner is passed through the optical link section composed of SMF.

Single receiver is composed of optical raised cosine filter indicated by the component Raised_cosine1 in Figure 3.3, PIN photodiode indicated by the component name Pin_Photodiode and low-pass Bessel filter indicated by the component name Bessel_electrical_filter. Electrical scopes with Gaussian filter are used to observe change in performance.

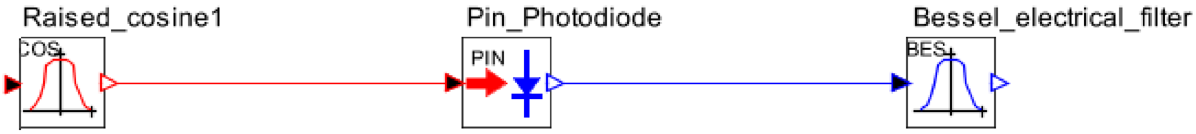

Figure3.3 Single Channel Receiver

Optical filter implements a raised cosine transfer function filter having band pass filter synthesis, 1 as raised cosine exponent, 0.2 raised cosine roll off, 193.0 THz Center freq, 1550 nm center wavelength, 40 GHz B.W.

PIN photodiode is used to detect the optical signal, i.e. conversion into electrical signal. Its parameter are 193.0THz nm reference frequency, 0.80 quantum efficiency, 0.99A/W responsivity, 3dB bandwidth 20 GHz and zero dark current

Electrical filter at the receiver side is implemented by lowpass Bessel filter. The filter is numerically implemented using an IIR (Infinite Impulse Response) algorithm together with the bilinear transformation method having 5 poles in number as 3 dB bandwidth 10 GHz.

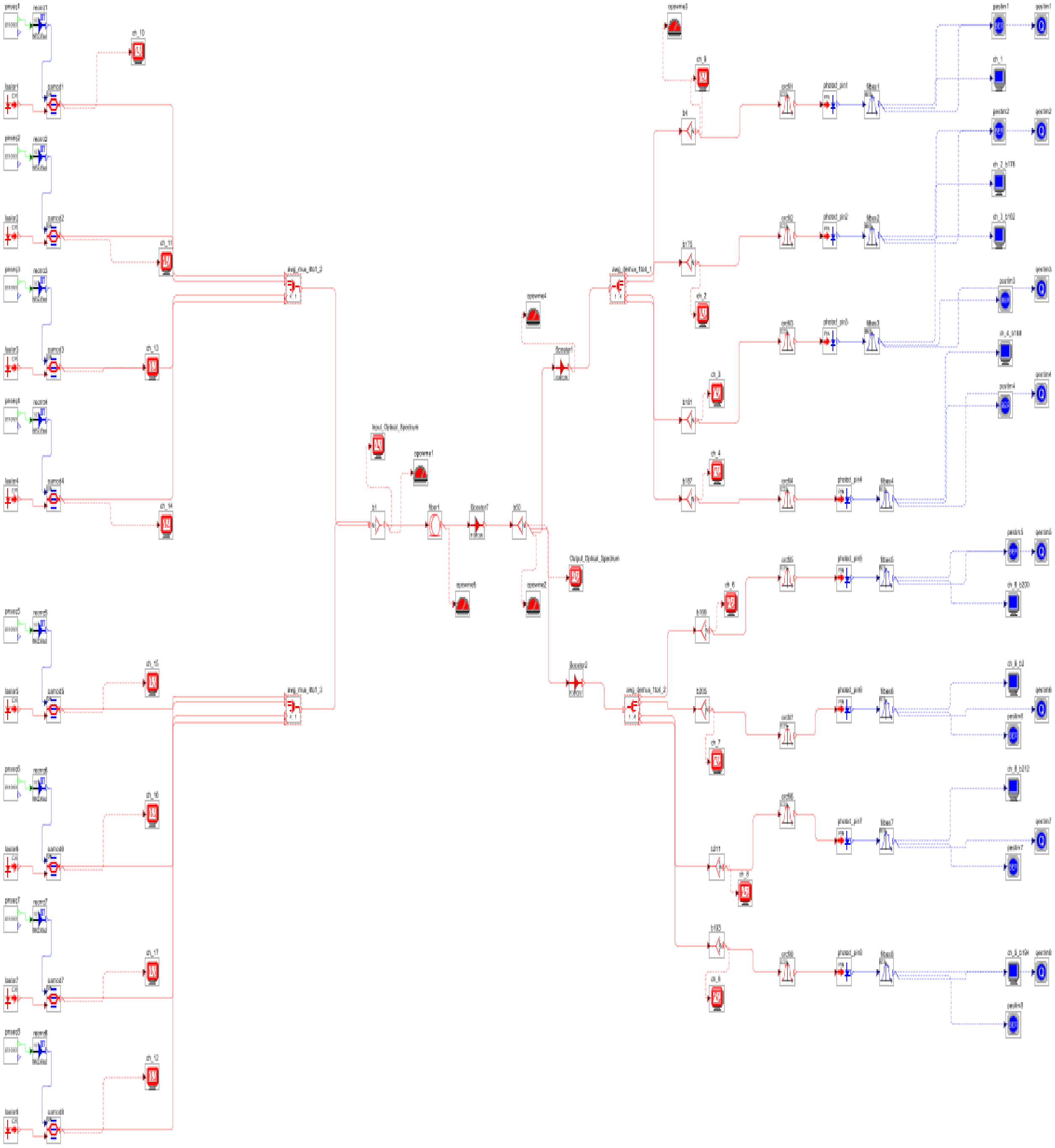

Figure3.4 Simulation Set Up

Optical transmission link based on AWG multiplexer and AWG demultiplexer has the simulation set up as shown in figure 3.4. It consists of three stages: an optical AWG multiplexer an optical AWG demultiplexer and between them a method of reconfiguring the paths. The AWG optical multiplexer, multiplexes the wavelength channels that are to continue on, from various nodes onto a single output fiber, through optical combiner. The optical AWG demultiplexer separates wavelengths in an input fiber on to ports. The reconfiguration can be achieved by optical fiber combiners and splitters that direct the wavelengths to the optical demultiplexer.

Optical splitter used here has an attenuation of 0dB at each output port so this component implements an ideal splitter without any insertion loss, i.e. a component that perfectly splits the input signals. The electrical scope is used to obtain eye diagram, and from the eye diagram the values of BER, Q factor, jitter and eye opening are determined.

3.4. RESULTS AND DISCUSSION

At the receiver measurements are made with the help of an optical spectrum analyzer, optical probe and electrical scope. The results of optical communication model based on AWG multiplexer and AWG demultiplexer can also be shown in tabular form as shown in Table 3.1, it presents a summary of comparative investigation on the performance metric indices viz. Q (dB); eye opening; BER and jitter (ns) operating at 10Gb/s with different data formats viz. NRZ Rectangular, NRZ Raised cosine, RZ Rectangular, RZ raised cosine and RZ super Gaussian, at different chirp factors (0, 0.5, 0.75, 0.85, 1.0).

Table 3.1 Comparison of the performance metric indices for 10 Gb/s optical AWG Multiplexer and AWG Demultiplexer based transmission link with different data formats

Parameter	NRZ Rectangular	NRZ Raised Cosine	RZ Rectangular	RZ Raised Cosine	RZ Super Gaussian
Q (dB)	22.270005	16.052290	21.182730	26.339403	20.770599
BER	1.002121 e -037	4.16353 e -10	6.89388 e -029	1 e – 040	9.56618 e -027
Eye Opening	0.00283308	0.00015899	0.00360707	0.00778901	0.00108648
Closure	0.866645	1.959473	1.027366	0.493155	1.029161
Jitter(ns)	0.000413399	0.0273738	0.0024203	0.00215466	0.00210132

Figures (3.5-3.20) shows the results obtained in the form of plots and eye diagrams. Figure 3.5 shows the input optical power spectrum of AWG multiplexer and demultiplexer based network, it is observed at transmission end and Figure 3.6 shows the output optical power spectrum which is observed at the receiver end.

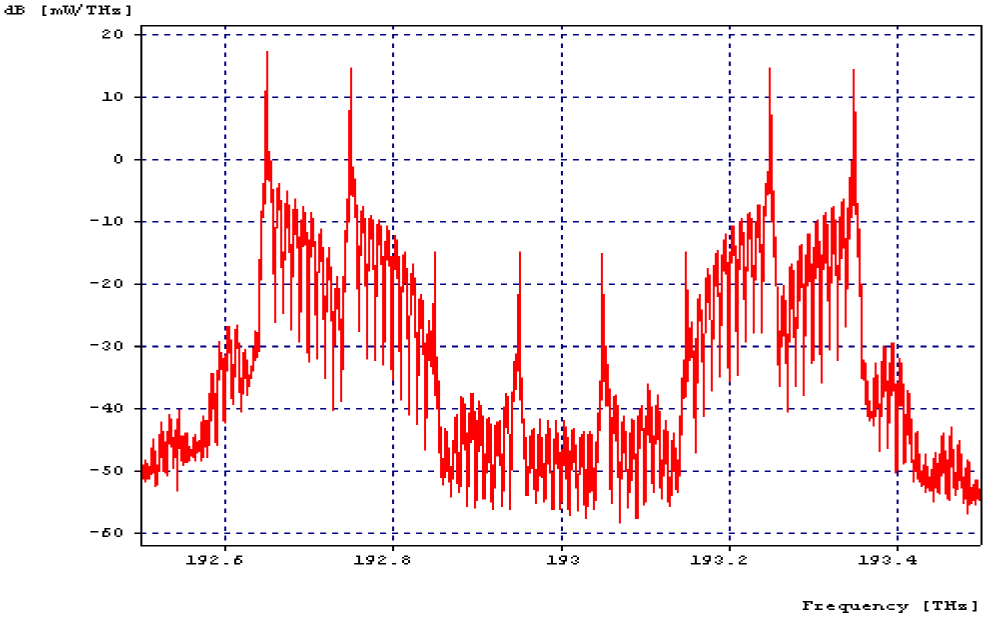

Figure 3.5 Input optical spectrum

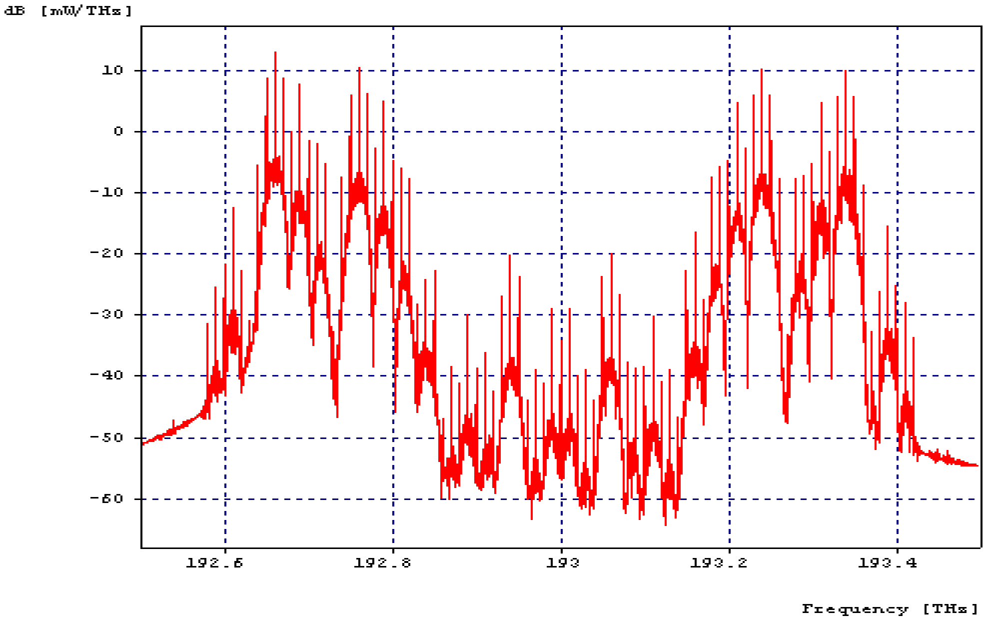

Figure 3.6 Output optical spectrum

Figures (3.7-3.11) shows the eye diagrams for various data formats and it is observed from our results that best eye diagram is for RZ Raised cosine with the lowest value of BER i.e. 1 $x10^{-40}$ and highest Q value of 26.33 dB. Also the jitter and eye opening values for RZ Raised Cosine are 0.0021 ns and 0.0077 respectively. These values can be compared with the values of the other data formats from the Table 1.

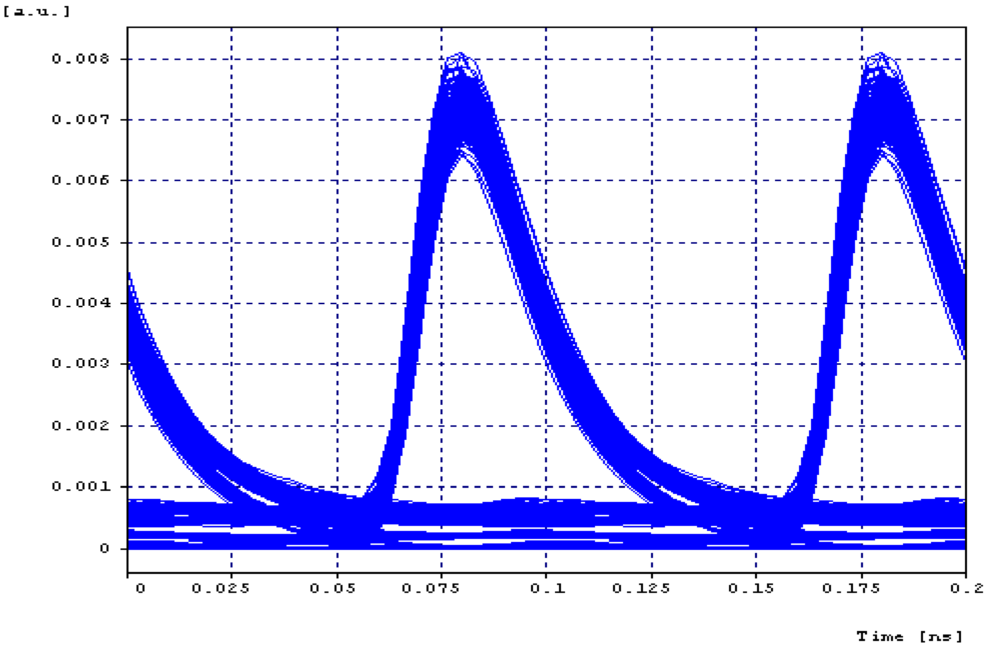

Figure 3.7 Eye diagram for NRZ Rectangular data format

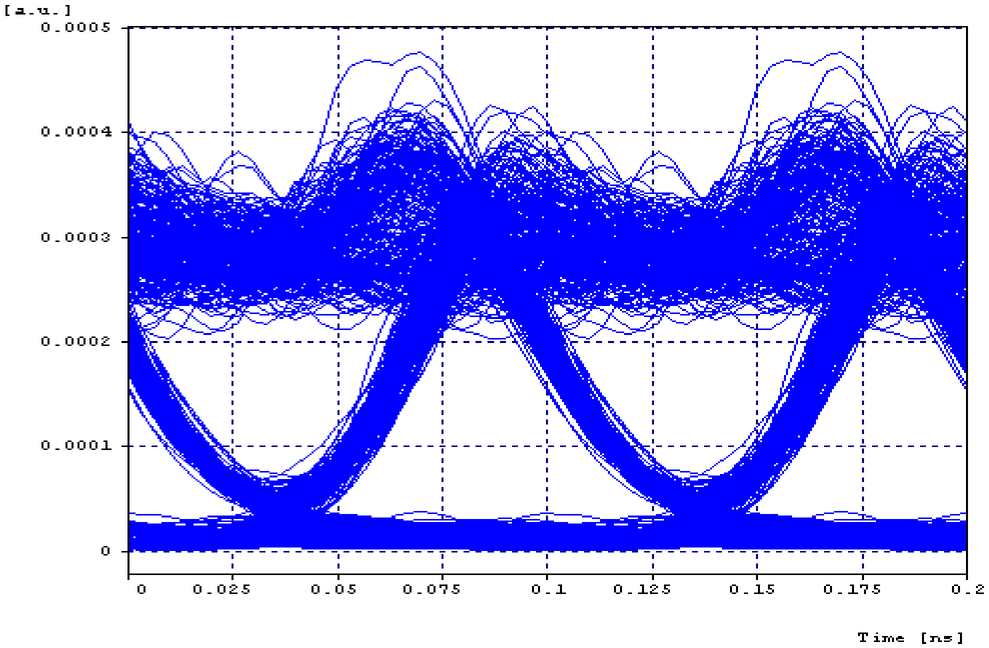

Figure 3.8 Eye diagram for NRZ Raised Cosine data format

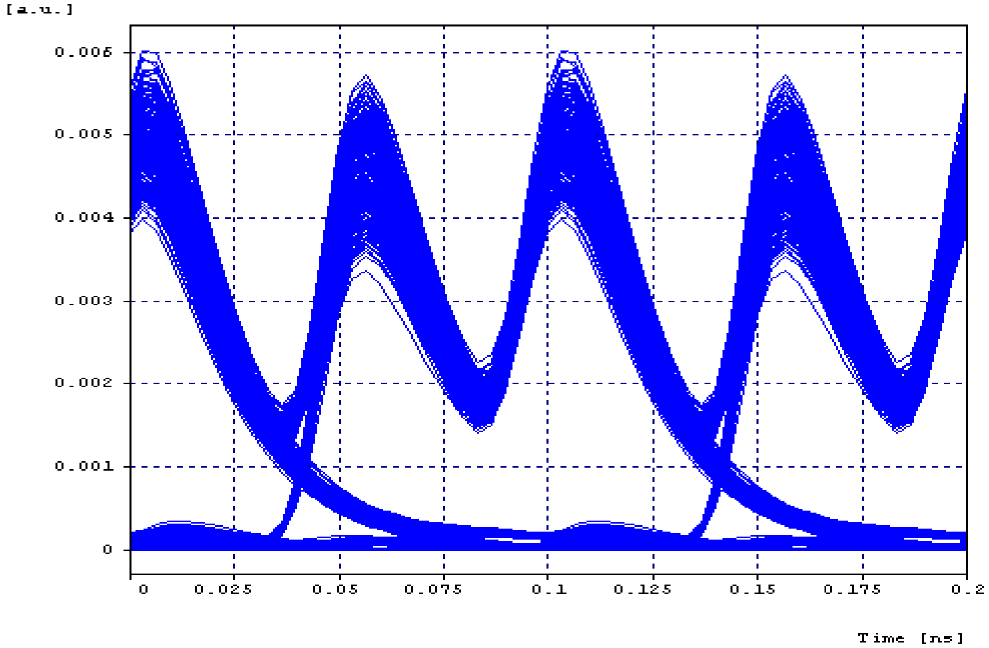

Figure3.9 Eye diagram for RZ Rectangular data format

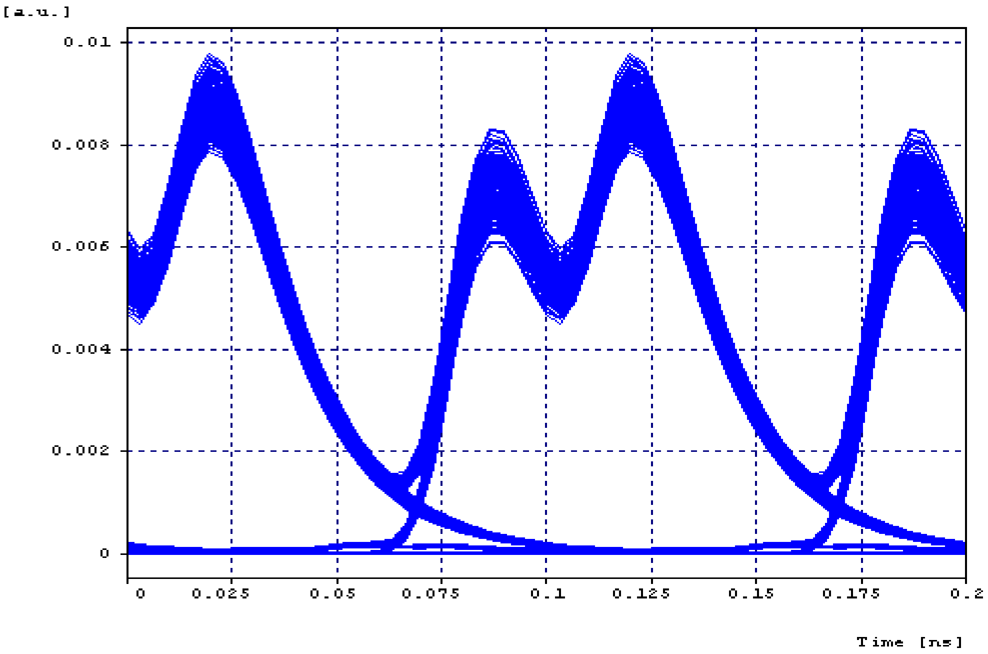

Figure 3.10 Eye diagram for RZ Raised Cosine data format

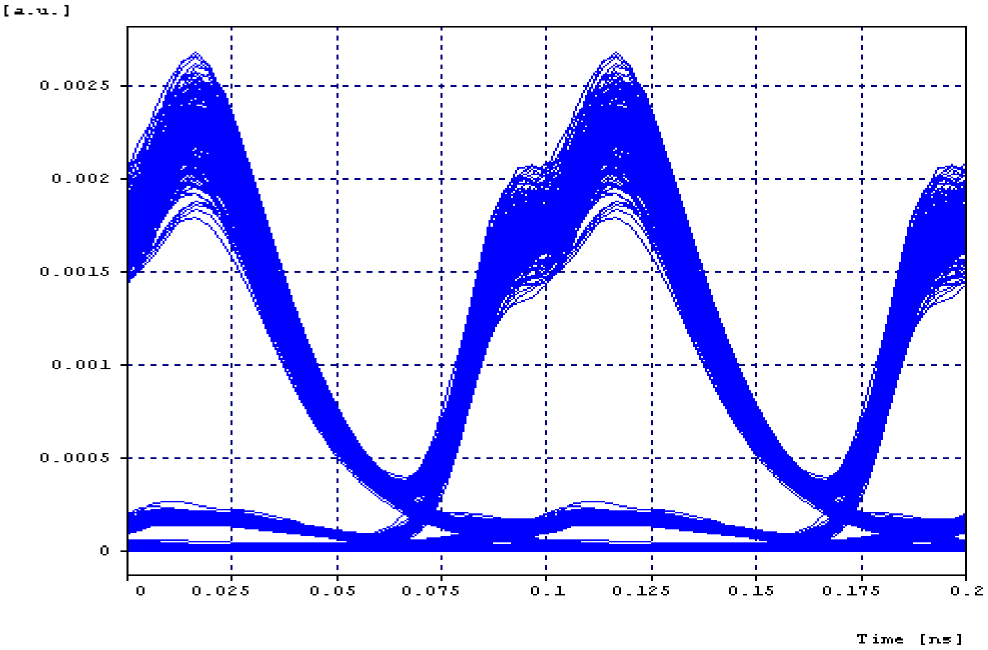

Figure 3.11 Eye diagram for RZ Super Gaussian data format

Figure 3.12 shows the BER rate plot for various data formats at different bitrates. This plot shows that the BER of RZ Raised Cosine is lowest when plotted against different values of bitrates. Figure 3.13 shows the BER plot for various data formats at different chirps. This shows that the BER of RZ Raised Cosine is lowest for different values of chirps.

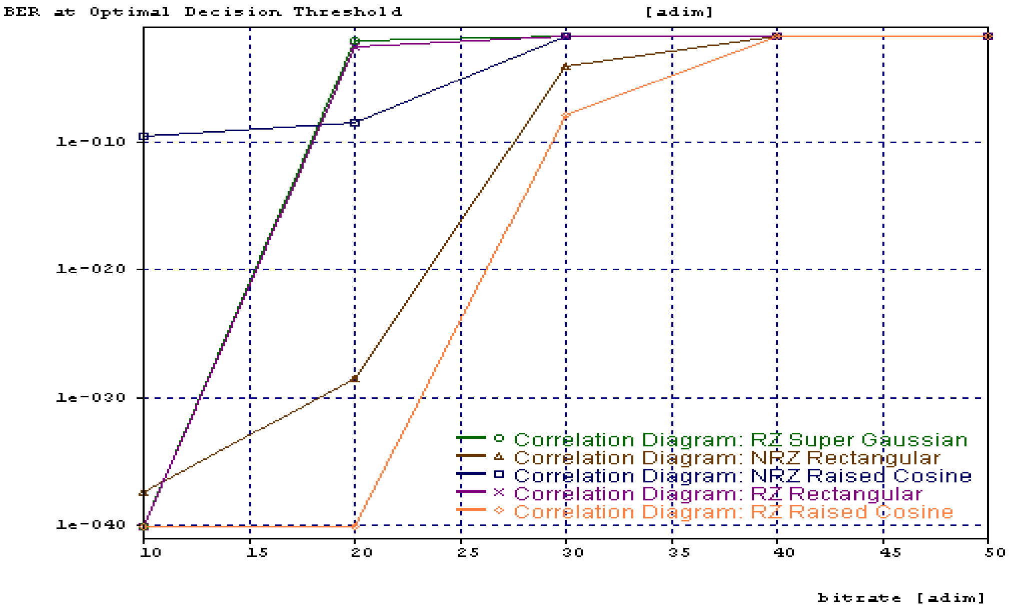

Figure 3.12 BER rate plot for various data formats at different bitrates

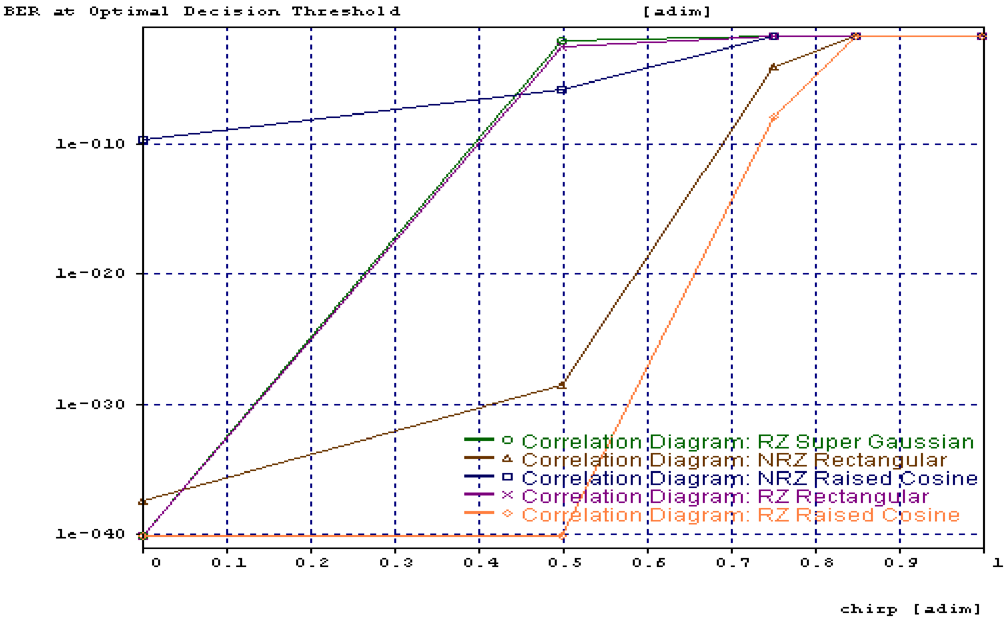

Figure 3.13 BER rate plot for various data formats at different chirps

Figure 3.14 shows the BER plot for various data formats at different dispersion values which shows that the lowest values of BER are for RZ Raised Cosine when plotted against various dispersion values. Figure 3.15 shows the BER plot for various data formats at different lengths. In this graph the lowest BER values are for RZ Raised Cosine Modulation format. Figure 3.16 shows the BER rate plot for various data formats at different powers. And, here again the lowest BER was for the RZ Raised Cosine Modulation format. Figure 3.17 shows the Q value plot for various data formats at different chirps. This graph shows that the Q value is highest i.e. 26.33 for RZ Raised Cosine. Figure 3.18 shows the Q value plot for various data formats at different lengths and again the Q value is highest for RZ Raised Cosine

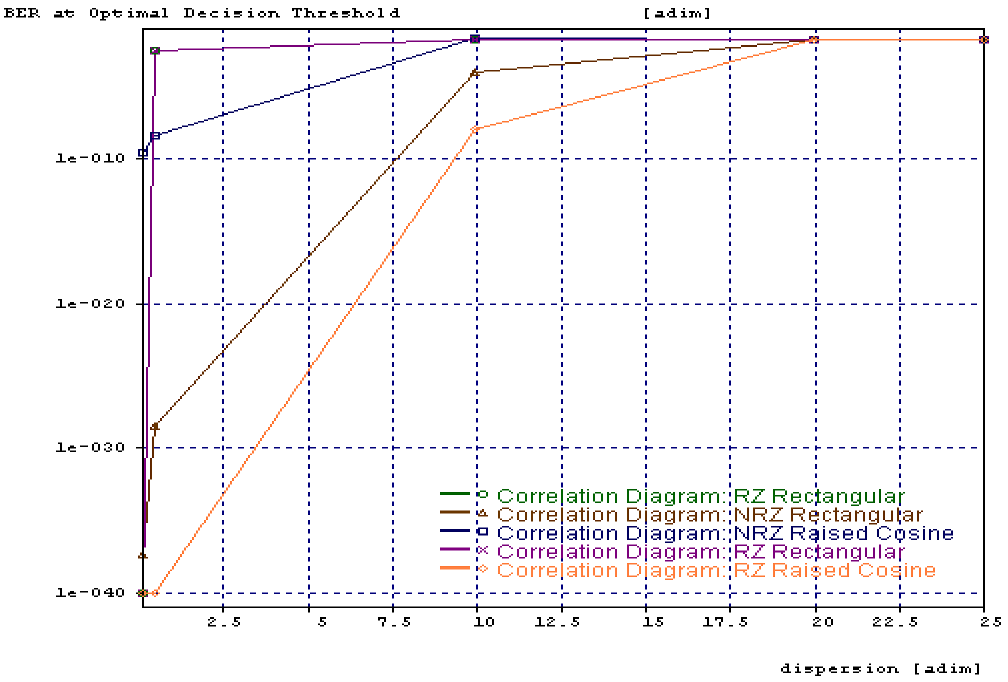

Figure 3.14 BER rate plot for various data formats at different dispersion values

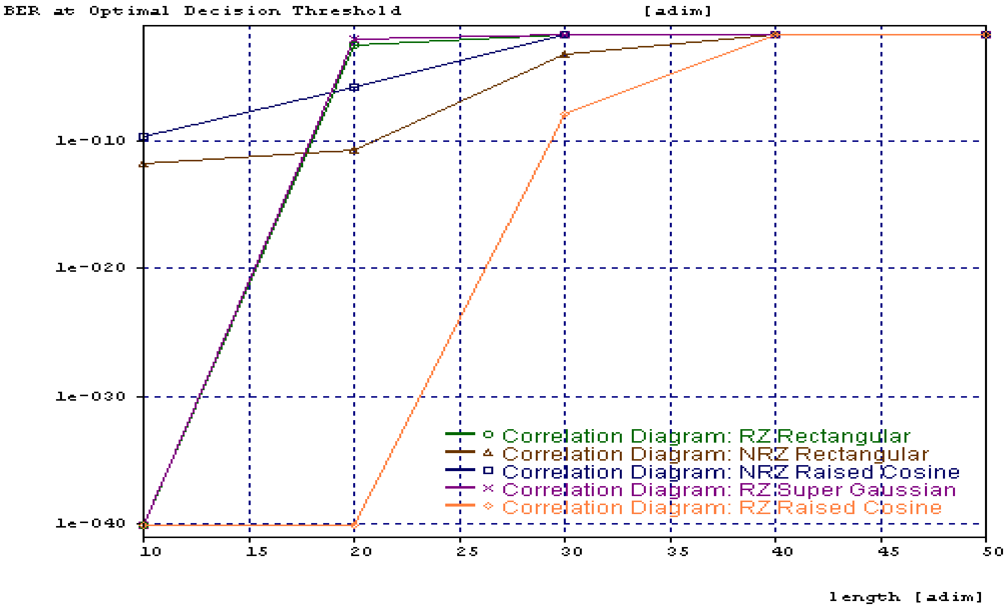

Figure 3.15 BER rate plot for various data formats at different lengths

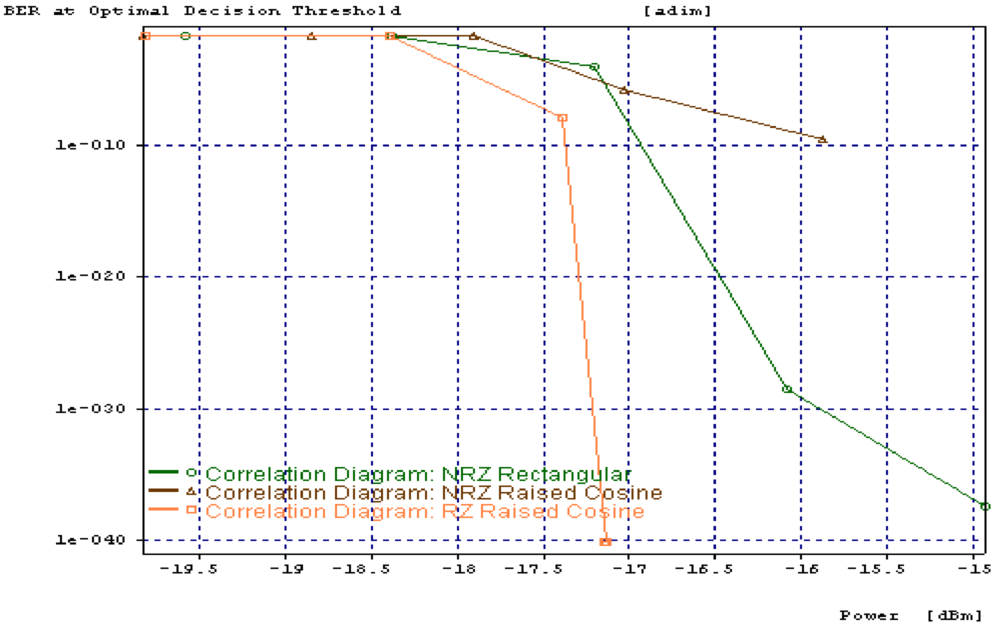

Figure 3.16 BER rate plot for various data formats at different powers

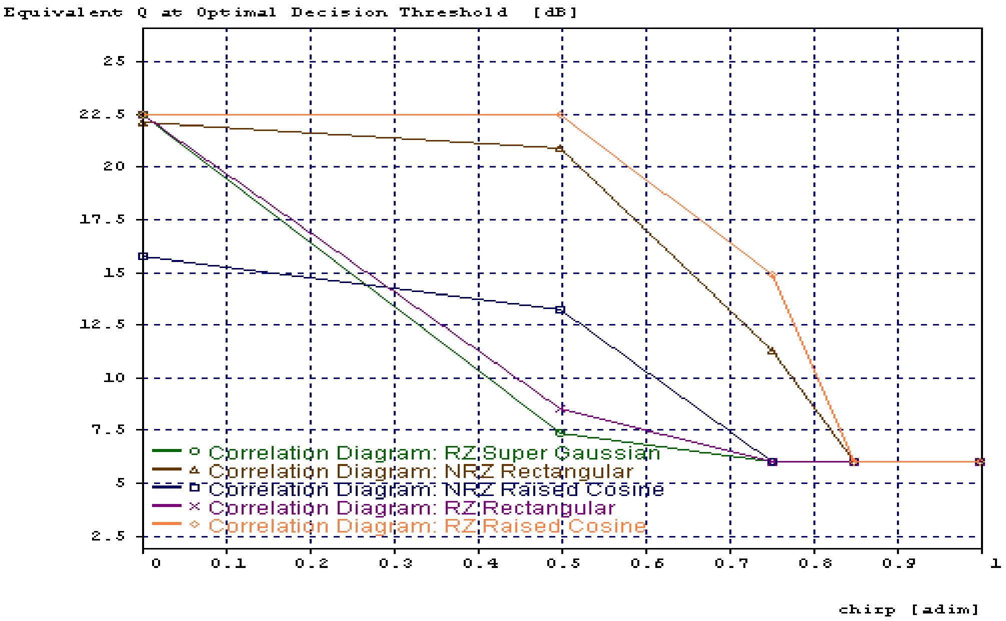

Figure 3.17 Q value plot for various data formats at different chirps

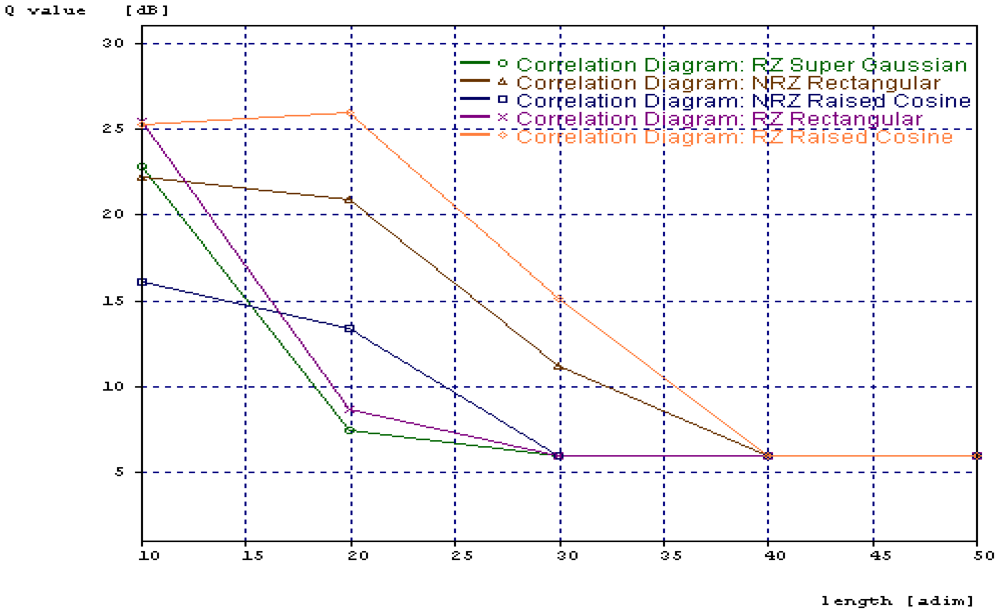

Figure 3.18 Q value plot for various data formats at different lengths

Figure 3.19 shows the Average eye opening plot for various data formats at different lengths. Here in this graph the widest eye opening of 0.0077 is recorded for the RZ Raised Cosine modulation format.

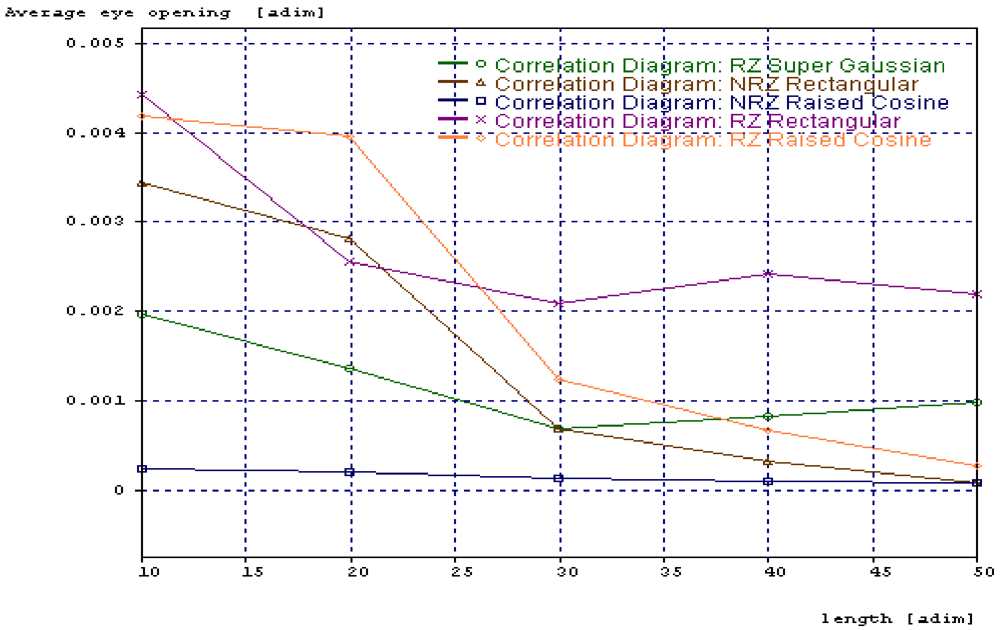

Figure 3.19 Average eye opening plot for various data formats at different lengths

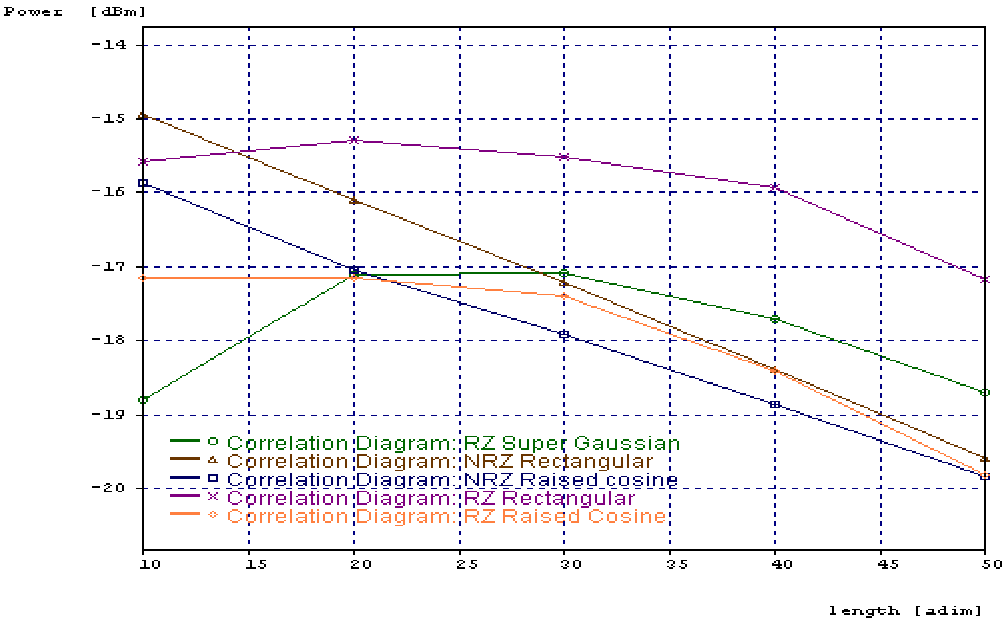

Figure 3.20 Power Vs length plot for different data formats

Figure 3.20 shows the Power Vs length plot for different data formats. Here, the Power Vs Length plot is best for RZ rectangular; however it is also reasonably good in case of RZ

Raised Cosine. We observed that Q-factor is highest; 26.33 dB in case of RZ raised cosine followed by NRZ Rectangular, RZ Rectangular and RZ super Gaussian and NRZ Raised Cosine with Q values 22.270005, 21.182730, 20.770599, 16.052290 respectively. Similarly, the lowest value of BER of order of 1 $x10^{-40}$ is obtained in the case of RZ Raised Cosine and $1.002121x10^{-37}$ for NRZ Rectangular while it is 6.89388 $x10^{-29}$ and 9.56618 $x10^{-27}$ for RZ Rectangular, and RZ super Gaussian, respectively, for ideal source(C = 0). Further it is reported that the jitter value remains low for all the data formats in general and also no considerable impact of chirp on jitter has been recorded. In a comparative investigation, eye opening in the case of RZ Raised cosine has been reported to be the best; however, it is also reasonably good for NRZ Retangular.

3.5. CONCLUSIONS

In this chapter, we have demonstrated the feasibility and the performance of the AWG multiplexer and AWG demultiplexer based 10 Gb/s network. Moreover, this network is scalable and cost-effective. Here, we observed that Arrayed Waveguide Gratings multiplexers and demultiplexers for WDM applications have proven to be capable of precise multiplexing and demultiplexing of a large number of channels with relative low losses and with a very low BER of 1 $x10^{-40}$ for a transmission distance of 50 km. This distance can be further increased by using optical amplifiers in the network. Hence, this network is a good choice for either upgrading or installing a new metropolitan area network and we also have carried out the comparative performance evaluation of various data formats in same optical transmission link. The results have been reported for different data formats, viz. NRZ Rectangular, NRZ Raised cosine, RZ Rectangular, RZ raised cosine and RZ super Gaussian. In the case of RZ raised cosine its highest value of Q (26.33dB), good eye opening, lowest BER and its non-susceptibility at different chirps makes it the best choice among the data formats mentioned. Jitter value remains low for all the data formats in general and also no considerable impact of chirp on jitter has been recorded. In a comparative study, power level in case of RZ Rectangular has been reported to be the best ; however ,it is also reasonably good (second best) for RZ raised cosine.

CHAPTER 4

PERFORMANCE ANALYSIS OF METRO WDM NETWORK BASED ON AN OPTICAL CROSS CONNECT AND ARRAYED WAVEGUIDE GRATING DEMULTIPLEXERS

In this chapter, we have demonstrated the quality-of-service offered by the metropolitan area network which is based on optical cross connect (OXC) and arrayed waveguide grating (AWG) demultiplexer operating at 10 Gb/s with 0.1 nm channel spacing for NRZ signal transmission. The data is successfully transmitted to a distance of 40 km with a reasonably good BER of 2.388 x 10^{-35}. The OXC and AWG Demultiplexers in the proposed architecture allow incremental expansion in terms of the number of wavelength channels to be transmitted. Dispersion and crosstalk are the main signal-degrading factors arising from the operation of the OXC and the effectiveness of each factor is individually investigated.

4.1 INTRODUCTION

Optical Cross connects (OXC) is one of the key components for all optical networking. It has high switching speeds, long term reliability and small switch element size. Optical crosses connect (OXC) is an optical switch with large port numbers that can interconnect optical signals between multiple inputs and multiple outputs [30]. The switching speed of the network is greatly increased by employing OXCs and Arrayed waveguide grating based demultiplexers in a metro network. One thing is certain that as carriers move towards the seamless optical transport network the fundamental building block will be the optical cross-connect or OXC . The OXCs join the metro and core network topologies together, adapting optical channels as they pass between the two, implementing new topologies (mesh for instance), as well as enhancing network utilization [31]. The OXCs also play a complementary role in network management functions, such as performance monitoring and alarm handling. Conversely, in traditional optical topologies, such as point-to-point links and optical rings where there are no OXCs, the end-to-end interconnection is carried out by optical add-drop multiplexers (OADMs) or optical terminal multiplexers (OTMs) in back-to-back configurations. In this context, optical transparency is largely confined within each basic topology .The wavelength division multiplexing (WDM) of optical signals is a promising way to increase the transmission capacity of a fiber [32]. In WDM systems, a wavelength multiplexer and demultiplexer based on an arrayed waveguide grating (AWG) is an essential component in order to multiplex and demultiplex the light signals. The optical cross-connect is emerging as the fundamental building block of a seamless optical transport network, one in which distributed intelligence, automated circuit provisioning and rapid time-to-service are the defining characteristics. The development of wavelength division multiplexing (WDM) has allowed us to exploit the large amount of bandwidth available in an optical fiber as multiple lower-capacity channels.

Table 4.1 Comparison between an optical network built upon basic topologies WDM point to point routes or rings and an OXC based architecture

Parameter	**Basic topologies**	**Cross connected networks**
Flexibility	Low	Very (high)
Time -to-service	Medium/long(a few weeks)	Very short
End to end configuration	Manual cross connections between the simple topologies	Remote (automatic)
Management	Partial and limited	Complete
Revenues	Acceptable/good	Better
Survivability	Few protection mechanisms; no restoration	New protection mechanisms/ restoration; portable better delay controlled back up switches
QoS	Guaranteed by back to back network element configurations	Guaranteed by OXCs that ensures service transparency
Customer facilities	Probably limited to fault reporting	Premium customers may manage their own circuits

With the introduction of Optical Cross-connects (OXCs), end-to-end optical connections (also known as lightpaths) allow packets to be carried without optical-to-electronic conversion in the intermediate hops, thus overcoming the electronic conversion bottleneck. OXC is rapidly evolving mainstream component that enables the switching and routing in dense wavelength division multiplexing (DWDM) networks and all optical networks (AON)

[33]. The OXC's within the key nodes of the AON enable optical transparent connections within the backbone and route the optical signals to the regional networks at the edges of core network [34]. The multiple optical inputs containing many different Wavelengths are first demultiplexed and then redirected by the OXC. The signals are further multiplexed to their desired output fibers by the multiplexers. Although physically the OXC's have only switching function by redirecting the light paths, they realize the wavelength routing with the help of optical multiplexers/ demultiplexers [35]. In addition the local optical signals can be added to or dropped from the OXCs simultaneously. In common electrical cross connects, optical signals coming from the input optical fibers need to be converted to the electronic signals in order to process the data, and then the electronic signals should be converted back to the optical form to deliver them to the desired output fibers [36]. These conversions of the electronic to optical and optical to electronic may induce delay and congestion, especially at the time of heavy burden. In contrast OXCs are able to handle the optical signals in their native form and directly switch them from multiple input fibers to their desired output without the need of any optical to electronic conversion. This greatly improves the switching throughput. The OXCs are expected to play the important roles in the backbone of the fiber optical communication systems while electronic remains on the edges of the networks [37].

Hai Yuan et al. [38] experimentally studied FBG-Based Bidirectional optical cross connects. A new bidirectional optical cross connect (BOXC) using fiber Bragg gratings (FBGs) and optical circulators for bidirectional wavelength-division-multiplexing ring networks is proposed. Dynamic and independent wavelength routing is achieved by employing cascaded tunable FBGs.

A.Q.Liu et al. [39] experimentally demonstrated optical cross connects using drawbridge micromirrors. Factors such as optical cross connect architectures, insertion losses and mirror motion types have been investigated for the design of optical cross connects having large port numbers.

Chun Tung Chou et al. [40] presented a hybrid optical network architecture consisting of optical cross connects and optical burst switches. The architecture allows carriers to gradually migrate from an OXC-based network to an OBS-based network with improved network utilization. In addition; queuing analysis is used to study the performance of this new architecture.

But up till now, no work has been done on the networks based on optical cross connects and AWG Demultiplexers. Today we need reliable, scalable and high switching speed networks to cope with these realities. So the network based on OXC and AWG Demultiplexers can be designed.

In this chapter we have analyzed the performance of this network operating at 10 Gb/s for the transmission of the data and this is successfully implemented at a very low BER of 2.38 $X10^{-35}$. The network based on optical cross connects and AWG demultiplexer can be used to provide a cost effective solution for the present metropolitan area networks.

The chapter is organized into four sections. Section 4.1 presents the introduction. Section 4.2 presents the simulation set up of the network and the description of its components. Section 4.3 includes the discussion of the results for the network based on optical cross connects and AWG demultiplexers. Section 4.4 presents the conclusion about the feasibility of the network.

4.2 DESCRIPTIVE MODEL

In the network based on optical cross connects and AWG demultiplexer a 4 node architecture is simulated and each node contains 4 transmitters and each transmitter has 4 channels so on the whole our network comprises of 16 channels as shown in Figure 4.1.

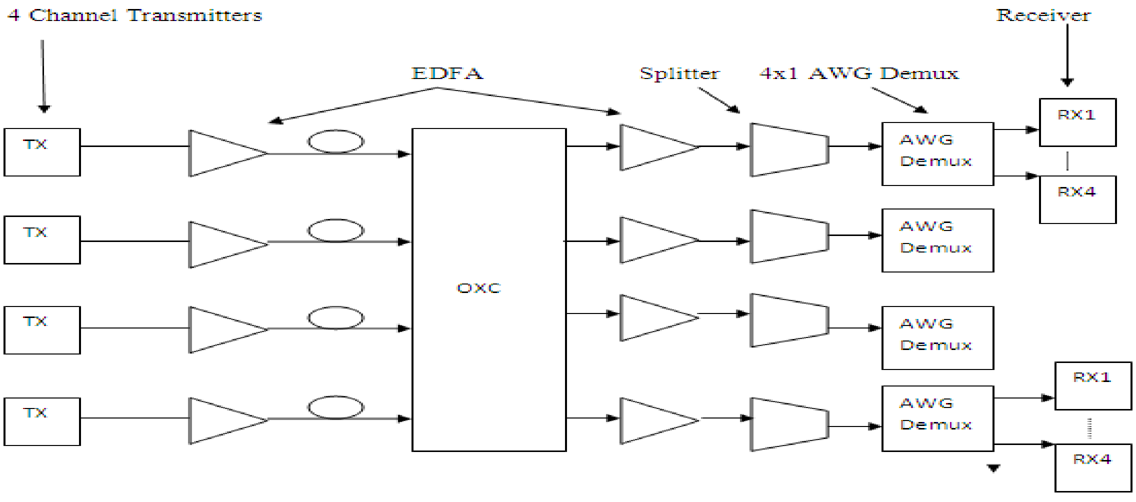

Figure 4.1 Block diagram of optical cross connect and AWG Demultiplexers based optical network

4.3 SIMULATION SET UP

The architecture is based upon optical cross connect indicated by the component name oxc4x4_1, four 4 x 1 splitters indicated by the component name op_spl_1 to opl_spl_4 and two 1 x 4 demultiplexers indicated by the component name awg_demux_1 and awg_demux_2. The AWG demultiplexers are at the receiver side to retransmit the optical signal fed to them through the optical cross connect to their final destinations. Figure 4.2 shows simulation set-up of 10 Gb/s optical transmission link. The fiber used in our architecture is 40 km long standard single-mode fiber (SMF). SMF offers an attenuation α is 0.2 dB/km with dispersion D is 16 ps/km nm at 193.1 THz. The central frequency of the fiber is 193.1 THz. Each node is further composed of, one transmitter source and one receiver source. The analysis of results is made by means of measurement blocks inserted in the iterate block. Also the central wavelength of each of the transmitter used comprising of four channels is 193.1 THz. The channel spacing is of 0.1 THz. The transmitter is composed of data source, laser source, optical amplitude modulator and optical link section.

Data source generates a binary sequence of data stream. Data source is customized by baud rate, sequence, logical signal level and the period length.

Laser block shows simplified continuous wave (CW) laser. The model considered has 193.1 THz center emission frequency, 1mw CW power, ideal laser noise bandwidth, 10 FWHM linewidth and laser random phase. The output from the driver and laser source is passed to the optical amplitude modulator.

Modulation driver here generates data format of the type NRZ Rectangular. The pulses are then modulated using MZ modulator at 10 Gb/s bitrate. Amplitude Dual-Arm Mach Zehnder Modulator is used to modulate optical signal of desired form at having the following parameters: offset voltage corresponding to the phase retardation in the absence of any (on both arms) electric field is 0.5V, 30 dB extinction ratio and average power reduction due to modulation is 3dB. The Erbium Doped Fiber Amplifiers used in this circuit has the gain of 5 dB.

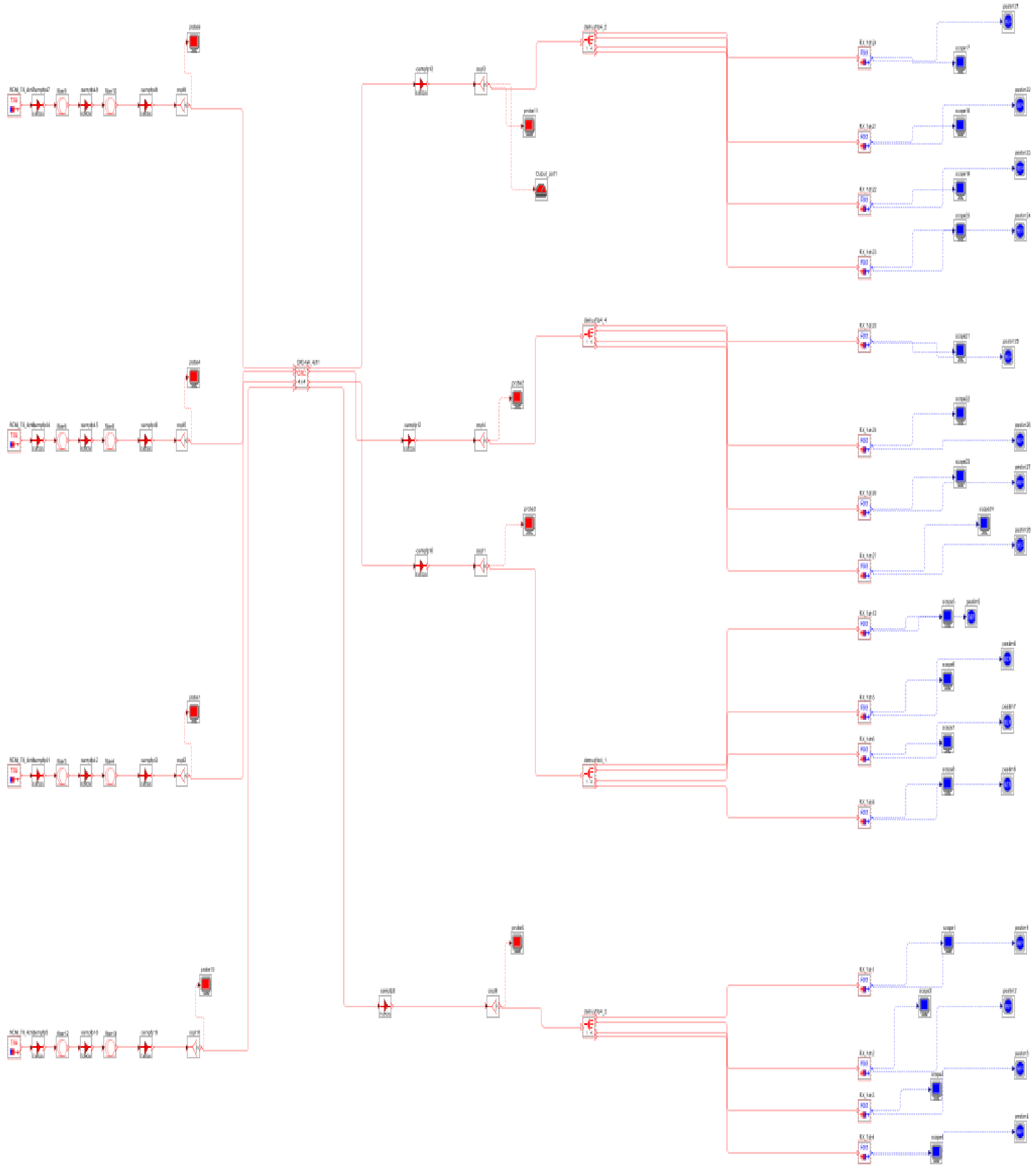

Figure 4.2 Simulation Set Up

An optical transmission link consists of three stages i.e. transmitter, an optical cross connect and optical AWG demultiplexers as shown in Figure 4.2. The optical AWG demultiplexer separates wavelengths in an input fiber on to ports. At the transmission side for dispersion compensation we are using dispersion compensation fiber. Length of the DCF used is 10 km and the loss α is 0.4 dB/km with dispersion D is -28 ps/km nm at 193.1 THz.

Optical cross connect has the filter roll off 0.2, insertion loss 2 dB, channel spacing 0.1, center frequency is 193.1 THz, filter bandwidth is 100 GHz and crosstalk is -100 dB.

Arrayed waveguide grating demultiplexer has the filter bandwidth of 100 GHz, center frequency is 193.1 THz, channel spacing is 0.1, insertion loss is 3 dB and filter roll off is 0.2.

Optical splitter used here has an attenuation of 0dB at each output port so this component implements an ideal splitter without any insertion loss, i.e. a component that perfectly splits the input signals

Single receiver is composed of optical raised cosine filter, PIN photodiode and low-pass Bessel filter. Electrical scopes with Gaussian filter are used to observe change in performance.

Optical filter component implements a raised cosine transfer function filter having band pass filter synthesis, 1 as raised cosine exponent, 0.2 raised cosine roll off, 193.1 THz Center freq, , 40 GHz B.W.

PIN photodiode is used to detect the optical signal, i.e. conversion into electrical signal. Its parameters are 193.0THz nm reference frequency, 0.80 quantum efficiency, 0.99A/W responsivity, 3dB bandwidth 20 GHz and zero dark current.

Electrical filter at the receiver side is implemented by lowpass Bessel filter. The filter has 5 poles in number and has 3 dB bandwidth 10 GHz. The measurement components used are electrical scope, optical scope, optical spectrum analyzer, BER tester, Q analyzer and power meter. The electrical scope is used to obtain eye diagram.

4.4 RESULTS AND DISCUSSION

Using the simulation setup, the values of input signals, wavelength spectrum, eye diagrams and received signal are measured. From the eye diagram the values of Q factor, jitter and eye opening are determined. Figures (4.3-4.19) show the results obtained in the form of plots and eye diagrams. Table 4.2 presents the summary of comparative investigation on the performance metric indices viz. Q (dB); eye opening; BER and jitter (ns) for 10 Gb/s optical transmission link based on optical cross connects and AWG demultiplexer with NRZ Rectangular data format.

Table 4.2 The summary of comparative investigation on the performance metric indices

Parameter	Output After OXC	Output after AWG Demultiplexer (Before dispersion compensation)	Output after AWG Demultiplexer (After dispersion compensation
BER	1e-40	1.26999e-007	2.38832 e -035
Q (dB)	30.1654	14.228246	21.920603
Eye Opening	0.00223436	9.5822e-005	2.62438E-12
Closure(dB)	0.424189	3.758954	0.801660
Jitter (ns)	0.0181747	0.0110053	0.0182844

Figure 4.3 shows the Input optical spectrum at the transmission end and Figure 4.4 shows the Output optical spectrum at the receiver end with optical cross talk parameter set to -200 dB. As the crosstalk parameter is increased from -200 the interference in the optical spectrum can be clearly seen from the figures (4.4-4.7).

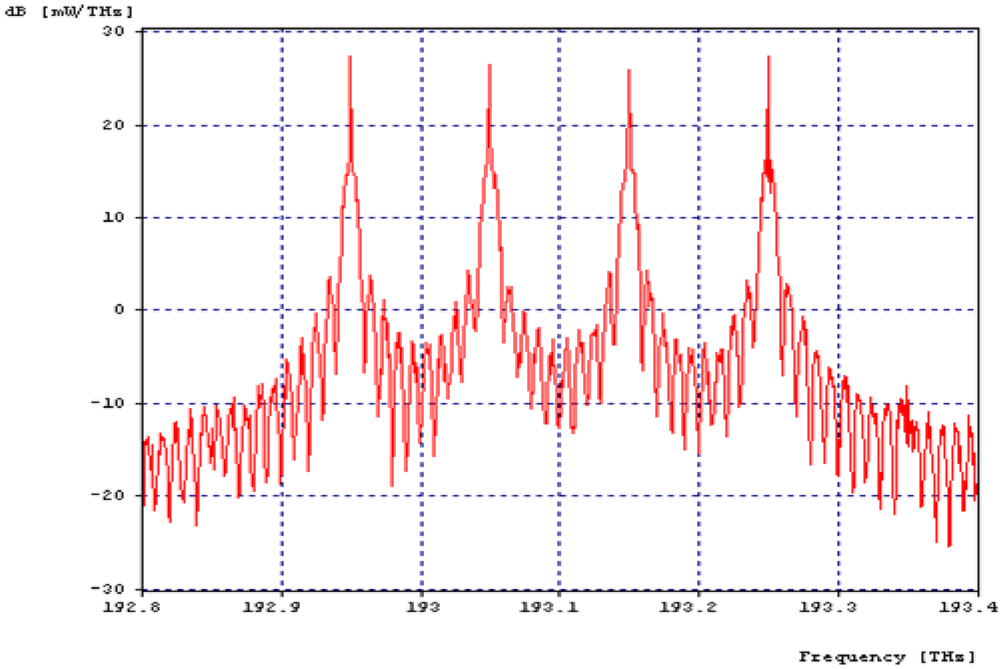

Figure 4.3 Input optical spectrum

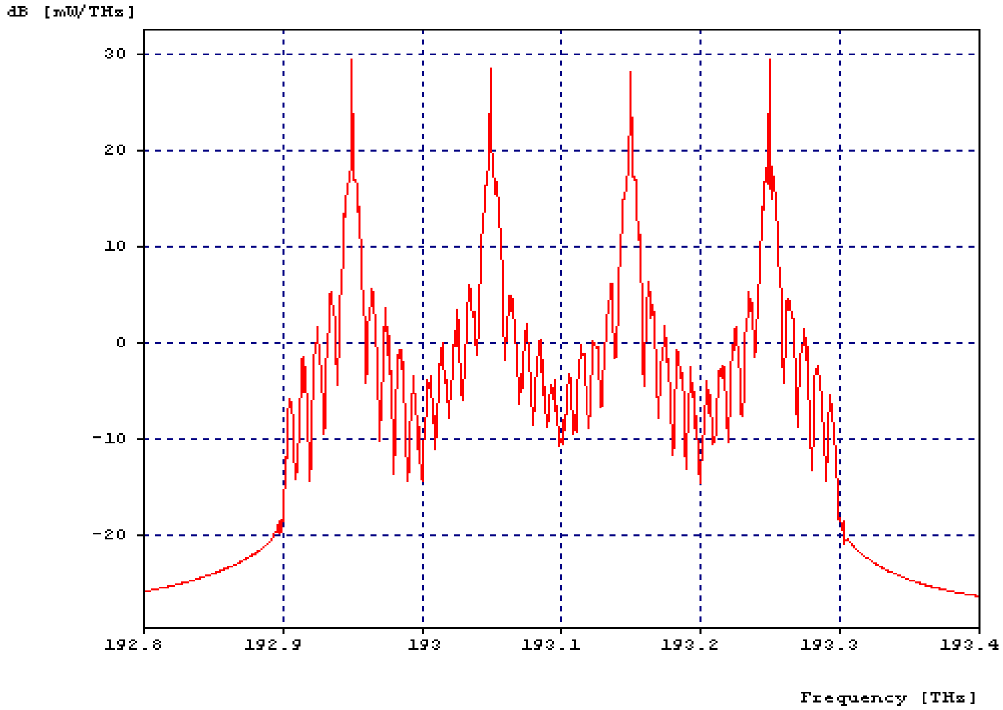

Figure 4.4 Received optical spectrum at crosstalk -200 dB

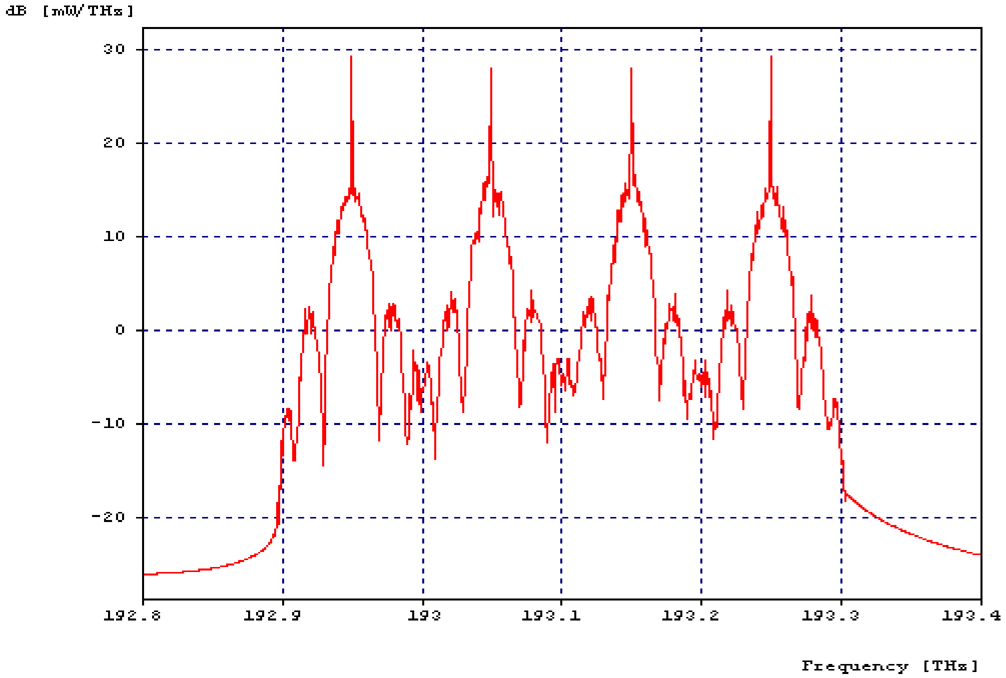

Figure 4.5 Received optical spectrum at crosstalk -100 dB

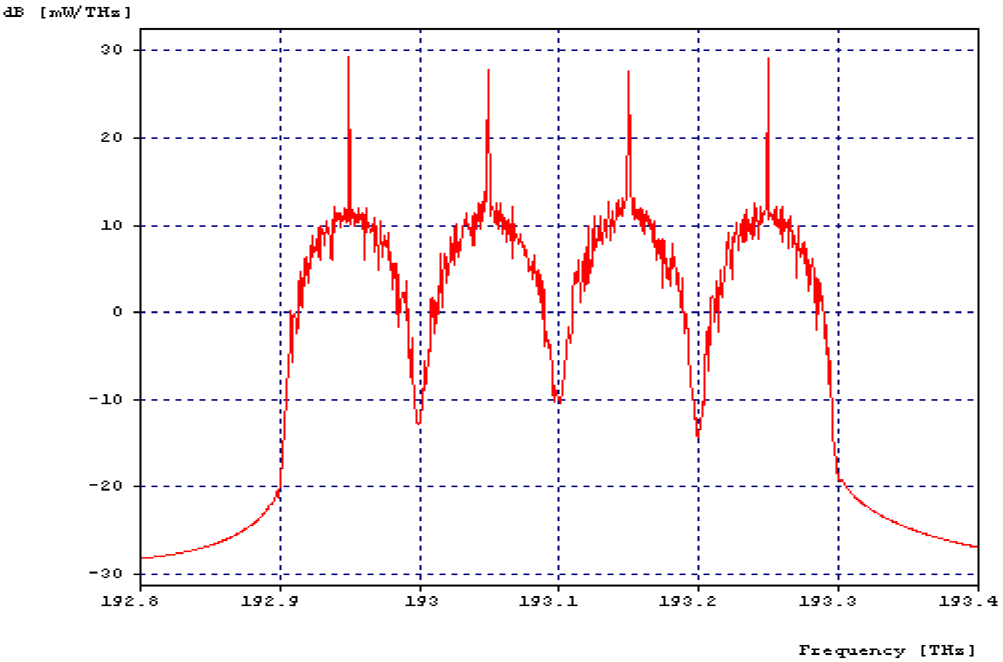

Figure 4.6 Received optical spectrum at crosstalk -20 dB

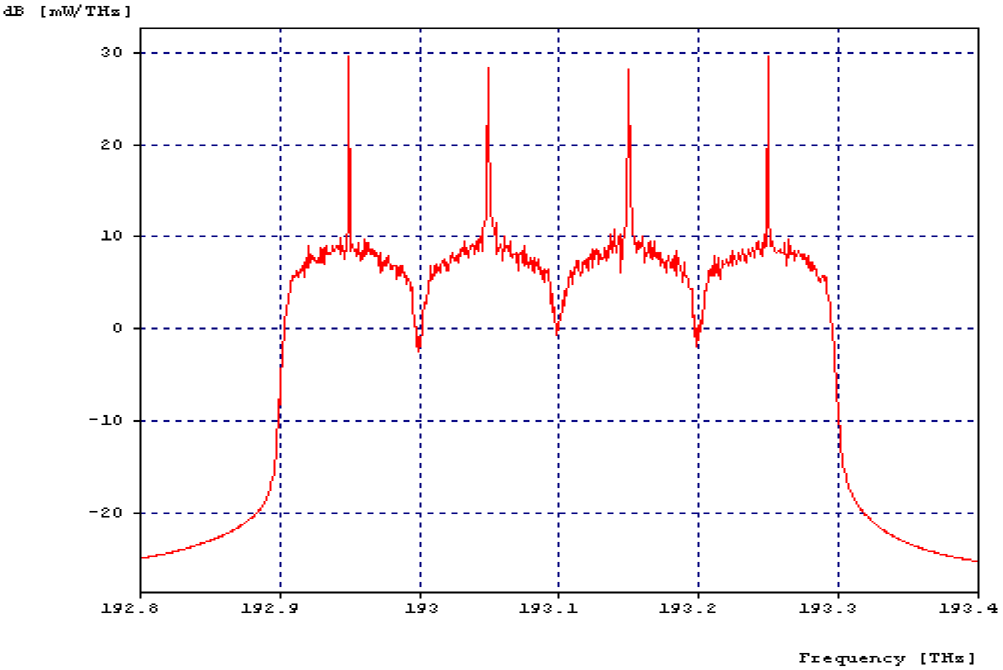

Figure 4.7 Received optical spectrum at crosstalk -5 dB

Figure 4.8 shows the eye diagram after the optical cross connect. The BER after the optical cross connect is 1 x10^{-40}. Figure 4.9 shows eye diagram after the AWG Demultiplexer before dispersion compensation. The BER here is 1.269 x10^{-7}.

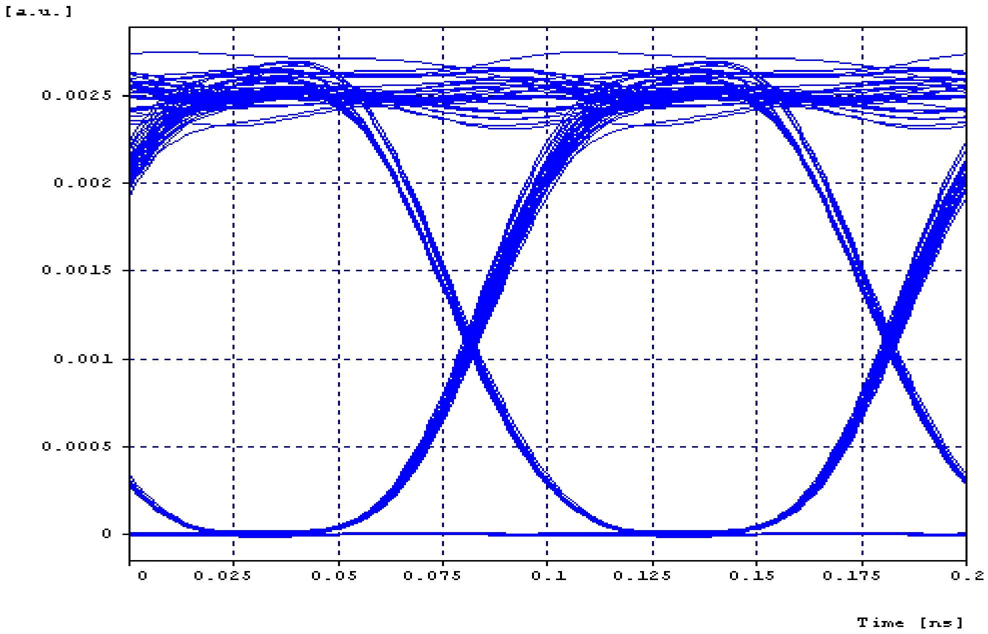

Figure 4.8 Eye diagram after the optical cross connect

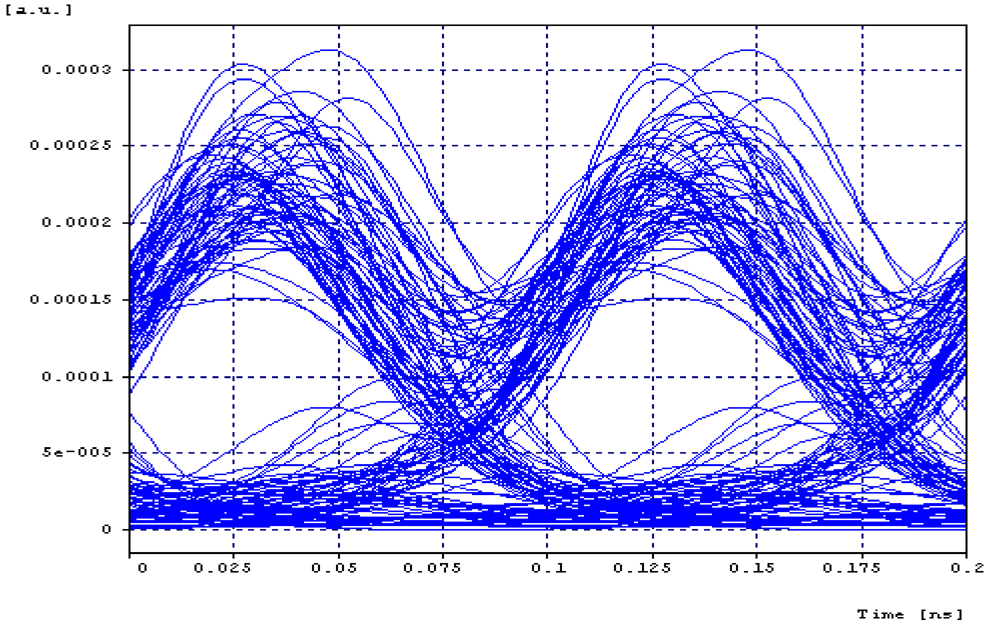

Figure 4.9 Eye diagram after the AWG Demultiplexer before dispersion compensation

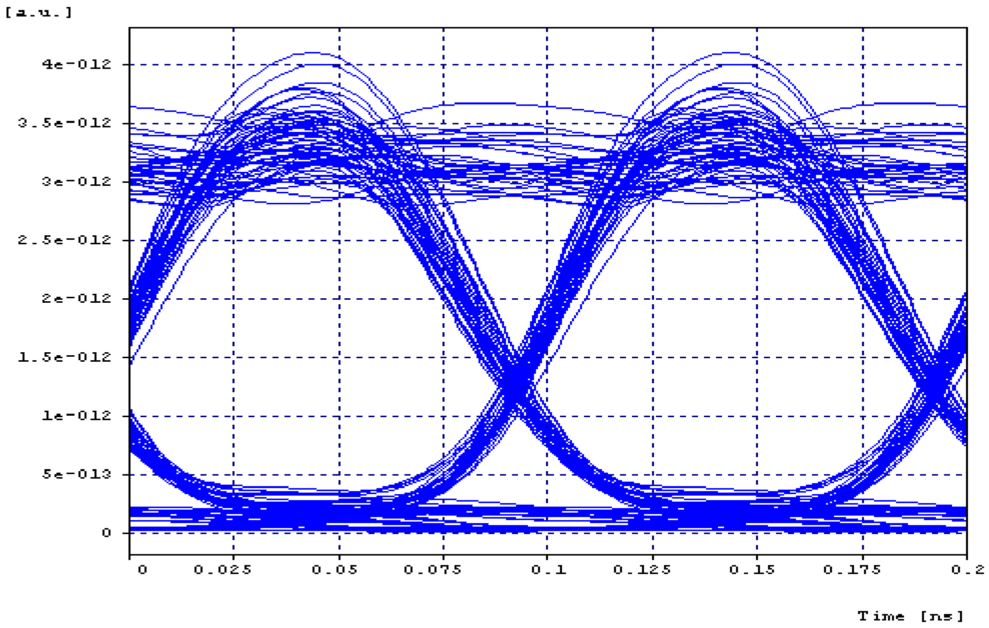

Figure 4.10 Eye diagram at the AWG Demultiplexer after dispersion compensation

Figure 4.10 shows the eye diagram at the AWG Demultiplexer after dispersion compensation. The BER here after dispersion compensation becomes reasonably good i.e. 2.388 x10^{-35}.

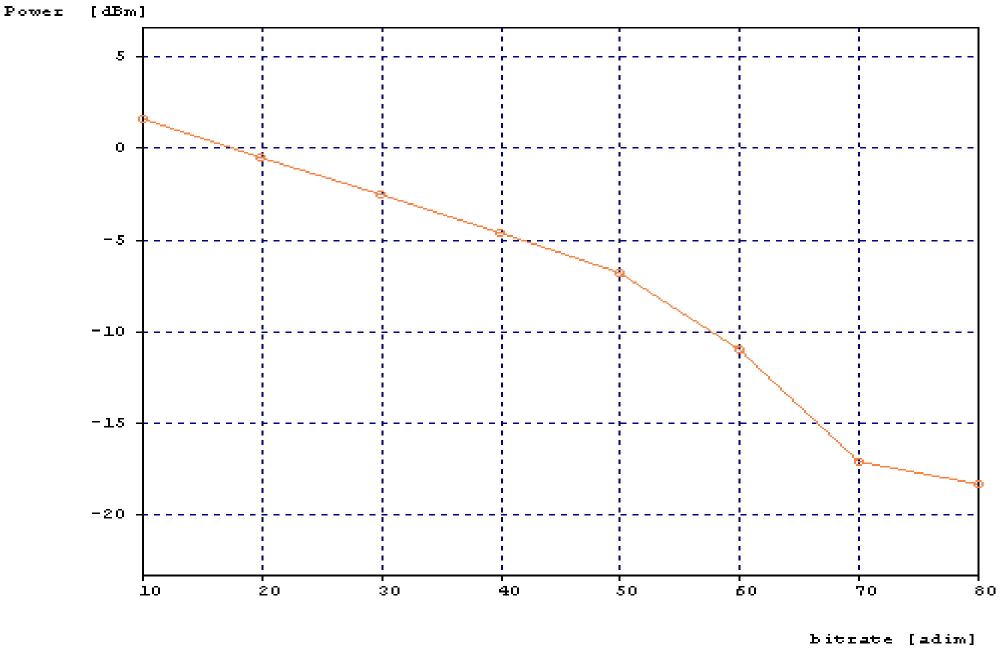

Figure 4.11 Power Vs Bitrate Plot

Figure 4.12 shows the Power Vs Bitrate Plot. It is observed that the power consequently decreases by increasing the bitrate from 10 Gb/s to 80 Gb/s in our network. Figure 4.13 shows the Power Vs length plot. This graph shows that as we are increasing the fiber length from 10 km to 100 km, the power is decreasing. Figure 4.14 shows Power Vs Crosstalk plot. The cross talk in this plot is varied from -200dB to 0dB and as we are increasing the value of cross talk i.e. from -200 to 0 dB, the power in the network is decreasing. Figure 4.14 shows the BER Vs Crosstalk plot. The BER increases in the plot with the increase in the crosstalk level. Figure 4.15 shows the Q Factor Vs dispersion plot. This graph shows that as the dispersion in the fiber is increasing the Q factor is decreasing.

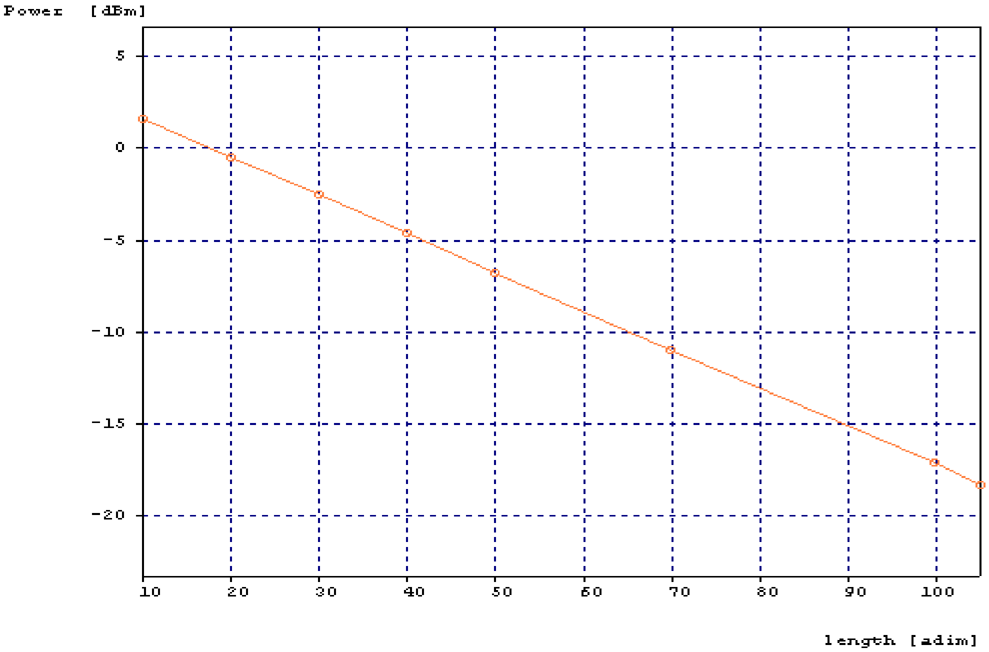

Figure 4.12 Power Vs length plot

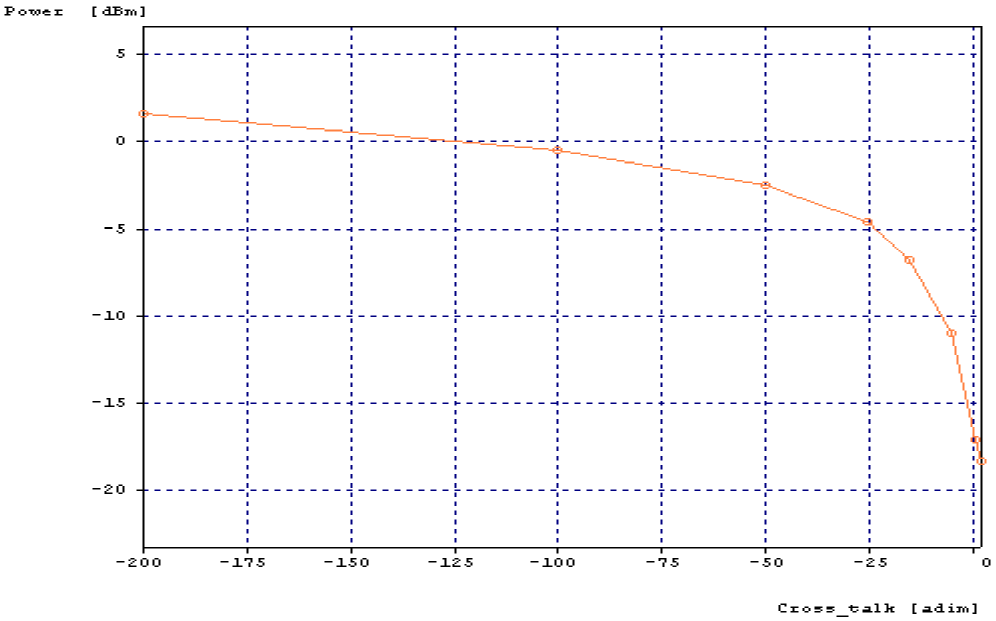

Figure 4.13 Power Vs Crosstalk plot

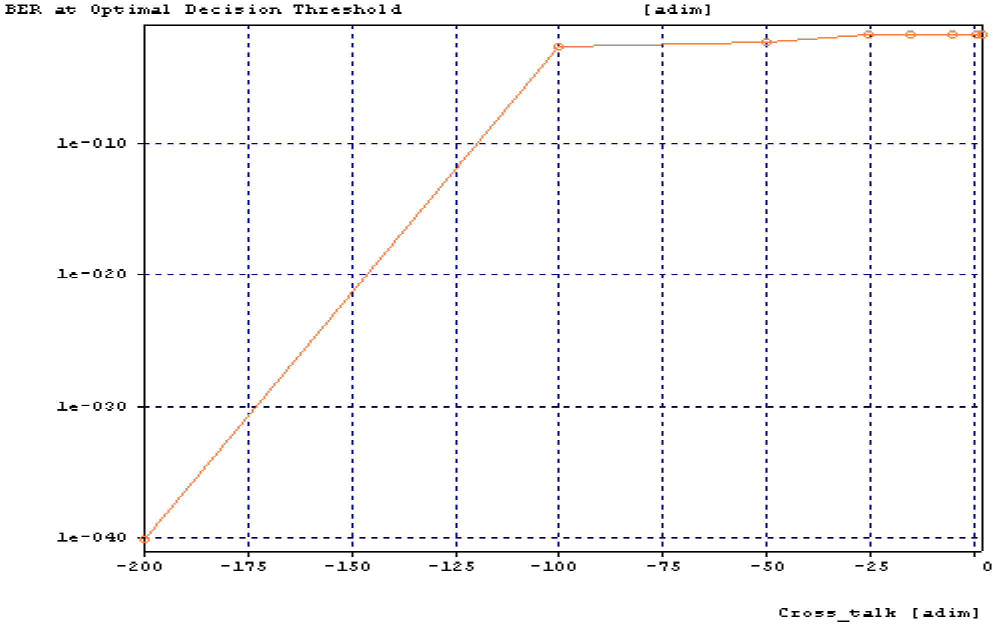

Figure 4.14 BER Vs Crosstalk plot

Figure 4.16 shows the BER Vs Chirp plot. For different chirps (0, 0.5, 0.75, 0.85 and 1) the lowest BER is reported for chirp value 0. Figure 4.17 shows BER Vs bitrate plot. As the value of bitrate is increasing from 10 Gb/s to 80 Gb/s,the BER is also increasing.

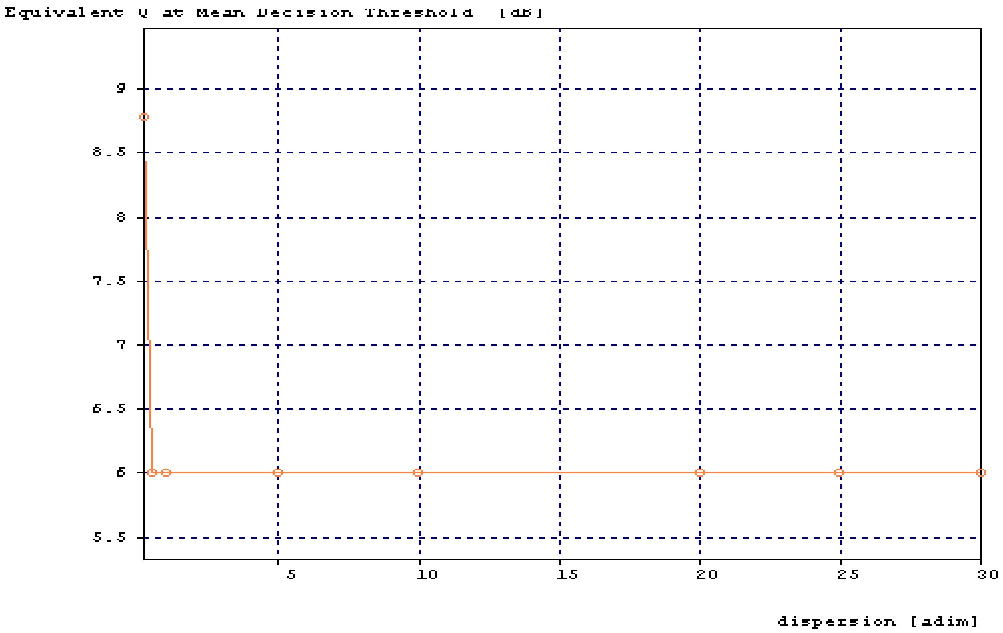

Figure 4.15 Q Factor Vs dispersion plot

Figure 4.18 shows the plot of BER Vs length. As the length is increased from 10 km to 100 km the BER is also increasing

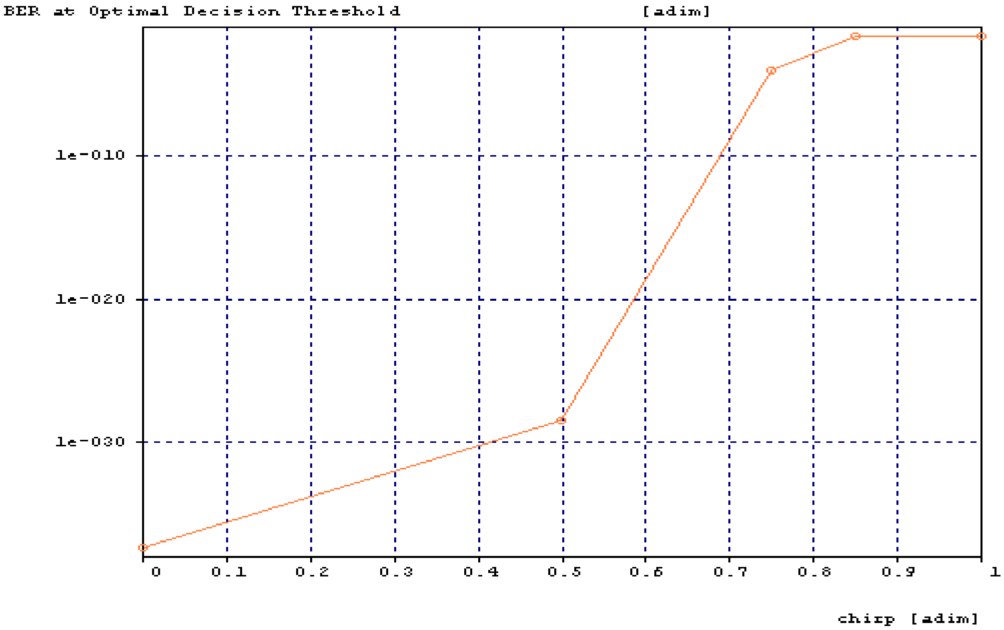

Figure 4.16 BER Vs Chirp plot

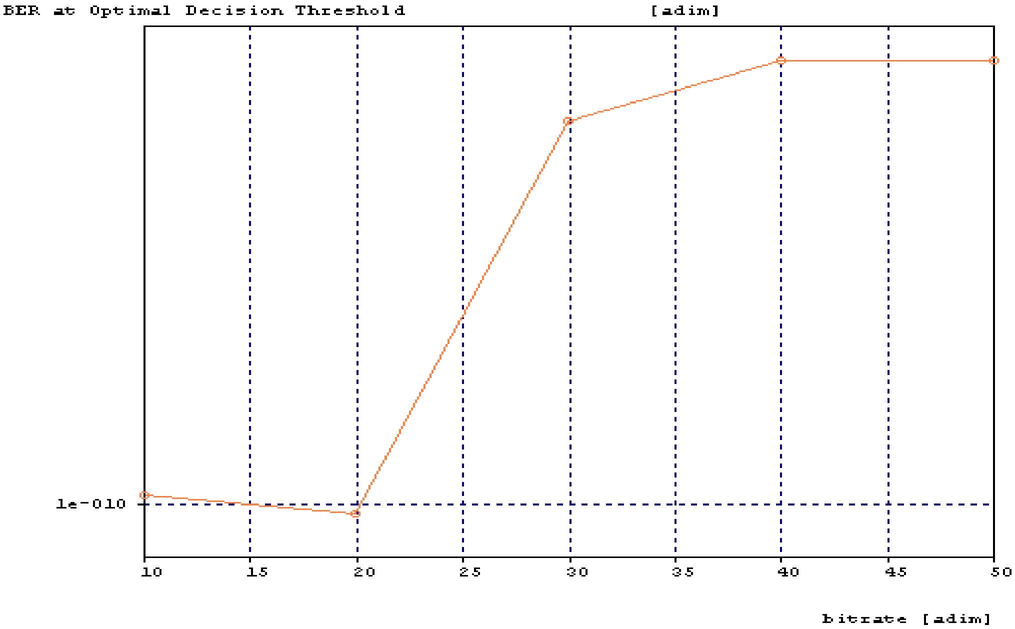

Figure 4.17 BER Vs bitrate Plot

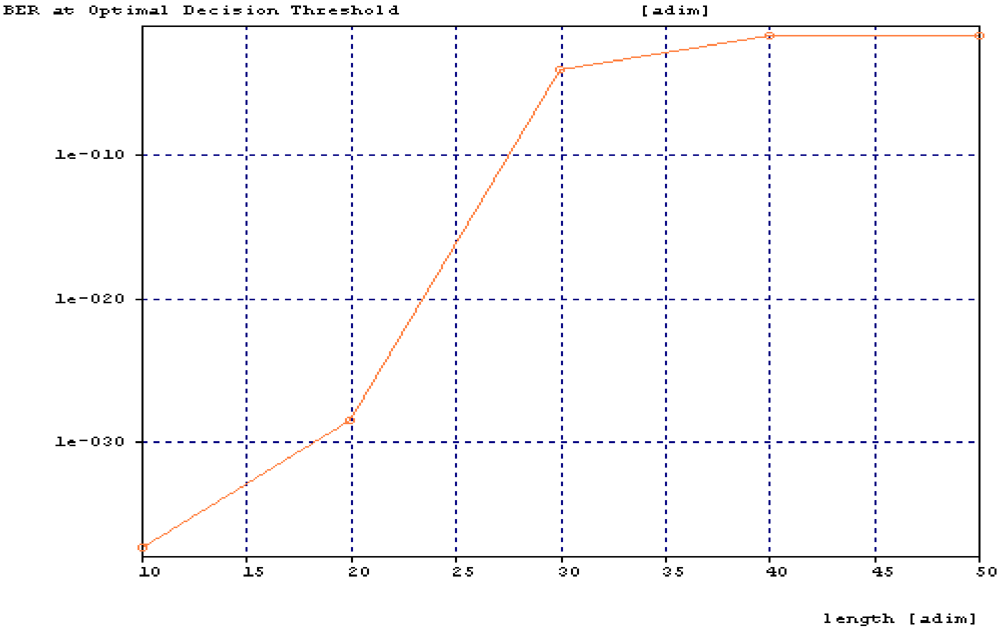

Figure 4.18 BER Vs Length Plot

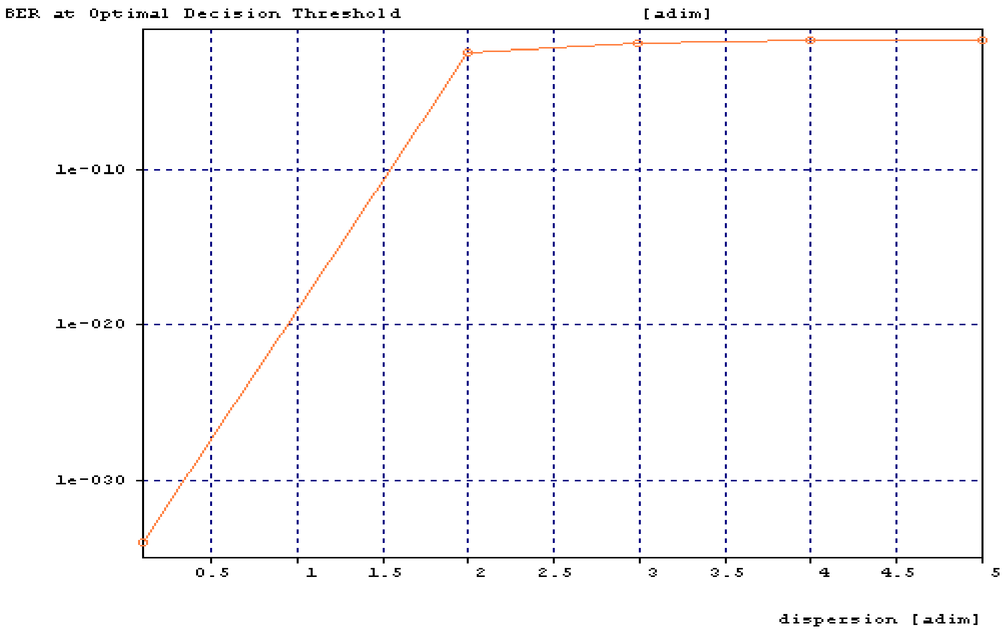

Figure 4.19 BER Vs dispersion plot

Figure 4.19 shows the plot of BER Vs dispersion. In this graph, as the dispersion values are increased for single mode fiber,the BER is also increasing with it. So it is observed that circuit involving optical cross connect and optical AWG demultiplexer works well i.e. at very low bit error rate. It is observed that that BER after the optical cross connect is 1 x10^{-40} and after the AWG demultiplexer if dispersion compensation is not employed the BER is quite high i.e. 1.269 x10^{-7}. So to improve this BER, the dispersion compensation is employed and the dispersion compensated fiber is used after the transmitter and before the single mode fiber, the BER rate is now investigated to be 2.388 x10^{-35} which is quite good.

4.5 CONCLUSION

In this chapter, we have demonstrated the feasibility and the performance of the network based on optical cross connects and AWG demultiplexer operating at 10 Gb/s with 0.1 nm channel spacing. Moreover, this network is also scalable and cost-effective. Hence, this network is a good choice for either upgrading or installing a new metropolitan area network. The results have been reported for NRZ Rectangular modulated data signal transmitted at 10 Gb/s. Jitter value remains low for this circuit for both with or without dispersion compensation. We have observed that the signal can be transmitted successfully to a distance of 40 km with a very low BER i.e. 2.388×10^{-35} with dispersion compensation. This distance can further be increased by increasing the number of optical amplifiers employed in the network and by increasing the length of the dispersion compensated fiber. Thus, the complete analysis of the network based on optical cross connects and AWG demultiplexers is done here, which proves to be beneficial for the deployment of optical cross connects and AWG demultiplexers as the main backbone in our present infrastructure.

CHAPTER 5
BROADBAND PASSIVE OPTICAL NETWORKS (BPON) BASED ON FTTH

In this chapter, we present a network architecture based on FTTH systems with broadband PON (passive optical networks) access. This architecture targets the delivery of very high speed, end to end optical communications between the edge nodes connecting the end users. Transmission allows the simultaneous delivery of real-time applications (Voice over IP, Video) and other data-oriented applications (Internet, peer-to-peer). To optimize the bandwidth in BPON the transmission through the optical fiber path employs the CWDM technique with data and voice component transmitted at wavelengths in the range of 1480-1500 nm, and video within the 1550-1560 nm range. Here the video signal is transmitted at 0.8 Gb/s and the high speed internet and the voice over IP is transmitted at 1.25 Gb/s. The comparative investigation and suitability of various data formats for internet and the voice over IP transmission and the three different modulations such as QAM, PSK and offset PSK for the video signal transmission is also demonstrated. It has been observed that the most suitable data format for data transmission is RZ Rectangular when QAM and PSK modulation is used for video signal modulation whereas for offset PSK modulated video signal most suitable data format is NRZ rectangular. It is also shown that the most suitable modulation technique is PSK modulation technique. Passive Optical Network (PON)-based Fiber-To-The-Home (FTTH) is a promising solution that can break through the economic barrier of traditional point-to-point solutions.

5.1 INTRODUCTION

Optical fiber access to the user, the so-called Fiber-to-the-Home (FTTH), is becoming a mature concept and a reality in many regions of the globe, with more than 8 million homes already connected, in an exponential growth. As it is widely accepted, FTTH is the only future-proof technology that will be able to support the upcoming interactive multimedia services, and nowadays operators are planning to substitute the existing telephone-line-based systems (Asymmetric Digital Subscriber Line ADSL, Plain Old Telephone Service POTS) or cable systems (Cable Television CATV) per optical fiber. First, point-to-point fiber links; recently, the more advanced point-to-multipoint Passive Optical Networks (PON) are being deployed to implement FTTH – currently in Asia and USA mainly [41]. Design and deployment activities for FTTH (fiber-to-the-home) and FTTP (fiber-to-the-premises) access networks are on the rise in order to support the increasing demands and delivery of new multimedia services to the customer premises such as interactive video, voice, and high-speed Internet. There are many types of FTTH technologies; the most popular one is based on the concept of using a passive fiber distribution network, known as a passive optical network (PON). FTTH employing PON access architecture is the accepted choice of delivery channel for triple-play services (voice, video and data) from service providers to the home and business users. Three major PON technologies are currently under consideration as the basis for FTTH deployments: Broadband PON (BPON), Gigabit PON (GPON), and Ethernet PON (EPON). Broadband PON is the most mature and widely used among them to the date. BPON is a set of standards that specify the service capabilities and network protocols for broadband services over fiber access. It is specified by the ITU-T, and published in the G.983.x series of ITU-T recommendations. In a PON, the active optoelectronics are situated on either ends of the passive network. Fiber-To-The-Home (FTTH) has been considered an ideal solution for access networks since the invention of optical fiber communications because of huge capacity, small size and lightness, and immunity to electromagnetic interference of optical fibers [42]. As more broadband applications appear, however, demands from end-users will soon outgrow the capacity of first generation access networks. Therefore, upgrading TDM-based optical access networks will be a major challenge. WDM has been considered an ideal solution to extend the capacity of optical networks without drastically changing the currently deployed fiber infrastructure. WDM can provide a virtual point-to-point link to each end-user over a PON without complicated MAC protocols, which simplifies tasks of network management, protection, and security to the level of traditional point-to-point networks [10]. WDM-PON, being based on the same PON architecture, shares many benefits of TDM-PON. In addition, WDM efficiently exploits the large capacity of optical fiber without much change in infrastructure and can provide a virtual point to- point connection to each end-user, which is totally independent of line rate and frame format. So once WDM devices have been installed, future upgrade would be as easy as in point-to-point networks. Thanks to the recent progress in the design of optical components, such as a thermal arrayed waveguide grating (AWG) routers and micro-electromechanical system (MEMS) switches, the signal paths can be either completely passive or at least consume power only during switching [43].

5.1.1 DRIVERS FOR BROADBAND PON BASED FTTH OPTICAL NETWORKS

Here we briefly review a few important applications that will be enabled by high speed BPON based FTTH optical networks [16].

Internet and Web browsing

Bandwidth requirements for each user of the Web have grown by a factor of eight annually at the same time; large numbers of new users are flocking to the Web. Also due to a huge increase in the file sizes downloaded from any server bandwidth requirements are increased. [44]

Graphics and visualization

The class of graphics and visualization applications is both data and compute intensive. In order to extend the capabilities of these applications to a distributed mode (for example, 3D terrain visualization using distributed databases, simultaneous viewing of experimental conditions by scientists in multiple locations), both small latency and gigabit rates will be required [45].

Medical image access and distribution

The distribution of the images (X-rays, MRIs, etc.) for medical consultation to multiple locations, either within a local region or to geographically dispersed locations, will require high-speed networks. This capability is critical in order to realize full telemedicine support, especially to remote rural sites where specialists may not be otherwise available.

Multimedia conferencing

The rapid introduction of video conferencing has reduced business costs and travel time by bringing parties together over audio/video channels [46]. Video typically requires high bandwidth (20–40Mbps for HDTV quality, or 2–6Mbps with MPEG compression), low latency and reasonable loss rates.

Broadband services to the home

Telephone companies and cable TV operators are attempting to offer innovative new services to their residential and small business customers. Thus telcos are going after video and Internet services while cable operators are providing data services over cable modems and are also exploring voice connections [47]. The near future promises to deliver exciting applications such as video-on-demand, interactive TV, distance learning, and electronic commerce. To provide such future services, both types of operators are currently upgrading their access infrastructure, often referred to as the “last mile.” Hybrid fiber-coax (HFC), fiber-to-the-curb (FTTC) and fiber-to-the-home (FTTH) are some of the planned access types. Optical networking has been identified as the key technology to bring such broadband services to the home.

Kyeong Soo Kim et al. [42] compared the current PON-based FTTH solutions, ATM-PON (APON), Ethernet PON (EPON) and provided a possible evolution scenario to future WDM PON. Once fibers are deployed with PON-based FTTH solutions, it becomes critical migrating to Wavelength Division Multiplexing (WDM)-PON from Time Division Multiplexing (TDM) used in current PON solutions.

Fu-Tai An et al. [10] investigated the key issues and reviewed enabling technologies for upgrading current-generation optical access networks with WDM techniques. It is studied that upgrading current-generation time division multiplexing (TDM)-based optical access networks will be a challenge in the future when end-user demand outgrows current network capacity.

Samir Chatterjee et al. [16] studied global infrastructures that are beginning to emerge and a host of broadband services appear and deliver economical service to users at offices and homes; optical networking will become a serious candidate for widespread implementation.

Up till now no work has been done on broadband passive optical networks (BPON) based on FTTH with CWDM technique for the simultaneous delivery of real-time applications (Voice over IP, Video) and other data-oriented applications (Internet, peer-to-peer). Moreover no work over the comparative analysis to find the suitable data format and to find the suitable modulation technique for video transmission has been done.

In this chapter, we have analyzed the performance of Broadband PON based FTTH network with CWDM technique, data signal is transmitted at 1.25 Gb/s and the video signal is transmitted at 0.8 Gb/s. This chapter also presents the comparative investigation and suitability of various data formats for internet and the voice over IP transmission and the three different modulation techniques such as QAM, PSK and offset PSK for the video signal transmission are discussed. The Broadband PON based FTTH network can be used to provide a cost effective solution for the service providers to offer broadband services to residential users at home with cost effectiveness.

The chapter is organized into four sections. Section 5.1 presents the introduction. Section 5.2 presents the simulation set up of the network and the description of its components. Section 5.3 includes the discussion of the results for the Broadband PON based FTTH network. Section 5.4 presents the conclusion about the feasibility of the network.

5.2 SIMULATION SET UP

Figure 5.1 depicts the simulation set up. An optical line termination (OLT) device is installed in the central office (CO), and an optical network termination (ONT) device is installed on the other end, in or near each home or business site as shown in Figure 5.1. Fiber distribution is done using a tree-and-branch architecture. A single fiber connected to the OLT can be split up to 32 times and connected to multiple ONTs. Current simulation models a typical BPON FTTH design with 10 subscribers and 20-km distance. Figure 5.1 depicts the simulation set up. The Central Office is connected through a 15-km standard single mode fiber to the first Remote Node with a 1:2 splitter. Each of the two outputs goes through another 4.5-km fiber and then enters the Remote Node with a 1:5 splitter. Outputs from the 1:5 splitters are connected to five end-users at the ONT though drop-off cables of 0.5 km. The triple-play service is realized as a combination of data, voice, and video signals. To optimize the bandwidth in BPON the transmission through the optical fiber path employs the CWDM technique with data and voice component transmitted at wavelengths in the range of 1480-1500 nm, and video within the 1550-1560 nm range. The high-speed internet component is represented by a data link with 1.25 Gb/s downstream bandwidth. The voice component can be represented as VOIP service (voice over IP, packet-switched protocol), which is gaining popularity as an alternative to traditional PSTN (public switched telephone network) with POTS (plain old telephone service) at the customer end. The video component is represented as a QAM, PSK and offset PSK subcarrier multiplexed (SCM) system.

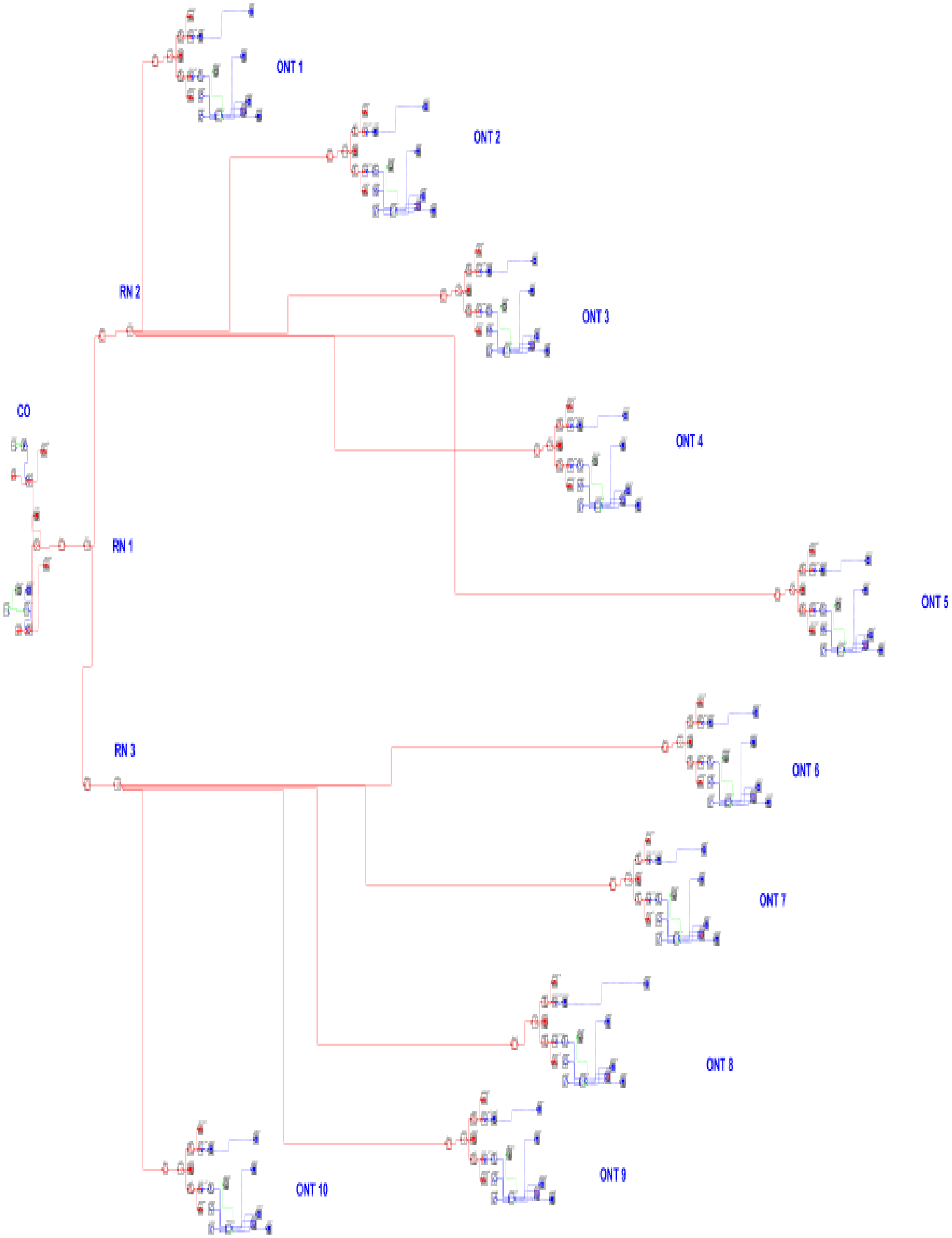

Figure 5.1 Simulation Set Up

5.3 RESULTS AND DISCUSSIONS

Using the simulation setup, the values of input signals, wavelength spectrum, eye diagrams, scattering diagrams and received signal are measured. From the eye diagram the values of Q factor, jitter and eye opening are determined. Figures (5.2-5.17) show the results obtained in the form of eye diagrams, scattering diagrams and plots. Table (5.1-5.6) presents the summary of comparative investigation on the performance metric indices viz. Q (dB); eye opening; BER and jitter (ns) for BPON based FTTH network on the basis of received data signal and video signal eye diagram.

Table 5.1 The summary of comparative investigations of the performance metric indices for the received eye diagram of data signal when the video signal is modulated with QAM

Parameter	QAM NRZ Rectangular	NRZ Raised Cosine	RZ Raised Cosine	RZ Rectangular	RZ Super Gaussian
Q(dB)	36.480430	30.733121	35.429517	36.559707	20.6960
BER	1e-40	1e-40	1e-40	1e-40	3.98939 e-027
Eye opening	4.72228e-006	5.10267e-006	4.08178e -006	5.33642 e-006	7.48173e-007
Closure (dB)	0.153057	0.242434	0.218504	0.151844	0.293415
Jitter (ns)	0.147072	0.1511	0.156906	0.155768	0.166077

Table 5.2 The summary of comparative investigations of the performance metric indices for the received eye diagram of QAM modulated video signal

Parameter	QAM NRZ Rectangular	NRZ Raised Cosine	RZ Raised Cosine	RZ Rectangular	RZ Super Gaussian
Q(dB)	6.020600	6.020600	6.020600	6.105756	6.020600
BER	0.0227501	0.0227501	0.0227501	0.0218135	0.0221636
Eye opening	5.49277e-008	5.75058e-008	5.47514e-008	2.89415e-007	2.85546e-007
Closure (dB)	14.116885	13.902785	0.218504	9.022166	9.162394
Jitter (ns)	1.10472	1.22237	0.156906	0.910673	0.972485

Table 5.3 The summary of comparative investigations of the performance metric indices for the received eye diagram of data signal when the video signal is modulated with PSK

Parameter	PSK NRZ Rectangular	NRZ Raised Cosine	RZ Raised Cosine	RZ Rectangular	RZ Super Gaussian
Q(dB)	36.199243	30.733615	35.434006	36.468397	20.511159
BER	1 e -40	1 e -40	1 e -40	1 e -40	1.38918 e -26
Eye opening	5.3689e -006	5.10271e -006	4.08184e -006	4.72129e -006	7.08083e -007
Closure (dB)	0.123753	0.242428	0.218455	0.200673	1.496020
Jitter (ns)	0.113554	0.151092	0.156906	0.162196	0.165115

Table 5.4 The summary of comparative investigations of the performance metric indices for the received eye diagram of PSK modulated video signal

Parameter	PSK NRZ Rectangular	NRZ Raised Cosine	RZ Raised Cosine	RZ Rectangular	RZ Super Gaussian
Q(dB)	6.020600	6.020600	6.020600	6.020600	6.020600
BER	0.0227501	0.0227501	0.0227501	0.0227501	0.0227501
Eye opening	4.25771e-008	4.25771e-008	4.25771e-008	4.25771e-008	4.25771e-008
Closure (dB)	12.982511	12.982511	12.982511	12.982511	12.982511
Jitter (ns)	0.113554	0.113554	0.113554	0.113554	0.113554

Table 5.5 The summary of comparative investigations of the performance metric indices for the received eye diagram of data signal when the video signal is modulated with offset PSK.

Parameter	Offset PSK NRZ Rectangular	NRZ Raised Cosine	RZ Raised Cosine	RZ Rectangular	RZ Super Gaussian
Q(dB)	36.555795	30.736282	35.428398	36.477926	20.512422
BER	1e-40	1e-40	1e-40	1e-40	1.37285e-026
Eye opening	5.33654e-006	5.10234e-006	4.08192e-006	4.7228e-006	7.07185e-007
Closure (dB)	0.152959	0.242742	0.218365	0.199275	1.501519
Jitter (ns)	0.145917	0.149801	0.156906	0.162196	0.164304

Table 5.6 The summary of comparative investigations of the performance metric indices for the received eye diagram of offset PSK modulated video signal

Parameter	Offset PSK NRZ Rectangular	NRZ Raised Cosine	RZ Raised Cosine	RZ Rectangular	RZ Super Gaussian
Q(dB)	6.020600	6.020600	6.020600	6.020600	6.020600
BER	0.0227501	0.0227501	0.0227501	0.0227501	0.0227501
Eye opening	5.33654e-006	5.10234e-006	4.08192e-006	4.7228e-006	7.07185e-007
Closure (dB)	0.152959	0.242742	0.218365	0.199275	1.501519
Jitter (ns)	0.105178	0.129814	0.135062	0.135059	0.132514

Figures (5.2-5.6) indicate the data eye diagrams for data formats viz. NRZ Rectangular, NRZ Raised cosine, RZ Rectangular and RZ super Gaussian.

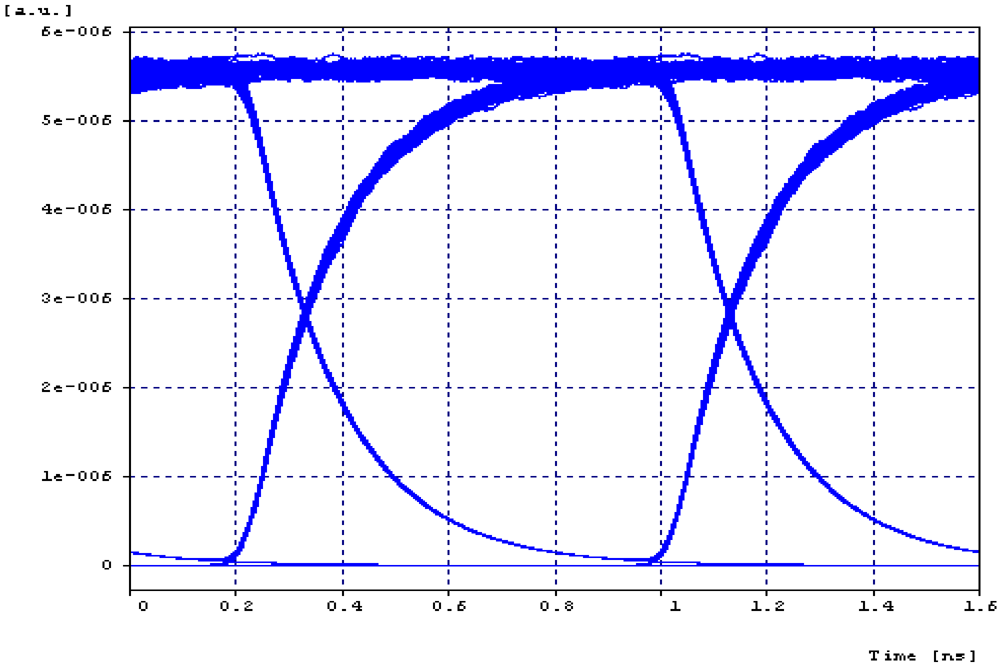

Figure 5.2 NRZ Rectangular eye diagram

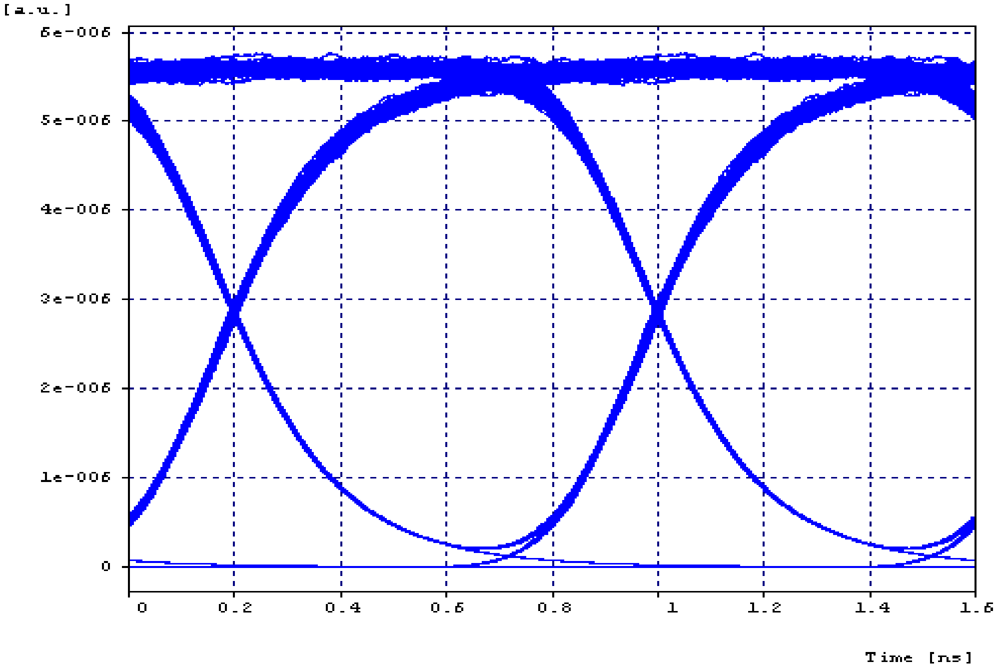

Figure 5.3 NRZ Raised Cosine eye diagram

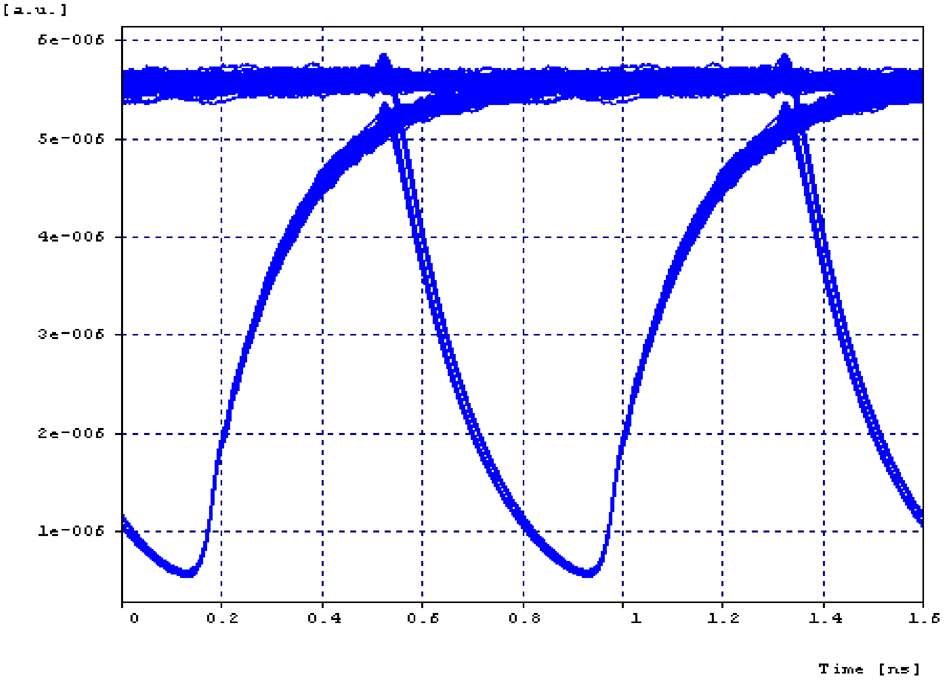

Figure 5.4 RZ Rectangular eye diagram

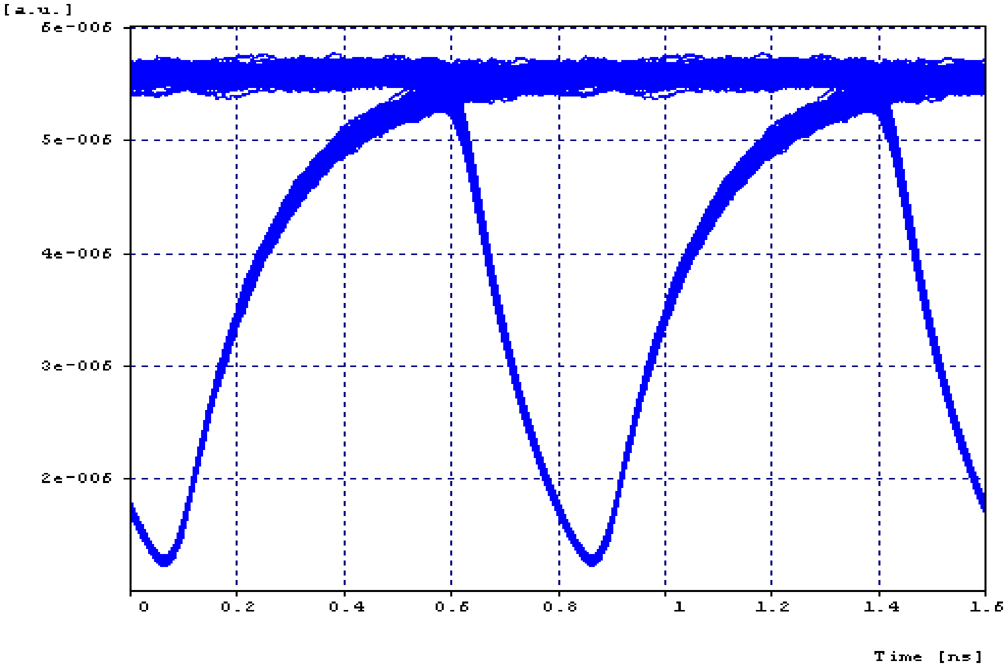

Figure 5.5 RZ Raised Cosine eye diagram

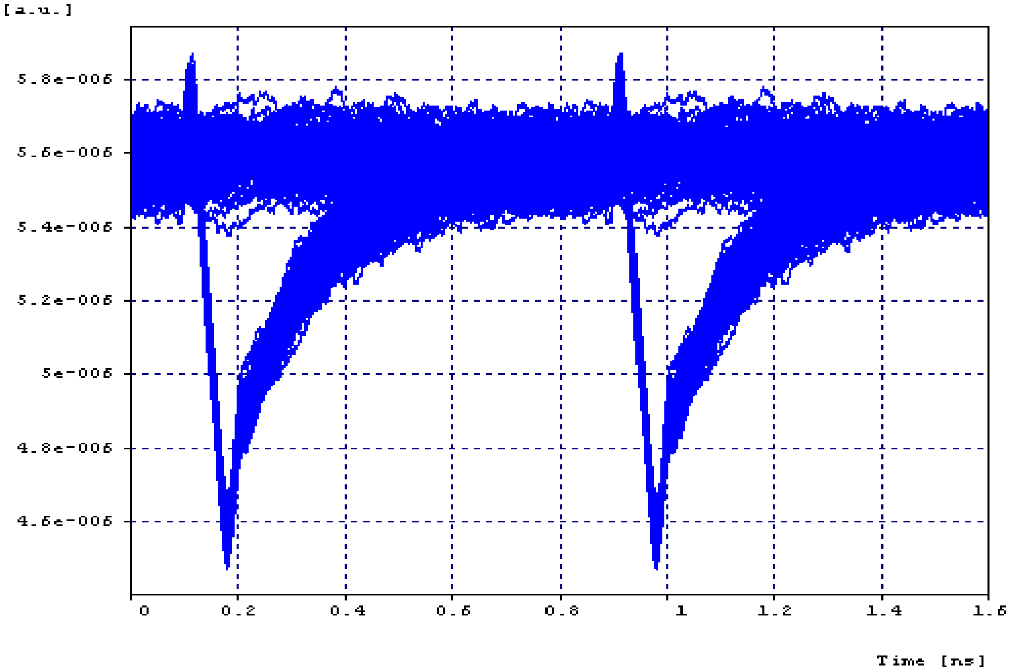

Figure 5.6 RZ super Gaussian eye diagram

Figures (5.7-5.12) indicate the scattering diagrams. Figure 5.7 shows the input scattering diagram where the data format used for data signal is NRZ Rectangular and modulation technique for video signal is PSK. Figure 5.8 shows the output scattering diagram for the same.

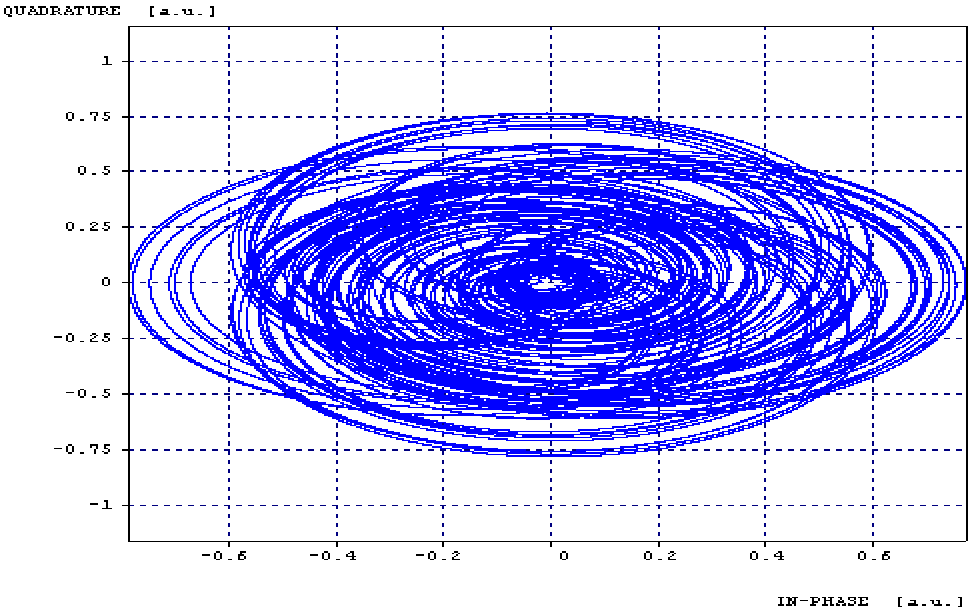

Figure 5.7 Input Scattering Diagram of PSK modulated video signal

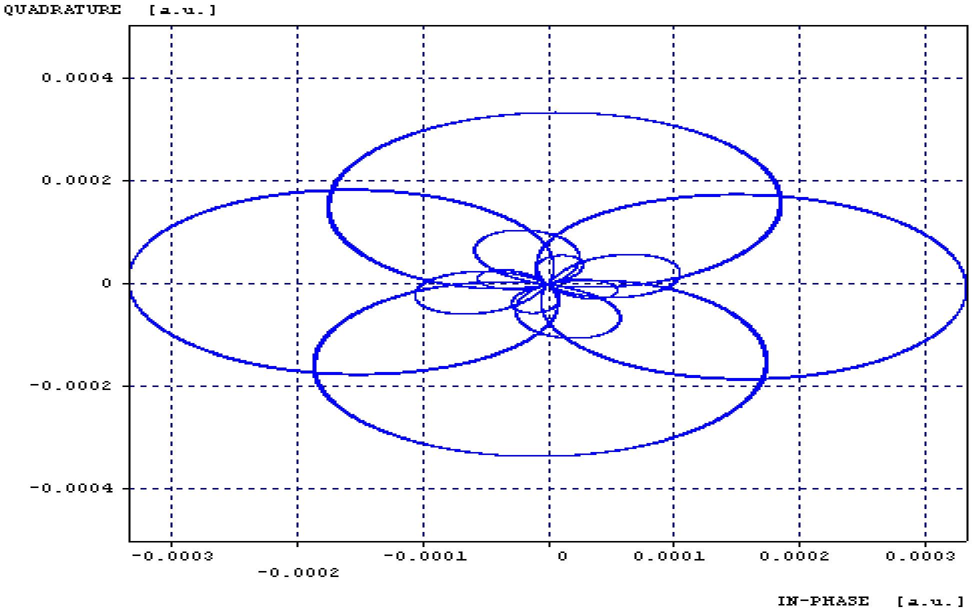

Figure 5.8 Output Scattering Diagram of PSK modulated video signal

Figure 5.9 shows the input scattering diagram where the data format used for data signal is NRZ Rectangular and modulation technique for video signal is offset PSK. Figure 5.10 shows the output scattering diagram for the same.

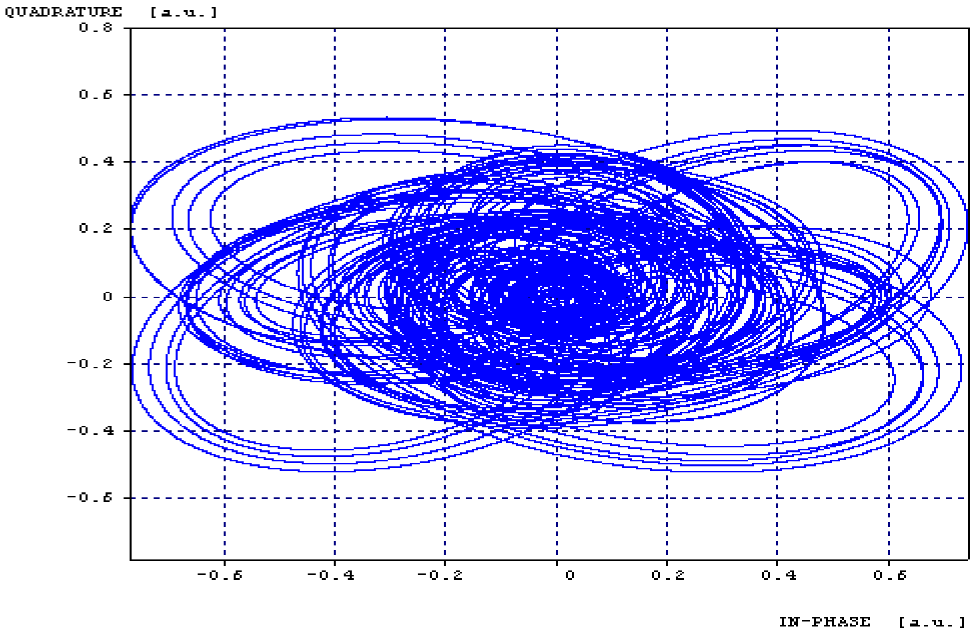

Figure 5.9 Input Scattering Diagram of offset PSK modulated video signal

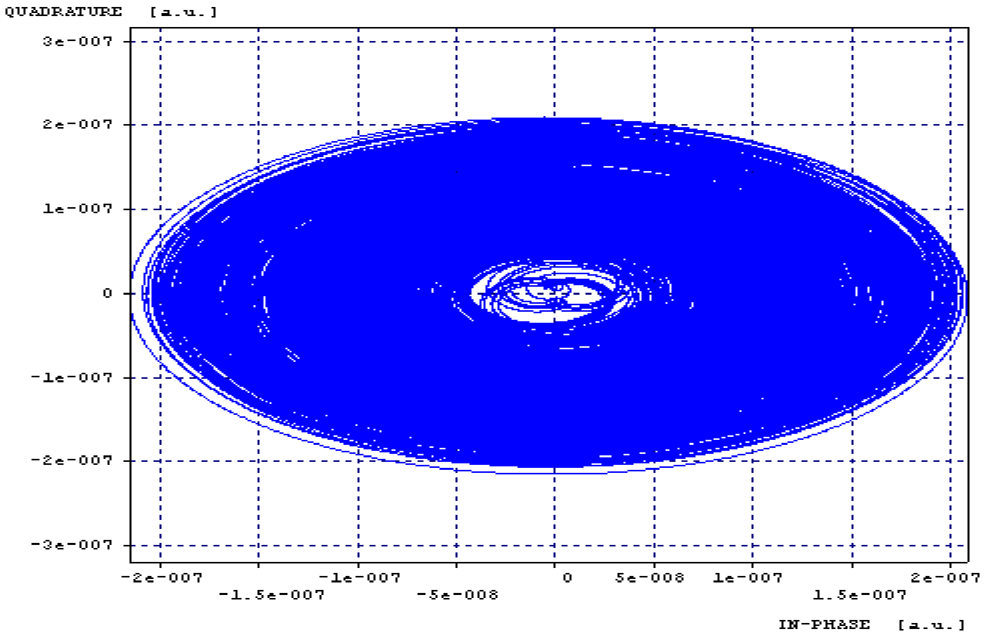

Figure 5.10 Output Scattering Diagram of Offset PSK modulated video signal

Figure 5.11 shows the input scattering diagram where the data format used for data signal is NRZ Rectangular and modulation technique for video signal is QAM. Figure 5.12 shows the output scattering diagram for the same.

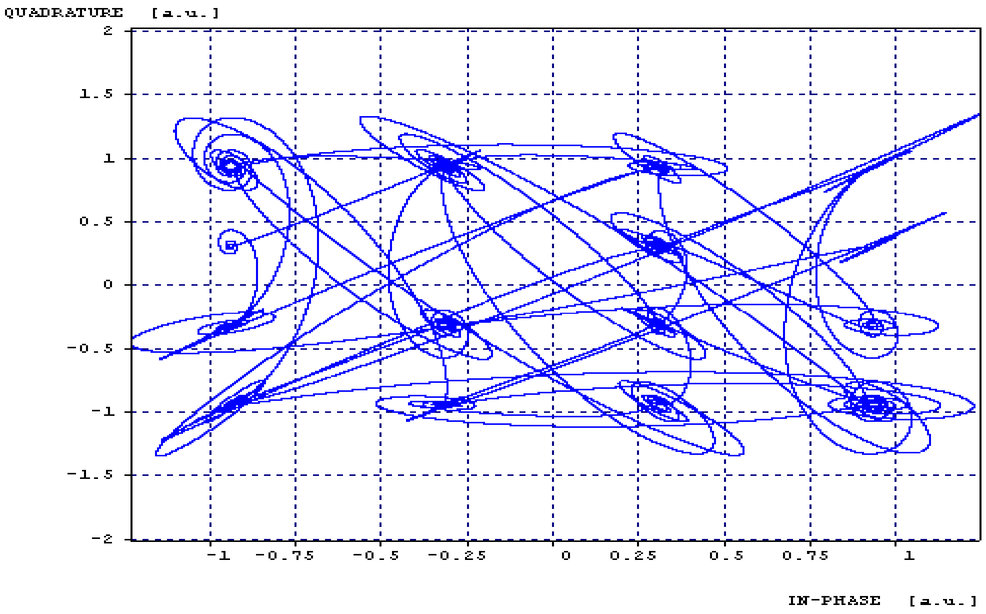

Figure 5.11 Input Scattering Diagram of QAM modulated video signal

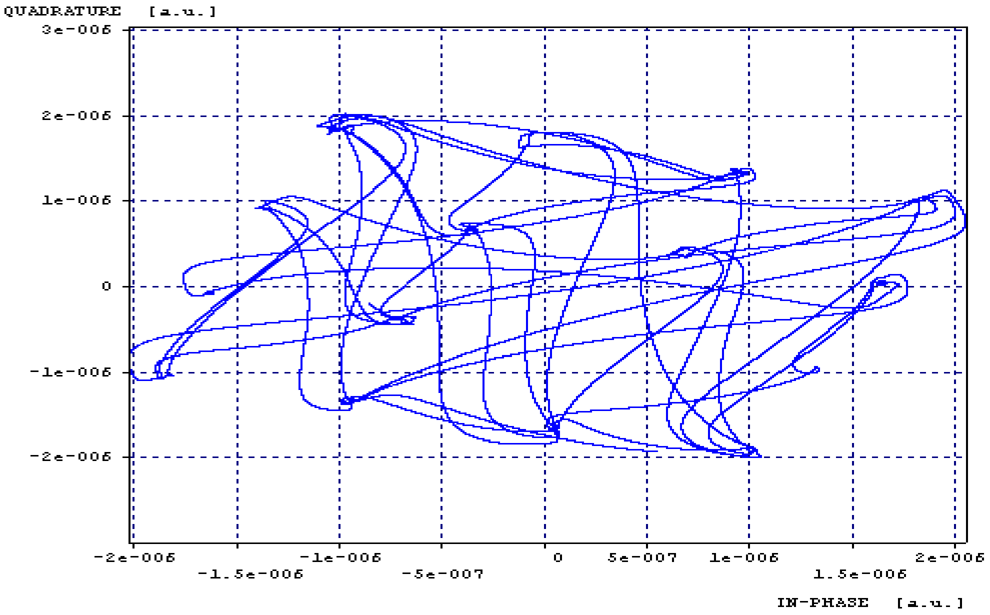

Figure 5.12 Output Scattering Diagram of QAM modulated video signal

Figure 5.13 shows power Vs length plot. It is observed that as the length is increased, the power decreases. Here the length is varied from 15 to 50 km. Figure5.14 shows power Vs bitrate plot for video signal. Here the bitrate is varied from 0.8 to 0.98 Gb/s. Figure 5.15 shows power Vs bitrate plot for data signal. Here the bitrate is varied from 1.25 to 1.65 Gb/s.

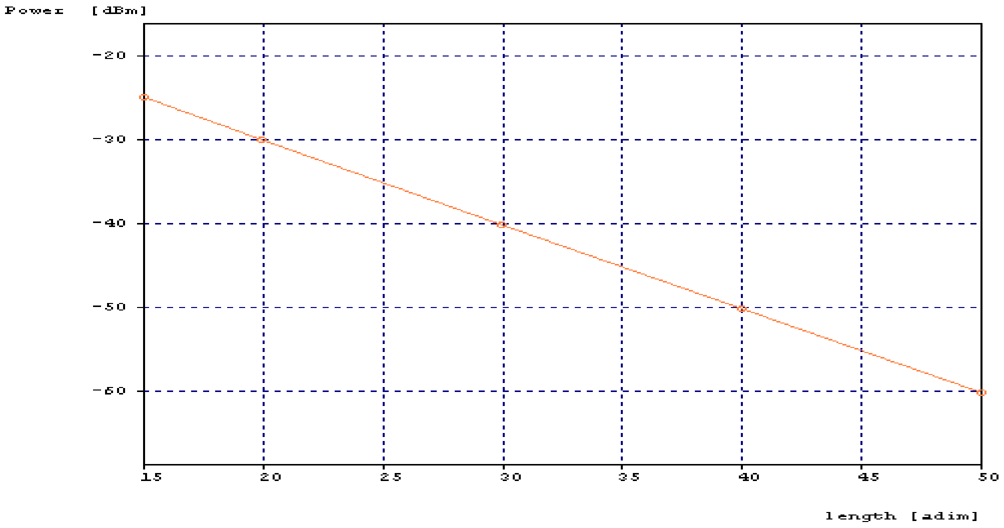

Figure 5.13 Power Vs Length plot

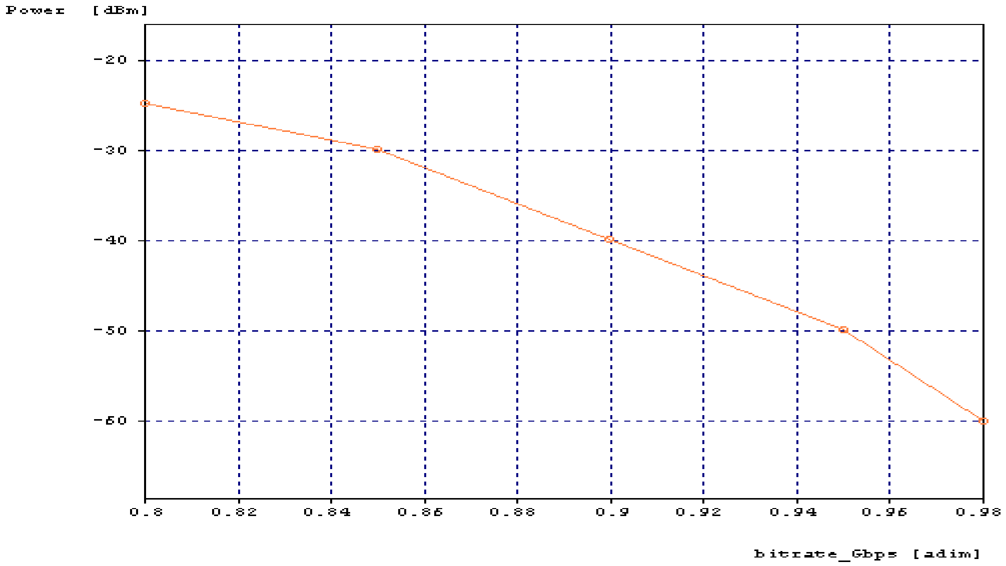

Figure 5.14 Power Vs bitrate plot for video signal

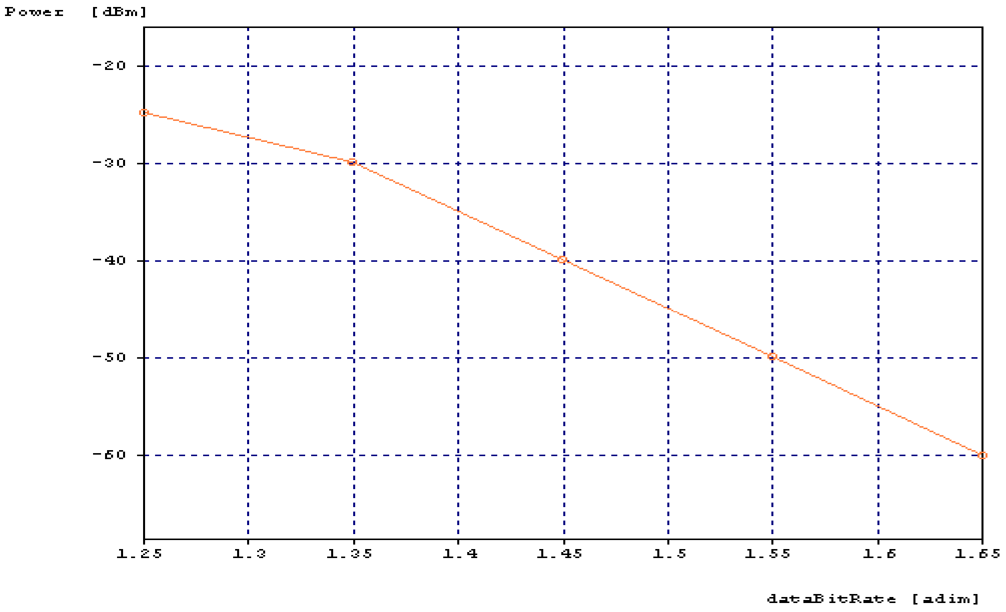

Figure 5.15 Power Vs bitrate plot for data signal

Figure 5.16 shows the optical spectrum of input signal. Here it is observed that the data/voice signal is transmitted at 1500 nm and the video signal is transmitted at 1550 nm. Figure 5.17 shows the optical spectrum of output signal.

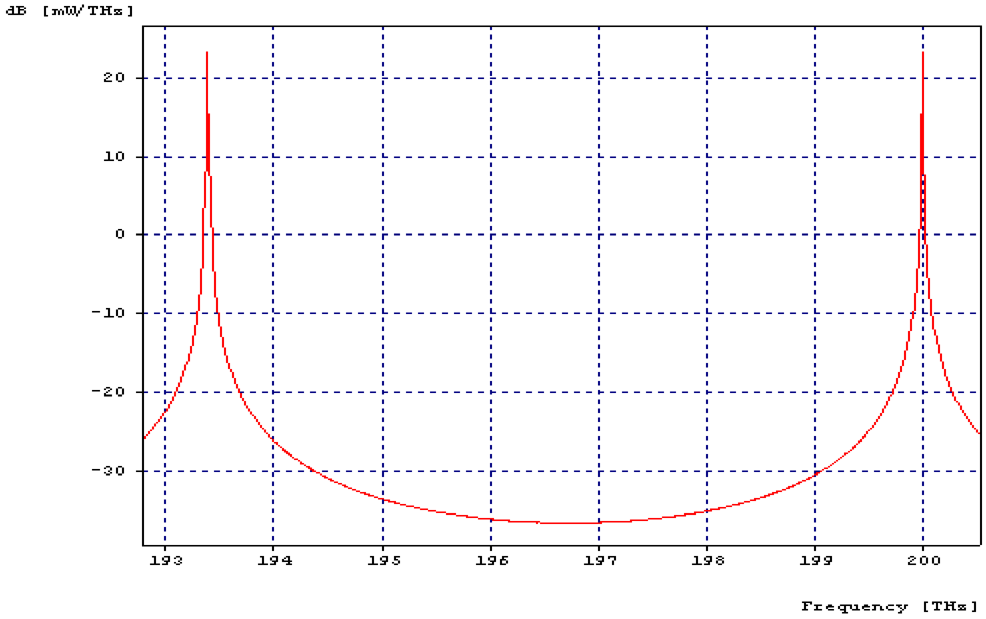

Figure 5.16 Input optical Spectrum

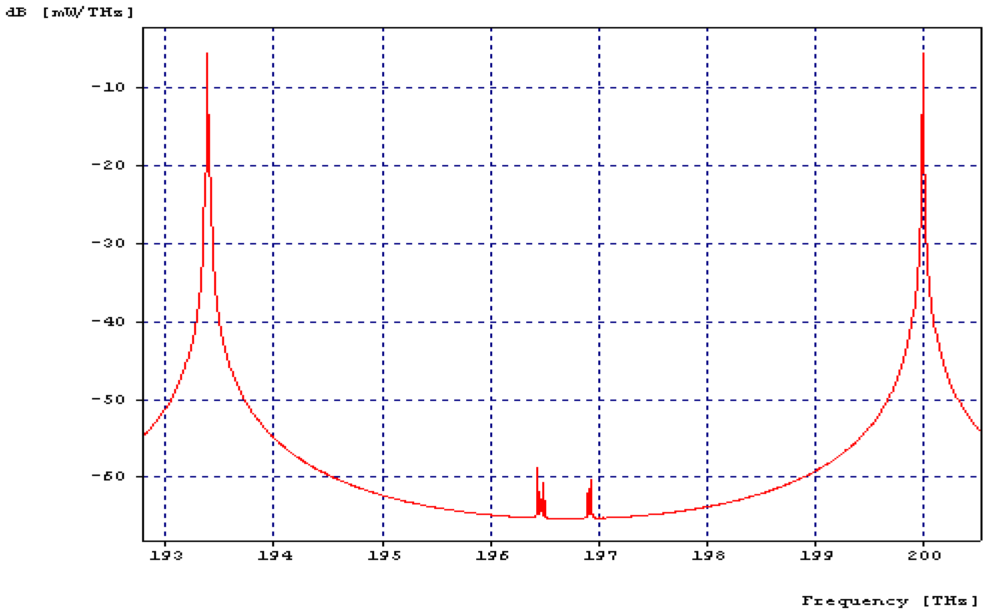

Figure 5.17 Output optical spectrum

5.4 CONCLUSIONS

In this chapter, we have described a broadband PON (Passive optical network) based FTTH (Fiber to the home network) for ten end users. To optimize the bandwidth in BPON the transmission through the optical fiber path employs the CWDM (Coarse Wavelength division multiplexing) technique with data and voice component transmitted at wavelengths in the range of 1480-1500 nm, and video within the 1550-1560 nm range. Here the video signal is transmitted at 0.8 Gb/s and the high speed internet and the voice over IP is transmitted at 1.25 Gb/s. We have also done the comparative investigation and suitability of various data formats for internet and the voice over IP transmission and the three different modulations such as QAM, PSK and offset PSK for the video signal transmission are studied. It has been observed that the most suitable data format for data transmission is RZ Rectangular when QAM and PSK modulation is used for video signal modulation whereas for Offset PSK modulated video signal most suitable data format is NRZ rectangular. It is demonstrated that out of these three modulation techniques, the most suitable modulation technique for video signal is PSK modulation technique. Here, the network is investigated for triple play services (voice, video and data) from service providers to the home and business users. Finally, the broadband PON based FTTH networks will play a critical role in the home networks, not only because they present an emerging market potential, but mainly because they introduce great opportunities for the operators and service providers to offer broadband services to residential users at home with cost effectiveness.

CHAPTER 6

CONCLUSIONS AND FUTURE PROSPECT

6.1 CONCLUSIONS

This chapter provides the summary of the research work done in this thesis. First the conclusions have been made from this study and then the suggestions for the future research are discussed. The major results obtained in this thesis are summarized as follows

1. We have demonstrated the feasibility and the performance of the AWG multiplexer and AWG demultiplexer based 10 Gb/s network. Moreover, this network is scalable and cost-effective. It is observed that Arrayed Waveguide Gratings multiplexers and demultiplexers for WDM applications have proven to be capable of precise multiplexing and demultiplexing of a large number of channels with relative low losses and with a very low BER of 1 $x10^{-40}$ for a transmission distance of 50 km. This distance can be further increased by using optical amplifiers in the network. Hence, this network is a good choice for either upgrading or installing a new metropolitan area network and we also have carried out the comparative performance evaluation of various data formats in same optical transmission link. The results have been reported for different data formats, viz. NRZ Rectangular, NRZ Raised cosine, RZ Rectangular, RZ raised cosine and RZ super Gaussian. In the case of RZ raised cosine its highest value of Q (26.33dB), good eye opening, lowest BER and its non-susceptibility at different chirps makes it the best choice among the data formats mentioned. Jitter value remains low for all the data formats in general and also no considerable impact of chirp on jitter has been recorded. In a comparative study, power level in case of RZ Rectangular has been reported to be the best ; however ,it is also reasonably good (second best) for RZ raised cosine.

2. We have demonstrated the feasibility and the performance of the network based on optical cross connects and AWG demultiplexer operating at 10 Gb/s with 0.1 nm channel spacing. Moreover, this network is also scalable and cost-effective. Hence, this network is a good choice for either upgrading or installing a new metropolitan area network. The results have been reported for NRZ Rectangular modulated data signal transmitted at 10 Gb/s. Jitter value remains low for this circuit for both with or without dispersion compensation. We have observed that the signal can be transmitted successfully to a distance of 40 km with a very low BER i.e. 2.388×10^{-35} with dispersion compensation. This distance can further be increased by increasing the number of optical amplifiers employed in the network and by increasing the length of the dispersion compensated fiber. Thus, the complete analysis of the network based on optical cross connects and AWG demultiplexers is done, which proves to be beneficial for the deployment of optical cross connects and AWG demultiplexers as the main backbone in our present infrastructure.

3. We have described a broadband PON (Passive optical network) based FTTH (Fiber to the home network) for ten end users. To optimize the bandwidth in BPON the transmission through the optical fiber path employs the CWDM (Coarse Wavelength division multiplexing) technique with data and voice component transmitted at wavelengths in the range of 1480-1500 nm, and video within the 1550-1560 nm range. The video signal is transmitted at 0.8 Gb/s and the high speed internet and the voice over IP is transmitted at 1.25 Gb/s. We have also done the comparative investigation and suitability of various data formats for internet and the voice over IP transmission and the three different modulations such as QAM, PSK and offset PSK for the video signal transmission are studied. It has been observed that the most suitable data format for data transmission is RZ Rectangular when QAM and PSK modulation is used for video signal modulation whereas for Offset PSK modulated video signal most suitable data format is NRZ rectangular. It is demonstrated that out of these three modulation techniques, the most suitable modulation technique for video signal is PSK modulation technique. Here, the network is investigated for triple play services (voice, video and data) from service providers to the home and business users. Finally, the broadband PON based FTTH networks will play a critical role in the home networks, not only because they present an emerging market potential, but mainly because they introduce great opportunities for the operators and service providers to offer broadband services to residential users at home with cost effectiveness.

6.2 FUTURE PROSPECTS

During the course of this thesis, several avenues for the continuation of this study became evident. The topics that were considered worthwhile are summarized as under:

We have neglected the all other fiber nonlinearities Cross Phase Modulation, Four Wave Mixing, Stimulated Raman Scattering and Stimulated Brillouin Scattering. All these nonlinearities can be simulated for different aspects. Therefore, in the presence of the fiber nonlinearities, it is of interest to see how these results change.

In this thesis, the polarization effects have been ignored. These effects along with dispersion and the fiber nonlinearities may be treated in simulation studies and results can be compared with present analytical methods.

Although it is conceptually simple, the use of AWG multiplexers and demultiplexers has many problems of its own. For example, since AWGs are very sensitive to temperature changes, this puts severe constraints on channel spacing. Otherwise it would be necessary to monitor the passband wavelengths of the AWG and to tune the DWDM sources. So the research study needs to be done over this area.

Although in this thesis, our focus is on optical access solutions, the real-world implementation of access networks will be a hybrid of optical fiber links, existing twisted-pair copper lines, wireless LAN, and even free-space optics. The interfaces between the different technologies and media in hybrid access create interesting research areas with challenges in size and power minimization.

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