Reach Extension in WDM-PON Using Raman Pump With Modulated Digital Signal

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Certificate

This is to certify that the dissertation title **"Reach Extension in WDM-PON using Raman Pump with modulated Digital Signal"** is the authentic work of **Mr. Mukesh Kr. Gupta** under my guidance and supervision in the partial fulfillment of requirement towards the degree of Master of Technology in **Microwave and Optical Communication Engineering**, jointly under the Dept .of Electronics and Communication Engineering and Dept. of Applied Physics in **Delhi Technological University (Formerly Delhi College Of Engineering).** The contents of this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

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Abbreviations

ASE	Amplified Spontaneous Emission
BER	Bit Error rate
BPSK	Binary Phase shift Key
CO	Central Office
CATV	Cable TV
CSO	Composite Second Order
CTB	Composite Triple Beat
CNR	Carrier to Noise Ratio
CW	Continuous Wave
CPE	Customer Premise Equipment
CAD	Computer Aided Design
CWDM	Coarse Wavelength Division Multiplexing
DWDM	Dense Wavelength Division Multiplexing
DOP	Degree of Polarization
EOM	Electro-Optic Modulator
FTTC	Fiber to the Curb
FTTB	Fiber to the Building
FTTH	Fiber to the Home
FEC	Forward Error Correction
FWM	Four Wave Mixing
GEPON	Gigabit Ethernet Passive Optical Network
IPTV	Internet Protocol Television
LASER	Light Amplification by Stimulated Emission of Radiation
LED	Light Emitting Diode

LAN	Local Area Network
ODN	Optical Distribution Network
OMI	Optical Modulation Index
OFDM	Orthogonal Frequency Division Multiplexing
OLT	Optical Line Terminal
ONU	Optical Network Units
PON	Passive Optical network
POP	Point of Presence
QAM	Quadrature Amplitude Modulation
RSOA	Reflective Semiconductor Optical Amplifier
SRS	Stimulated Raman Scattering
SBS	Stimulated Brillion Scattering
SMF	Single Mode Fiber
SPM	Self Phase Modulation
TDMA	Time Division Multiple Access
TDM	Time Division Multiplexing
WDMA	Wavelength division Multiple Access
XPM	Cross Phase Modulation

ABSTRACT

Optical fiber access technology is key to realize a broadband communication for everyone, and the passive optical network (PON) is enabling customer to enjoy high-speed internet access now. As the demand for the broadband access is still growing, a study to find out technologies to realize wide bandwidth for the access system is quit important. At this moment, wavelength division multiplexing (WDM) PON is the most promising technology for the future optical fiber access system.

Current PON system covers a reach of within 20km from a central office, because the market of the access system is focusing on well-populated area. It is required to extend the reach of the PON system to enhance the applicable area, because there is many region in the world where are not so highly populated. Therefore, this work is focusing on to it compensates for the attenuation of data signal due to SRS cross-talk as well as it helps extending the reach of WDM PON. In order to enhance the reach of the WDM-PON system even though, there are several effect that cause performance degradation of the system by introducing the Raman amplifier. It is important to clarify such effect and to provide solution.

Hence, using remote Raman amplification serves two purposes: it compensates for the attenuation of data signal due to SRS cross-talk as well as it helps extending the reach of PON.

CHAPTER 1

INTRODUCTION

The access network, also known as the “first-mile network,” connects the service provider central offices (COs) to businesses and residential subscribers. The bandwidth demand in the access network has been increasing rapidly over the past several years. Residential subscribers demand first-mile access solutions that have high bandwidth and offer media-rich services. Fibre to the home is solution of first-mile network in which all users connected to service provider by using optical fibre cable replacing copper wire.

1.1 Fibre to the Home (FTTH)

Fibre-to-the-home fibre reaches the boundary of the living space, such as a box on the outside wall of a homes, means there is no copper cable between carriers to user end. The flexibility and capacity of Fibre to the Home enables providers to "future proof” their infrastructure [1]. With technology moving so fast, the future demands on the network are uncertain. Yet Fibre to the Home networks can accommodate future applications and bandwidth demand more easily than other network architectures.
Three different architectures have been proposed that facilitate the roll out of Fibre-to-the-Home (FTTH) infrastructure.

- Ring architectures of Ethernet switches
- Star architectures of Ethernet switches
- Tree architectures using PON technologies

Ethernet is a popular standard for data communication over various networks, including optical networks. It was originally developed for LAN applications where several computers shared a common coax cable medium for communication.

Ring architectures of Ethernet switches provides excellent resilience against fiber cuts and can be built cost-effectively, but it has the disadvantage of sharing a bandwidth over each access ring (1 Gbps) that is comparatively small in relation to long-term requirements, thus providing a challenge for scalability of the architecture.

Star architectures provide dedicated fibers (typically single-mode, single-fiber with 100BX or 1000BX Ethernet transmission) from every endpoint to the point of presence (POP), where they are terminated on a switch.

Tree architecture using Passive optical networks are at the front line of advancement of fibre optics toward end users. In a typical PON, many users are passively connected to a central office [2]. This implies that the optical network devices (between the transmitter and receiver) are non-powered, i.e. no electrical devices are used. The central office is generically called optical line terminal (OLT) and the users are called optical network unit (ONU).

1.2 PONs with Wavelength Division Multiplexing Access (WDMA)

Wavelength Division Multiplexing Passive Optical Network (WDM PON) are the next generation in development of access networks [3]. Ultimately, they can offer the largest bandwidth at the lowest cost. In principle, the architecture of WDM PON is similar to the architecture of the PON. The main difference is that ONUs operates on different wavelengths and hence higher transmission rates can be achieved. The illustrative example of this architecture is shown in Figure 1.1

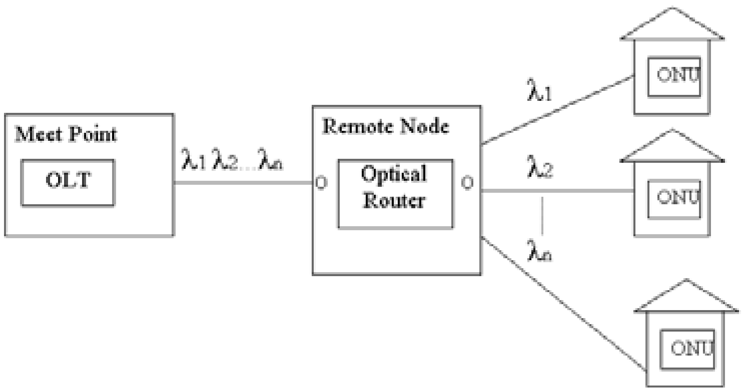


Figure 1.1 Configuration of WDM-PON FTTH Network[3].

The main problem with WDM PONs is that usually the wavelength is assigned to an ONU in a fixed manner. This makes upgrades in the network topology difficult as they require manual reconfiguration of the equipment in the customer's premises, which significantly increases the cost of maintenance. The solution to this is the development of so called “colourless” ONUs. In such a scheme the ONU detects what wavelength is used in the downstream direction and sends its data on this wavelength in the upstream direction. In the upstream direction, an ONU modulates the carrier wavelength provided by the OLT with its data. The advantage of such an approach is that ONUs do not have to be equipped with expensive light sources. This not only lowers the overall cost of the equipment but also makes ONUs transparent to the signal and different wavelengths can be used at any time.

The disadvantage of WDM PONs is the high cost of equipment. Much research was focused on enhancing WDM PONs ability to serve larger numbers of customers in attempt to increase revenue from invested resources and its cost efficiency. As a result, some hybrid structures have been proposed where both WDMA and TDMA models are used to increase the number of potential users.

1.3 Nonlinear effects in fibre

Nonlinearities refer to optical phenomena involving a nonlinear response to a driving light field. Lasers allow generating light with very high intensities. These can give rise to a number of nonlinear effects, the most important of which are:

- Parametric nonlinearities occur in certain crystal materials with $\chi^{(2)}$ nonlinearity, giving rise to effects like frequency doubling, sum and difference frequency generation, and parametric amplification (nonlinear frequency conversion).

- The Kerr effect raises the refractive index by an amount which is proportional to the intensity, leading to effects like self-focusing, self-phase modulation, and four-wave mixing.

- Spontaneous and stimulated Brillouin scattering is the interaction of light with "acoustical phonons" and typically involves counter propagating waves.

- Spontaneous and stimulated Raman scattering is the interaction of light with "optical phonons". Raman amplification is based on the Stimulated Raman scattering.

1.3.1 Raman Amplification

During Raman scattering, light incident on a medium is converted to a lower frequency [4]. This is shown schematically in Figure 1.2

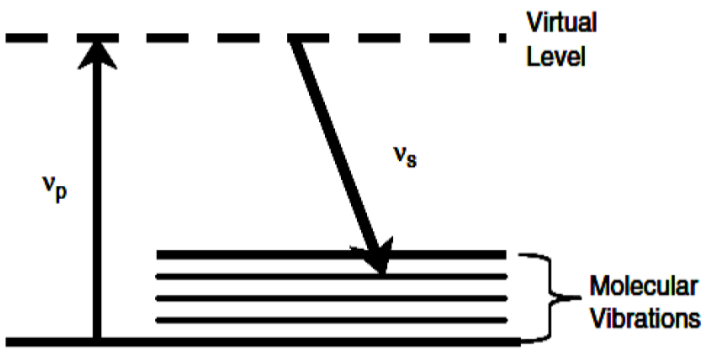


Figure 1.2 quantum mechanical process taking place during Raman scattering [4].

A pump photon, νp, excites a molecule up to a virtual level (non-resonant state). The molecule quickly decays to a lower energy level emitting a signal photon νs in the process. The difference in energy between the pump and signal photons is dissipated by the molecular vibrations of the host material. These vibration levels determine the frequency shift and shape of the Raman gain curve. Due to the amorphous nature of silica the Raman gain curve is fairly broad in optical fibres.

For high enough pump powers, the scattered light can grow rapidly with most of the pump energy converted into scattered light. This process is called SRS, and it is the gain mechanism in Raman amplification

1.4 Thesis Overview

In this thesis, we propose the amplification of the optical signal using remote Raman pump and crosstalk mitigation using modulated digital video signal. Proposed methods employed to overcome the cross-talk losses suffered by the low wavelength signal and to extend the reach of PON.

The thesis is organized into five chapters. Chapter 1 gives the over view of project background and Chapter 5 discusses conclusion and future work.

Chapter 2 shows the literature reviews in which we discuss the various methods which are used till now for mitigation of SRS and increase the reach of PON and proposed our used method in project. Chapter 3 gives the detail analysis of our method that used in our work. It also show the block model or simulated model of Raman amplified PON. Chapter 4 gives the performance of amplifier for different span of fibre and gives the practical results. This chapter also verify the reach extension for WDM PON .

CHAPTER 2

LITERATURE REVIEW

Nonlinear effects in fibre came in light at high optical power. Due to SRS, transfer of energy from low wavelength signal to high wavelength signal occurs. Stimulated Raman scattering (SRS) is one of the biggest obstacles in cable television (CATV) overlay passive optical networks (PONs), where a 1550-nm subcarrier-multiplexing CATV signal co-propagates with a downstream baseband signal carried at 1480~1500nm and signal get degraded.

2.1 Existing Methods

Murakami et al [5] has proposed a method for reducing the crosstalk by decreasing the wavelength spacing between the baseband and CATV signals. As in Raman cross talk low wave length signal suffer more loss compare to high wave length. If wavelength spacing between different wavelengths signal is less, signal will suffer minimum loss. In many PONs, however, the minimum wavelength spacing is specified by the standards and recommendations (e.g., baseband channel wavelength 1480–1500 nm, CATV channel wavelength 1550–1560 nm, in broadband-PON of ITU-T G983.3), and thus there is not much room for a system designer to change the wavelength spacing.

F. Coppinger and D. Piehler [6] have described that crosstalk depends on the square of the average optical power of interference signal (i.e., the baseband signal in our case), a 1-dB reduction in baseband optical power can lead to a 2-dB improvement in the composite second order (CSO) / composite triple beat (CTB) performance of CATV channels [4-5]. Crosstalk in a two-wavelength 1550-nm standard fibre system at subcarrier frequencies 50–800 MHz is investigated. The dependence of the crosstalk on subcarrier frequency, wavelength spacing, and optical power is measured and analyzed. The observed crosstalk is attributed to three primary mechanisms: stimulated Raman scattering, cross-phase modulation and the optical Kerr effect combined with polarization-dependent loss. At wavelength spacing greater than 9 nm, stimulated Raman scattering dominates. At wavelength spacing less than 5 nm, the primary contributor can be the optical Kerr effect with polarization dependent loss, except at higher modulation frequencies where cross-phase modulation also is significant. At even modest (by CATV standards) optical power, the crosstalk is as high as -40 to -45 dB. The biggest concern of this approach, however, is that it sacrifices the power budget of baseband signals, possibly resulting in the reduction of the transmission distance or splitting ratio.

A pre-emphasis technique was proposed by M. Aviles et al [7] for decreasing the cross talk in which a modest increase in the optical modulation index (OMI) is applied to low-number CATV channels, can also remedy to some extent the CSO/CTB degradation for those channels at the slight expense of a CSO/CTB increase in other CATV channels . This work studies the Raman coupling effect in ITU-T G.983.3-based PON systems carrying sub-carrier modulated analog video. They find the Raman Effect is present but is controllable to negligible levels, provided that system parameters are optimised. The CNR, CSO, and CTB were measured for a selection of channels over the hand. In all cases, the CSO and CTB were in the high 50's, so there was no issue with distortions. The first is the video operating without the data signal at all. In this case, all the channels are performing well. Note that the very highest channels drop below 48 dBc, but this was found to be due to excess RF loss in the output stage of the triplexer electronics, and not intrinsic to the optical signal.

Hoon Kin et al [8] has proposed the method for reduction in SRS cross talk. This techniques does not induce the performance degradation of baseband and CATV signals. In cable television (CATV) overlay passive optical networks (PONs), where a CATV signal co propagates with a downstream baseband signal, the crosstalk components mediated by stimulated Raman scattering (SRS) limit the performance of low-number CATV channels. In this letter, they propose and demonstrate a way of reducing the SRS-induced crosstalk in CATV overlay PONs. The proposed scheme utilizes a high-speed polarization scrambler in the transmitter to make the SRS-induced Crosstalk independent of polarization evolution along the fibre and a subtractor module to compensate for the crosstalk. Demonstration shows that crosstalk can be reduced by 9 dB. This employs a high-speed polarization scrambler at the CATV transmitter and an electrical subtractor module at the receiver. Since the SRS process is highly polarization-dependent, they first depolarize the CATV signal using the polarization scrambler and then compensate for the crosstalk with the subtractor module [7].They first measured the degree of polarization (DOP) of the CATV LD output as a function of the driving voltage of the polarization scrambler. The DOP decreases nearly linearly with increasing driving voltage. It is expected to be decreased until the driving voltage reaches V_{π} of the scrambler. The DOP is measured to be < 10% when the driving voltage is higher than $.9 \times V_{\pi}$. They measured the power fluctuation of the SRS crosstalk component located at 62.5 MHz while changing the polarization controller at the output of the polarization scrambler. In the absence of polarization scrambling, the power fluctuation was measured to be 9 dB due to the polarization dependence of the SRS process.

Kavan Acharya and M. Yasin Akhtar Raja [9] have proposed a method to reduced SRS cross talk in WDM-PON. All these above discussed methods have been successful in reducing the effect of SRS crosstalk by a few dBs. The effect of Stimulated Raman Scattering (SRS) crosstalk in Passive Optical Network (PON) has been reported in several papers. They present a possible solution of this problem in PON systems carrying sub-carrier multiplexed video signals. This is done by the use of Quadrature amplitude modulation (QAM) for modulating the video signals instead of implementing the widely used analog RF-overlay method [9]. The data signal was maintained at a constant 2dBm and the power of RF-video signal was varied from 10dBm to 20dBm. The increase in link-budget varied from 0.12 to 0.8 dB. A WDM-PON topology with 3 video channels and 2 data channels was simulated. It was observed that, instead of overlaying the analog RF channels, if QAM is used, the excess loss of the data signal resulting from SRS crosstalk is less than 1dB. This further supports the implementation of IPTV as a preferred method of transmitting video signals. By this method they minimized only cross talk but reach is not extended.

B. Colella et al [10] present a new solution to the Raman coupling problem in PON systems carrying sub-carrier modulated analog video. This is done by shaping the spectrum of the digital signals while maintaining the line signal format. More recent analyses have demonstrated the presence of the Raman effect in PON systems, and characterized this phenomenon as an appreciable impairment to transmission. A key finding of this work is that the crosstalk ratio has a low-pass characteristic, making its impact on the lower video channels more severe than the higher channels. However, all of these works consider the digital signal to be an immutable factor dictated by the particular line protocol used. In many respects this is true, as the protocols have already been standardized and implemented. Yet, there is a possibility of controlling the digital signal if we consider the higher layer meaning of the signalling on the link. In this method they minimized cross talk 13 dBm but reach is not extended.

Daisuke Umeda et al [11] developed a method to increase the reach of the system. a bidirectional 3R repeater for GE-PON systems and confirmed the excellent repeating performance without degradation in the optical characteristics. It is able to increase the system budget between an OLT and ONUs by 33dB. It's also suitable for multiple repeating connected in series, and we succeeded in 50km CWDM transmission of GE-PON signals between two repeaters. Limitation of this method is that using 3R repeater system change into active. For the demand of future bandwidth and data speed it is necessary that system should be in passive.

K. Y. Cho et al [12] proposed a simple self-polarization-stabilization technique for the wavelength-division-multiplexed passive optical network implemented with reflective semiconductor optical amplifiers (RSOAs) and self-homodyne coherent receivers. By placing a 45^{o} Faraday rotator in front of the RSOA in the optical network unit, the state-of-polarization of the upstream signal becomes orthogonal to that of the linearly polarized seed light at the input of the coherent receiver regardless of the birefringence in the transmission link. Thus, they achieve the polarization stability of the upstream signal at the input of the coherent receiver. They first implement a self-homodyne receiver by using the proposed self-polarization-stabilization technique and measure its sensitivity by using 2.5-Gb/s binary phase-shift keying signals in the laboratory. The result shows an excellent receiver sensitivity of -46.4 dBm. They also confirm the efficacy of the proposed technique in the transmission experiment over 68-km long link partially composed of installed (buried and aerial) fibres. No significant degradation in the receiver sensitivity is observed during the 10-h experiment despite the large polarization fluctuations occurred in these installed fibers. By this method reach extent ion are limited by 68 km.

Chul Han Kim et al [13] analyze the performance of bidirectional WDM PON architecture which utilizes distributed Raman amplification and pump recycling technique. The maximum reach at data rates of 622 Mb/s and 1.25 Gb/s in the proposed WDM PON architecture is calculated by taking into account the effects of power budget, chromatic dispersion of transmission fiber, and Raman amplification-induced noises with a given amount of Raman pump power. From the result, the maximum reach for 622 Mb/s and 1.25 Gb/s signal transmission is calculated to be 65 km and 60 km with a Raman pump power of 700 mW, respectively. They used very high Raman pump power in this method but not able to extend reach to 100 Km.

K. Acharya and M. Raja et al [14] proposed a solution that can be used to compensate the signal attenuation Energy Transfer due to SRS crosstalk. Proposed solution can also be used to increase the reach of PON, in an effort to merge access and metro networks. This is done by using remote Raman amplification where, a CW counter-propagating pump is placed at one of the ONUs. A -15 dB amplification of the downstream signal is observed with a BER < $l0e^{-12}$. A WDM-PON topology with 2 data channels and 3 Video channels was simulated With a counter-propagating Raman pump replacing one of the ONUs amplifying the downstream data signal. A 15dB of data signal amplification was observed caused by the Raman amplification. Because the pump is kept at the user premises (near ONU), the outside plant is still passive as required by PON. Even though SRS crosstalk is observed, this amplification results in a much stronger signal reaching the receiver. Initial simulations show that with this amplification, increase the link length two folds approximately (40 km). Hence, using remote Raman amplification serves two purposes; it compensates for the attenuation of data signal due to SRS crosstalk as well as it can help almost double the reach of PON. In this method, they did use any techniques for reduction in the cross talk.

K .Acharya and M. Raja [15] propose a relatively simple solution that can compensate the signal attenuation due to stimulated Raman scattering cross-talk in a wavelength division multiplexed passive optical network (WDM-PON) .The proposed solution also significantly increases the reach of the PON segment, enabling the merger of access and metro network boundaries. This can be accomplished using remote Raman amplification where a continuous wave counter-propagating pump is injected from one of the optical node units. A ~13 dB amplification of the downstream signal is observed with a bit error rate 1×10^{-12} for a 20-km fiber span. The reach of WDM-PON can be extended to ~40 km for typical 32 splits or up to 25 km for 64 splits using the proposed technique. Also report the effect of pump polarization on the amplification. By this method extended reach that is 40 Km

2.2 Objective

We studied various proposed method which are used for cross talk mitigation and reach extension. They mitigate the SRS about few dB and reach extension also proposed but not satisfactory. In our work we employed digital for video signal and increase the link length up to 100 km. If analog video signal are used then SRS depend on analog signal frequency ω, so BER vary between the extended reach. So by using our method we got linear relationship between BER and link length, can used all extended reach as analysed in chapter 4.

CHAPTER 3

PASSIVE OPTICAL NETWORK WITH DIGITAL MODULATED VIDEO SIGNAL

In our work we used digital modulated video signal for reduction of SRS cross talk. Modulation, which is the process of converting digital data in electronic form to an optical signal that can be transmitted over the fibre. Demodulation process, which is the process of converting the optical signal back into electronic form and extracting the data that was transmitted.

3.1 Raman Amplified PON Block Model

Figure 3.1 illustrates the logical schematic of the topology which is used in our simulation. We have used full length Bidirectional 20 Km fibre and placed 1:32 splitter just before optical node units(ONUs) to demonstrate the worst case for Raman scattering by keeping channel spacing > 8nm . Optical line terminal (OLT) transmit optical data through optical fibre .We have used either a circulator or WDN just in front of splitter and transmitting the CW Laser as pump signal via WDM.

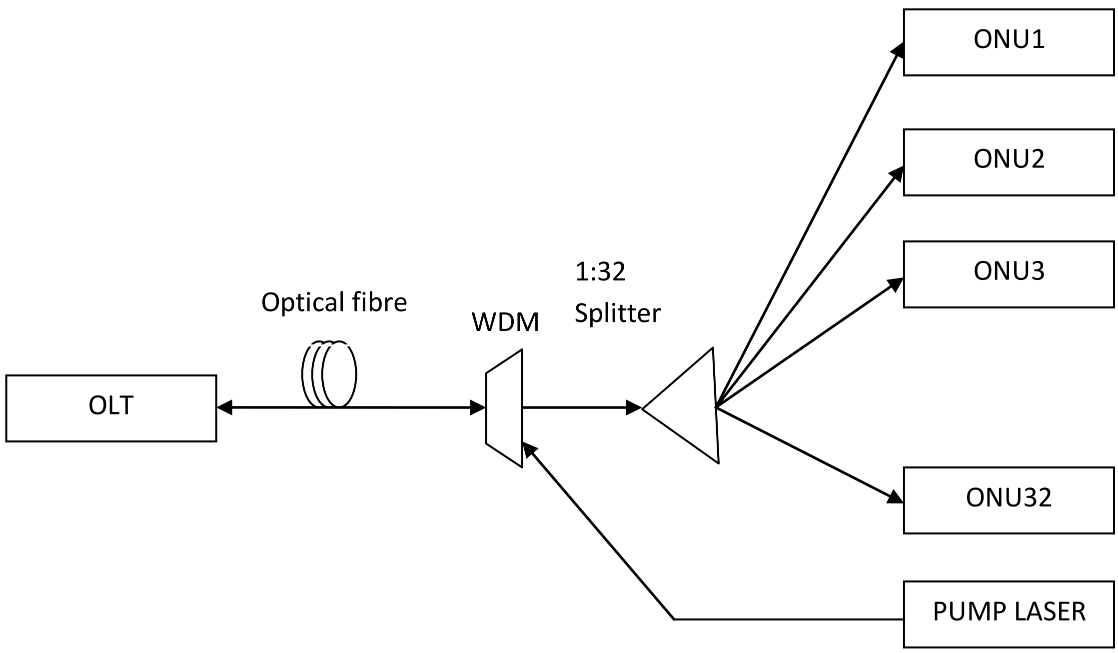


Figure 3.1: Raman amplified-WDM PON

An optical line termination (OLT) is a device which serves as the service provider endpoint of a passive optical network. It provides two main functions

- To perform conversion between the electrical signals used by the service provider's equipment and the fibre optic signals used by the passive optical network.

- To coordinate the multiplexing between the conversions devices on the other end of that network (called either optical network terminals or optical network units).

An Optical Network Unit (ONU) converts optical signals transmitted via fibre to electrical signals. These electrical signals are then sent to individual subscribers. ONUs is commonly used in fibre-to-the-home (FTTH) or fibre-to-the-curb (FTTC) applications. An ONU system consists of a closure that is a metallic or non-metallic enclosure that provides physical and environmental protection for the active electronic, optoelectronics, and passive optical components it houses. It terminates optical fibres from the Optical Distribution Network (ODN) and processes the signals to and from the Customer Premises Equipment (CPE).

3.2 Raman Pump Laser

Raman amplification can be obtained by either co propagating or counter propagating the pumps. For co propagation, the signal gain is high at the input of fibre when the pump power is high. The pump power is exponentially depleted as it travels through the fibre, and hence, the gain received by the signal is less toward the end of fibre at the destination. This leads to an uneven gain and also results in a further increase in the SRS cross-talk. However, for a counter propagating pump as shown in figure 3.2, as the pump is travelling opposite to the signal, one obtains low gain on the input side of the fibre because the counter propagating pump power is smaller at the fibre input and avails high gain toward the end of fibre (receiver side) from where the pump is launched. This results in an even gain of the signal. Hence, a counter propagating pump is the preferred method.

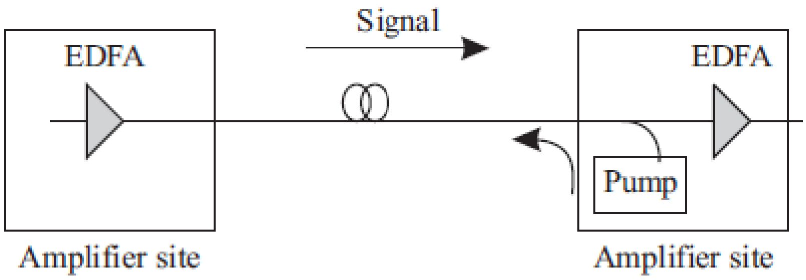


Figure 3.2: Raman amplifier using a backward propagating pump

We used CW Laser as a Raman Pump that used to amplify low power data signal in PON. We studied stimulated Raman scattering (SRS) as one of the nonlinear impairments that affect signals propagating through optical fiber. The same nonlinearity can be exploited to provide amplification as well. As we saw in Figure 3.3, the Raman gain spectrum is fairly broad, and the peak of the gain is cantered about 13 THz below the frequency of the pump signal used. In the near infrared region of interest to us, this corresponds to a wavelength separation of about 100 nm.

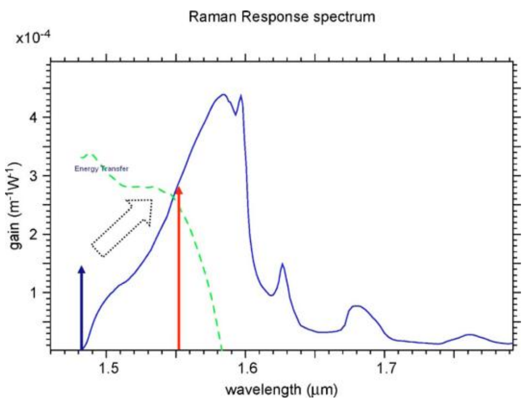


Figure 3.3: Raman response in silica fibre

Therefore, by pumping a fiber using a high-power pump laser, we can provide gain to other signals, with a peak gain obtained 13 THz below the pump frequency. For instance, using pumps around 1405–1415 nm provides Raman gain in the 1460–1500 nm window. Thus Raman amplification can potentially open up other bands for WDM, such as the 1310 nm window, or the so-called S-band lying just below 1528 nm. Also, we can use multiple pumps at different wavelengths and different powers simultaneously to tailor the overall Raman gain shape.

Raman threshold

The Raman threshold is defined as the input pump power at which the Stokes power becomes equal to the pump power at the fibre output [5]

$$P_S(L) = P_P(L) \equiv P_0 \exp\,(-\alpha_P L) \qquad (3.1)$$

where $P_0 = I_0 A_{\text{eff}}$ is the input pump power and A_{eff} is the effective core area ,Ps(L) signal power at fibre length L , α_P attenuation coefficient of power ,Pp(L) pump power at fibre length L.

Assuming a Lorentz an shape for the Raman-gain spectrum, the critical pump power, to a good approximation, is given by [5]

$$\frac{g_R P_0^{cr} L_{eff}}{A_{eff}} \approx 16 \qquad (3.2)$$

Where g_R is Raman gain coefficient, L_{eff} is effective length, A_{eff} effective core area P_0^{cr} is critical pump power.Raman threshold power approximately in which Raman Effect start is 1 watt.

Signal –Pump Amplification

The evolution of the pump, *Pp*, and signal, *Ps* , powers along the longitudinal axis of the fiber *z* in a Raman amplified system can be expressed by the following equations [4]:

$$\frac{dP_s}{dz} = g_R P_p P_s - \alpha_s P_s \qquad (3.3)$$

$$\frac{dP_S}{dz} = -\frac{\omega_P}{\omega_S} g_R P_P P_S - \alpha_P P_P \quad (3.4)$$

where $g_R(W^{-1}m^{-1})$ is the Raman gain coefficient of the fiber normalized with re-spect to the effective area of the fiber A_{eff} , $\alpha s/p$ are the attenuation coefficient at the pump and signal wavelength, and $\omega_s/_p$ are the angular frequencies of the pump and signal. The ± signs represent a co- and counter propagating pump wave, respectively. The first term on the right-hand side of Eq. (3.3) (Eq. (3.4)) represents the signal gain (pump depletion) due to SRS; the second term represents the intrinsic signal (pump) loss. If the depletion of the pump by the signal is ignored, Eq. (3.3) can be solved for the counter propagating case to give ,$Pp\ (z) = P_0e^{-\alpha p(L-z)}$, where P_0 is the input pump power and L is the fiber length. This result is substituted into Eq. (3.4)

$$P_S(L) = P_S(0)\exp\left(g_R \frac{P_0}{A_{eff}} L_{eff} - \alpha_S L\right) \quad (3.5)$$

Where

$$L_{eff} = \frac{1-\exp(-\alpha_P L)}{\alpha_P} \quad (3.6)$$

and the resulting differential equation can be solved analytically to yield and G_N is the net gain. Equation (3.5) is a first-order approximation of the signal evolution in the fiber. The relation between the on–off Raman gain and the Raman gain efficiency is given as[5]

$$G_A = \frac{P_S(L)\ with\ pump\ on}{P_S(L) with\ pump\ off} \quad (3.7)$$

$$= exp\left(g_R P_0 L_{eff}\right) \quad (3.8)$$

Where Ps *(L)* with pump on is assumed to be the amplified signal power without the amplified spontaneous emission (ASE) and thermal noise with pump on is assumed to be the amplified signal power without the amplified spontaneous emission (ASE) and thermal noise.

3.3 Electro-optics modulator

Electro-optic modulator (EOM) is an optical device in which a signal-controlled element displaying electro-optic effect is used to modulate a beam of light. The modulation may be imposed on the phase, frequency, amplitude or polarization of the modulated beam. Certain materials change their optical properties when subjected to an electric field. This is caused by forces that distort the positions, orientations, or shape of the molecules constituting the material. The electro-optics effect is the change in the refractive index resulting from applications of a dc or low-frequency electric field.

There is three types of electro-optics modulator

- Phase modulator
- Amplitude modulator
- Polarization modulator

3.4 Phase modulator

The simplest kind of EOM consists of a crystal, such as lithium niobate, whose refractive index is a function of the strength of the local electric field. That means that if lithium niobate is exposed to an electric field, light will travel more slowly through it. But the phase of the light leaving the crystal is directly proportional to the length of time it took that light to pass through it. Therefore, the phase of the laser light exiting an EOM can be controlled by changing the electric field in the crystal. The electric field can be created by placing a parallel plate capacitor across the crystal. Since the field inside a parallel plate capacitor depends linearly on the potential, the index of refraction depends linearly on the field (for crystals where Pockels effects dominates), and the phase depends linearly on the index of refraction, the phase modulation must depend linearly on the potential applied to the EOM.

Liquid crystal device are electro-optical phase modulators if no polarizer are used.

3.5 Raman Amplified PON Using OptSim

OptSim is a CAD environmental tool developed by Rsoft for drawing and simulating the schematics of the WDM, TDM, and DWDM based design models. OptSim has two types of simulation modes namely single and block mode simulations. In block mode simulations, data signal is carried out as a block of data between the blocks of the design transmitted between the blocks. Advantage of block mode is easy switching between time domain and frequency domain with the data sent as a block between the optical design models. In sample mode, the input data signal is sent over the design blocks of the model in the form of single sample for every time step. Advantage of sample mode is it can cover unlimited sequence length of data signal when compared to block mode in which data signal is of limited length represented as a block. Sample mode simulations are done in time domain. Performance analysis is done by using eye diagram, BER and Q factor parameters and tools used in OptSim tool are spectrum analyzer, scopes (electrical and optical) and signal analyzer.

In this project we used Block model for simulation .Usage of Optsim tool gives you greater accuracy of the design model and capable of varying power parameters easily. Simulations in optsim tool depend on embedded spice engine, which simulate the electrical circuit from the combined component design model . To simulate the designs in optsim tool, one needs a dongle and license file. Both are correlated using a serial number provided by Rsoft. Figure 3.4 shows the simulated topology and the segment highlights of the OLTs and ONUs. Figure 3.4(a) below shows the OLT topology.

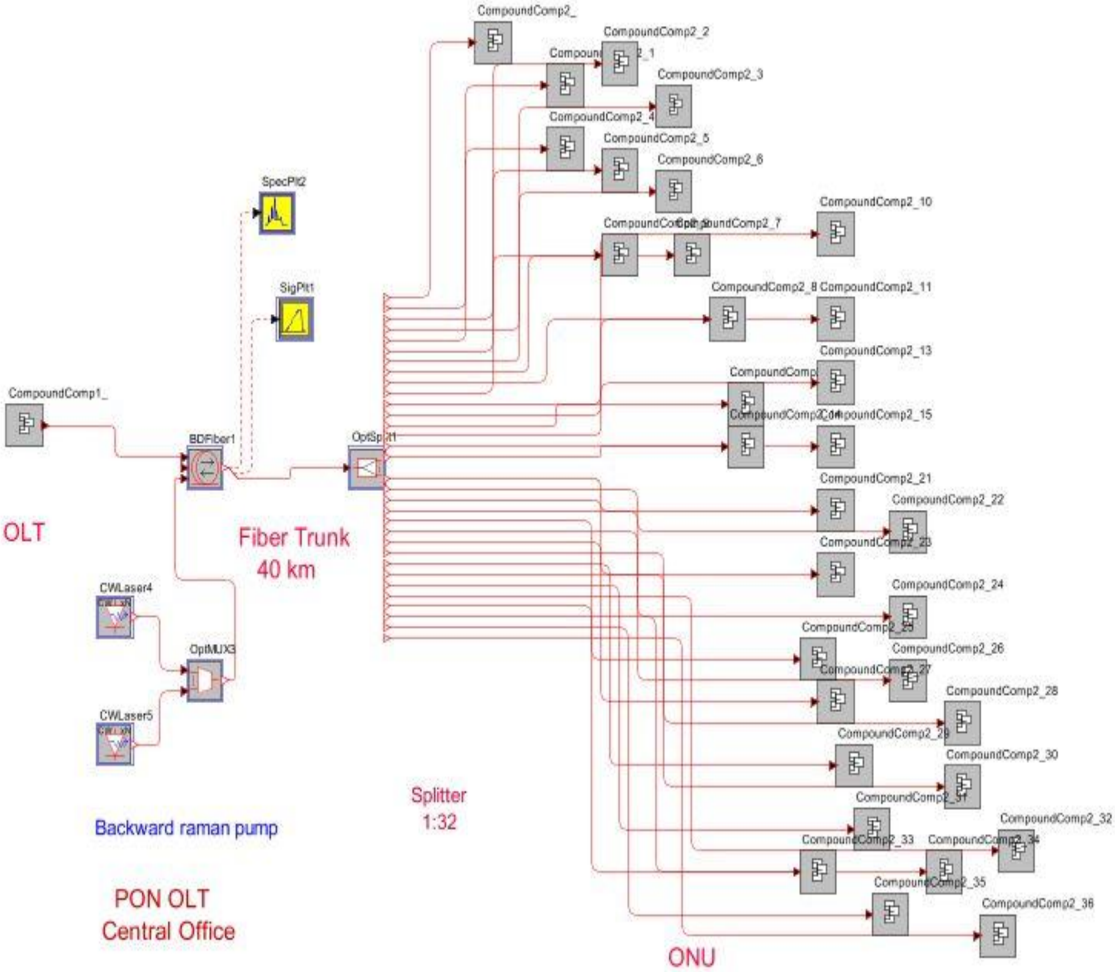


Figure 3.4: *Schematic lay-out design of WDM-PON*

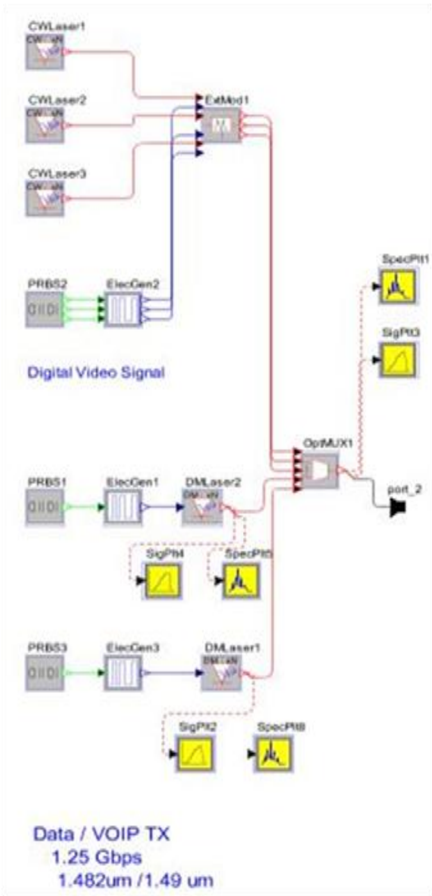


Figure 3.4 (a): Optical Line Terminal (OLT)

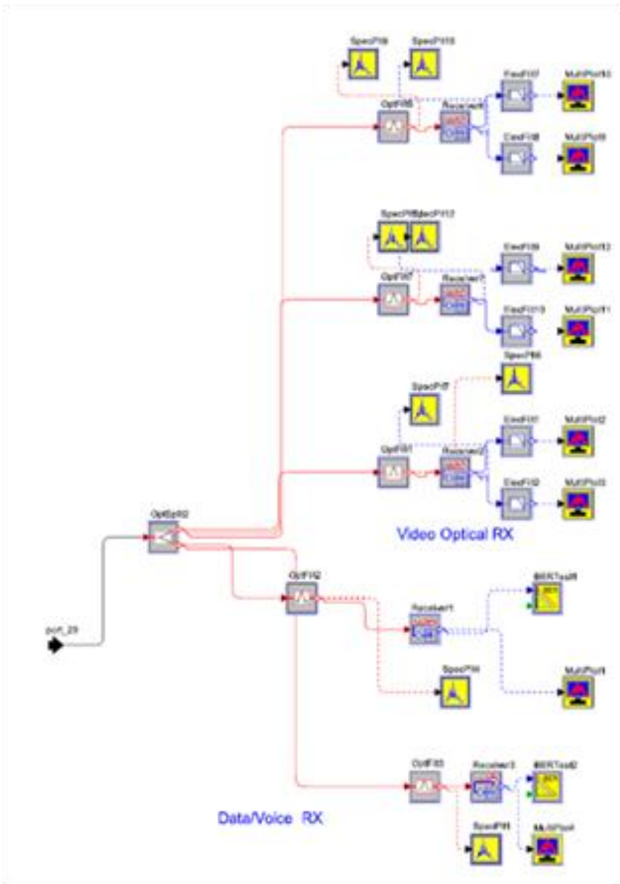


Figure 3.4(b): Optical Network Unit (ONU)

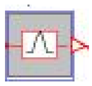
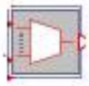
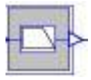
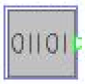
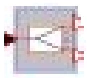
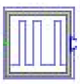
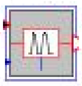
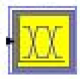
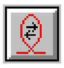
At the OLT site, A BPSK video signal is overlaid on fiber and transmitted at three wavelengths at 1542, 1550, and 1558 nm. We used phase modulaton as a modulation techniques instead of direct modulated analog overlay of the video signal .This techniques minimise the effect of SRS cross-talk between the video and data signals. Two data signals at 1490 and 1482 nm with data rate of 1.25 Gbps are multiplexed with these three video signals using a WDM multiplexer, and the signal is transmitted via 40 km of SMF-28 fiber. Here, the signal passes through a WDM multiplexer and 1:32 splitter and reaches 32 ONUs. At the ONU, a Gaussian filter separates the video and data signals. Figure 3.4(b) shows the ONU topology. A counter propagating Raman pump (p~180 mW), much less than conventional Raman pumps) is launched that amplifies the downstream signal. Extends the reach and serves more users with a high reliability and signal integrity.

The simulations were carried out with realistic and practical parameters which shown in table 4.1.

3.4 Description of components used in Raman amplified PON model

The Raman amplified PON model has been designed with OPTSIM simulation software using various components. Table 3.1 represent the various symbols used for these components.

Table 3.1: Symbol Used for System Design

S.No	Symbol	Name of the component	S.No	Symbol	Name of the component
1		Mode Locked Laser	8		Optical filter
2		CW Laser	9		Photo-detector
3		Optical Multiplexer	10		Electrical filter
4		PRBS Data Generator	11		Optical Splitter
5		Electrical Signal Generator/ Driver	12		Wavelength1 Multiport
6		Modulator	13		Eye diagram Analyser
7		Bidirectional fibre	14		Bit error rate Tester

3.5 Eye Diagram Analyzer

The eye diagram technique is a simple but powerful measurement method for assessing the data-handling ability of a digital transmission system [16]. This method has been used extensively for evaluating the performance of wire systems and also can be applied to optical fibre data links. The eye pattern measurements are made in the time domain and allow the effects of waveform distortion to be shown immediately on the display screen of standard BER test equipment. Figure 3.5 shows a typical display pattern, which is known as an eye pattern or an eye diagram.

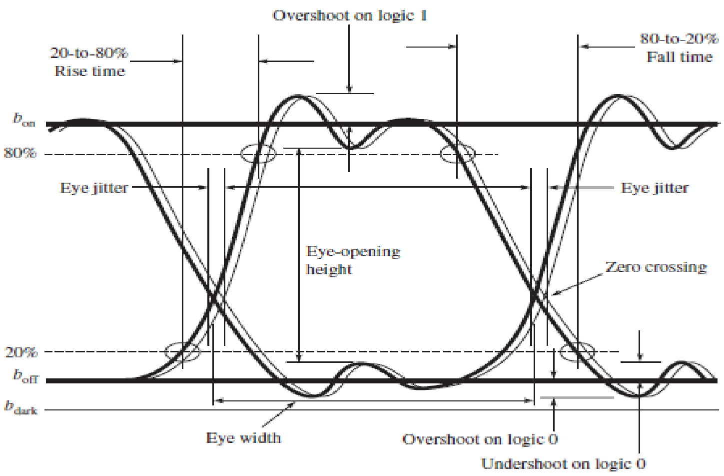


Figure 3.5 Schematic eye pattern of digital signal

The width of the eye opening defines the time interval over which the received signal can be sampled without error due to interference from adjacent pulses (known as intersymbol interference).

The height of the eye opening defines the best to sample the received waveform. This height is reduced as a result of amplitude distortion in the data signal. The vertical distance between the top of the eye opening and the maximum signal level gives the degree of distortion. The more the eye closes, the more difficult it is to distinguish between 1s and 0s in the signal.

The height of the eye opening at the specified sampling time shows the noise Margin or immunity to noise.

Timing jitter (also referred to as eye jitter or phase distortion) in an optical fibre system arises from noise in the receiver and pulse distortion in the optical fibre. If the signal is sampled in the middle of the time interval (i.e., midway between the times when the signal crosses the threshold level), then the amount of distortion ΔT at the threshold level indicates the amount of jitter.

Timing jitter is thus given by Eq. 3.9

$$\text{Time jitter (percent)} = \frac{\Delta \mathrm{T}}{\mathrm{T_b}} \times 100 \tag{3.9}$$

where T_b is the bit interval.

Traditionally, the rise time is defined as the time interval between the point where the rising edge of the signal reaches 10 percent of its final amplitude to the time where it reaches 90 percent of its final amplitude. However, in measuring optical signals, these points are often obscured by noise and jitter effects. Thus, the more distinct values at the 20 percent and 80 percent threshold points normally are measured. To convert from the 20 to 80 percent rise time to a 10 to 90 percent rise time, one can use the approximate relationship given in Eq. 3.10

$$T_{10\text{–}90} = 1.25 T_{20\text{–}80} \tag{3.10}$$

Any nonlinearity of the channel transfer characteristics will create an asymmetry in the eye pattern. If a purely random data stream is passed through a purely linear system, all the eye openings will be identical and symmetric.

CHAPTER 4

RESULTS AND DISCUSSION

The mitigation of SRS cross talk and reach extension for WDM-PON using digitally modulated video signal design in chapter 3 was simulated on OptSim software. This chapter present the simulation result and analysis of the result. Used simulation parameter given in table 4.1.

Table 4.1: Used Parameters for simulation

PARAMETER	VALUE
Bit Error Rate	1.25Gbps
Attenuation of Optical Fibre	0.25 dBm
Effective Area of Optical Fiber, A_{eff}	80 μm^2
Raman Gain, g_R	9.8E-14 m/W
Raman pump reference wavelength	1.0E-6 m
Dispersion of Optical Fibre	16.75 ps/nm/km
Fibre Loop Length	40 Km, 60Km, 80Km, 100Km
Pump Power	180 mW

4.1 Analysis of Raman amplifier with fibre length with pump power at 180 mW

4.1.1 Fibre length 40 Km

When signal passes through the optical fibre then due to nonlinear effects of optical fibre the signal get degraded. Low wavelength signal are more effective than high wave length signal. so in this simulation we analysis the effect of scattering on low wavelength signal (data signal) i.e. 1482 nm ,1490 nm. Scattering effects are on signal shown in optical spectra which are shown below.

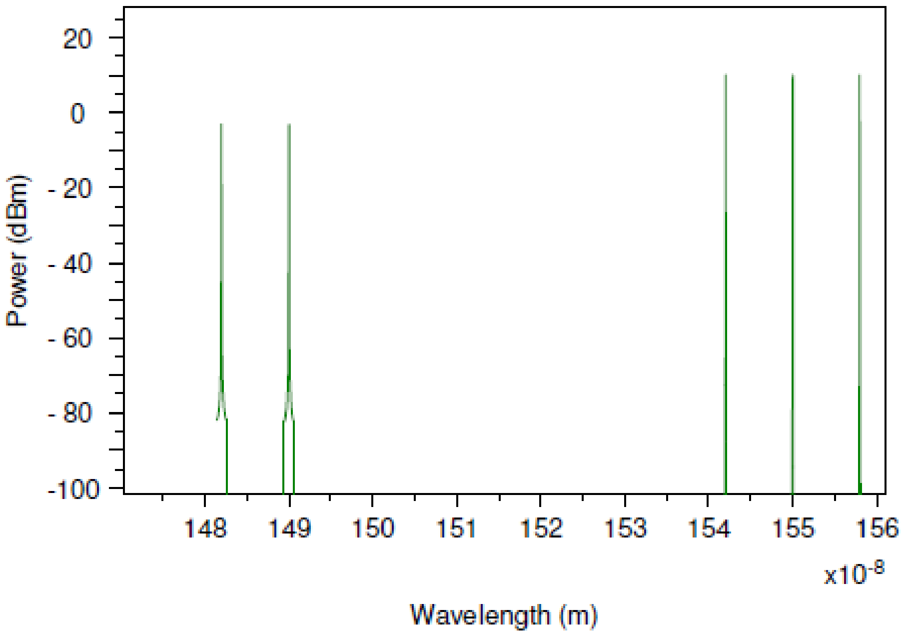


Figure 4.1 (a): Input Signal Spectrum

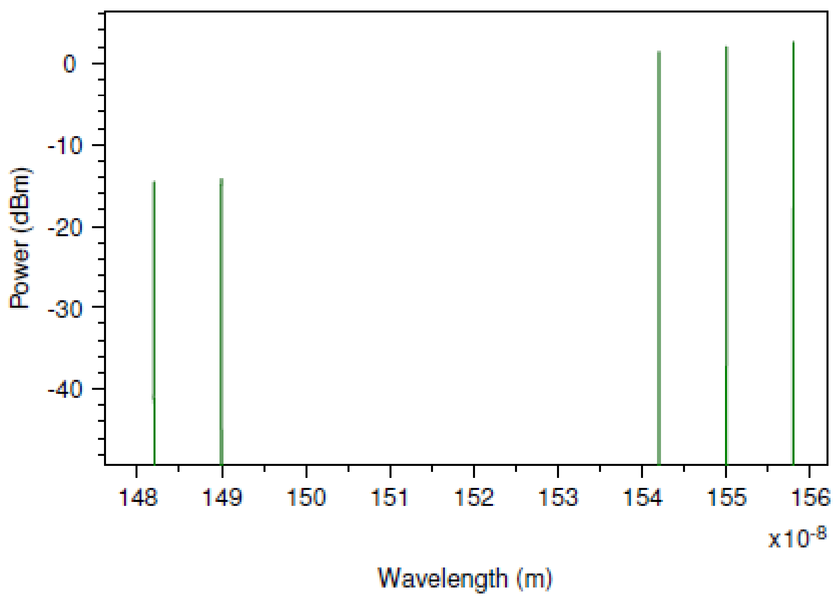


Figure 4.1 (b): Signal after Raman Scattering

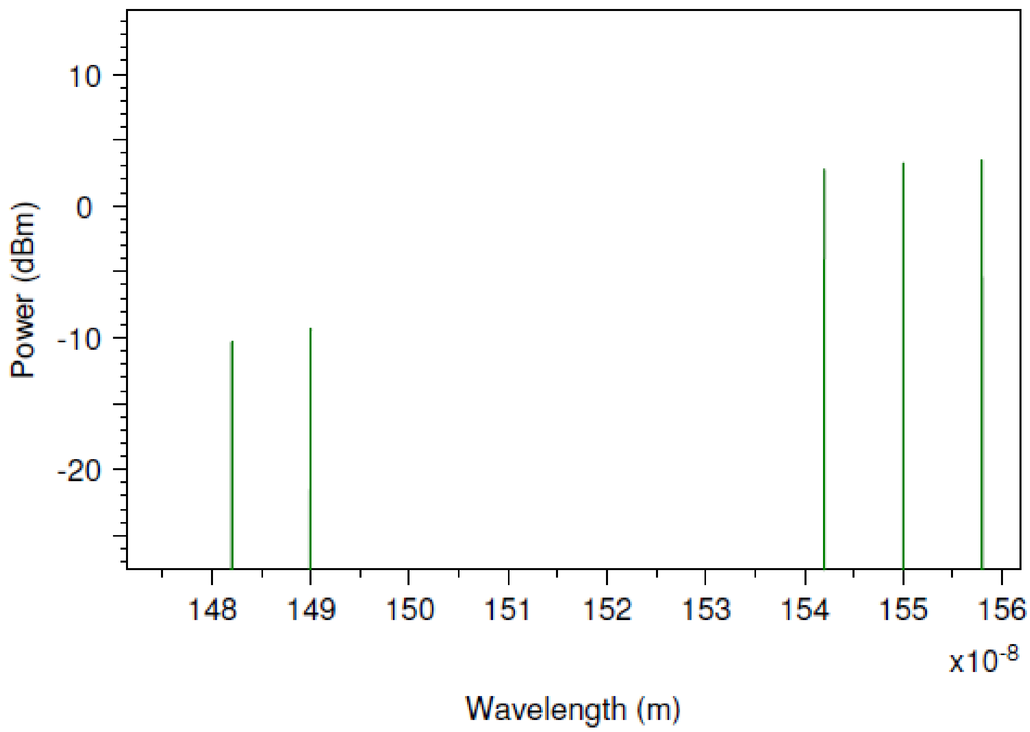
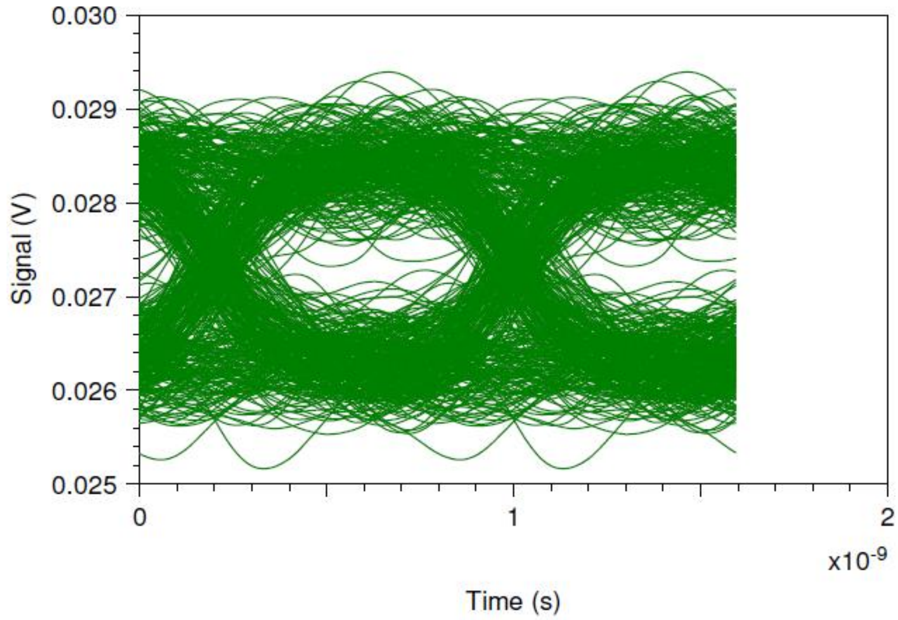
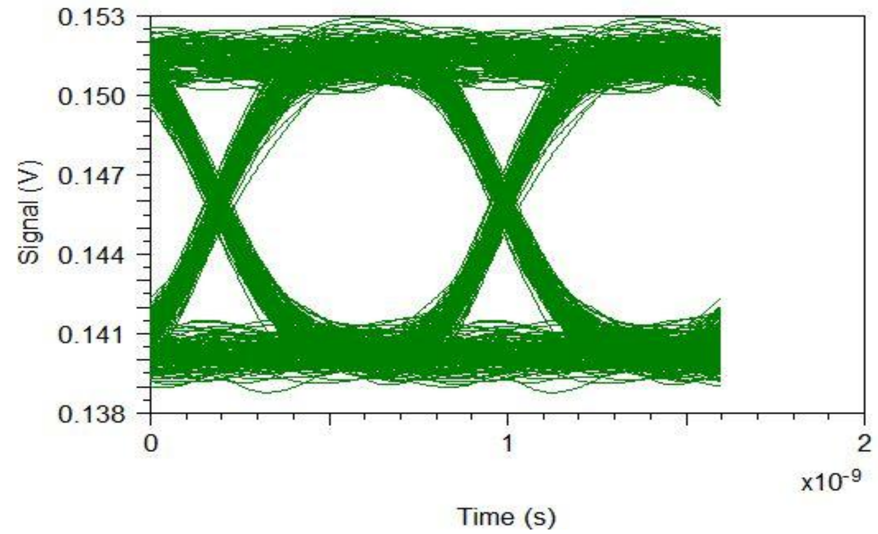


Figure 4.1 (c): Signal after Raman Amplifier

Figure 4.1(a) shows the input signal power spectrum at OLT which is -3dBm power for data and 10.5 dBm power video signals. Similarly figure 4.1(b) shows the scattered optical spectrum powers after passing through the fibre are -14.5 dBm for data and 1.6 dBm for video signal. Figure 4.1(c) shows the output spectra with Raman amplification. We observed from above figures that when input signal passes through optical fibre then signal get degraded due to stimulated Raman scattering and signal degraded from 2.6 dBm . After SRS, signal get reduce to -14.5 dBm for data signal and 1.6 dBm for video signal. Degraded signal quality can measure using BER tester, eye diagram.

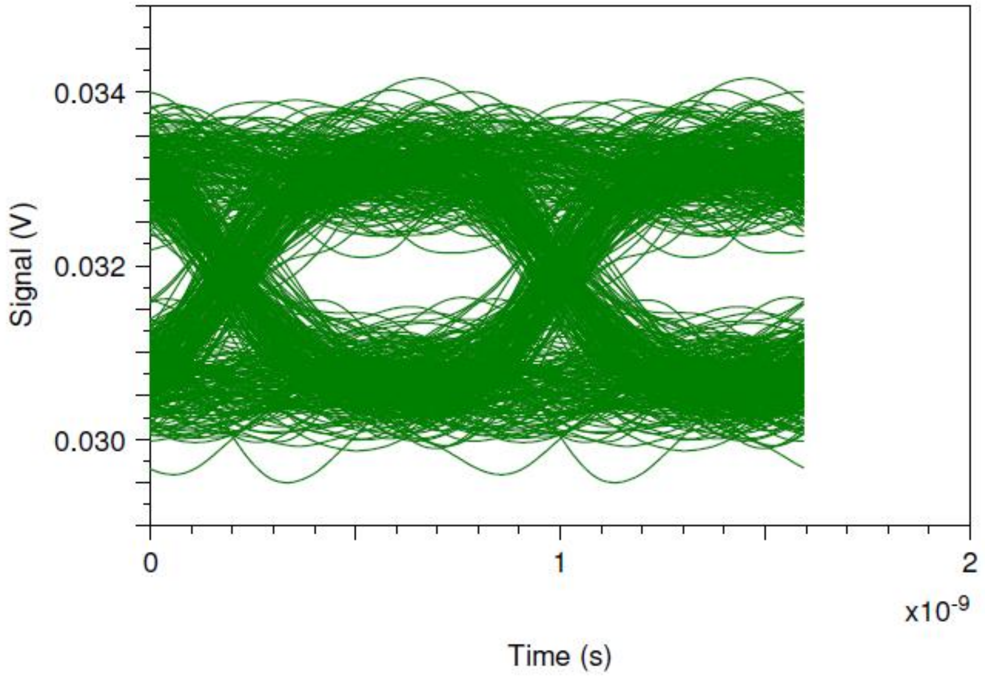


(a)

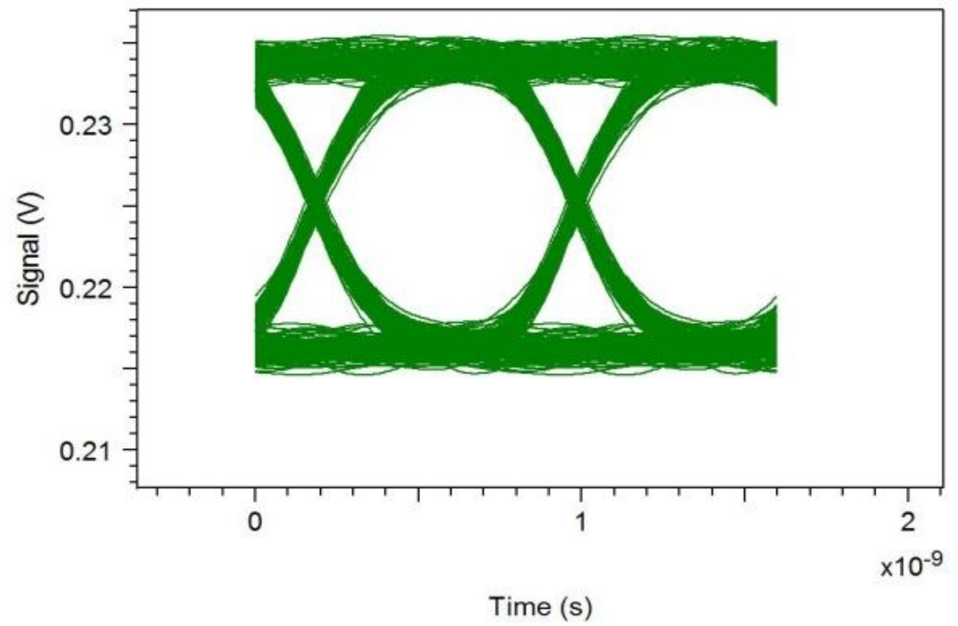


(b)

Figure 4.2 Eye diagrams at 1482 nm (a) without Raman pump (b) with Raman pump



(a)



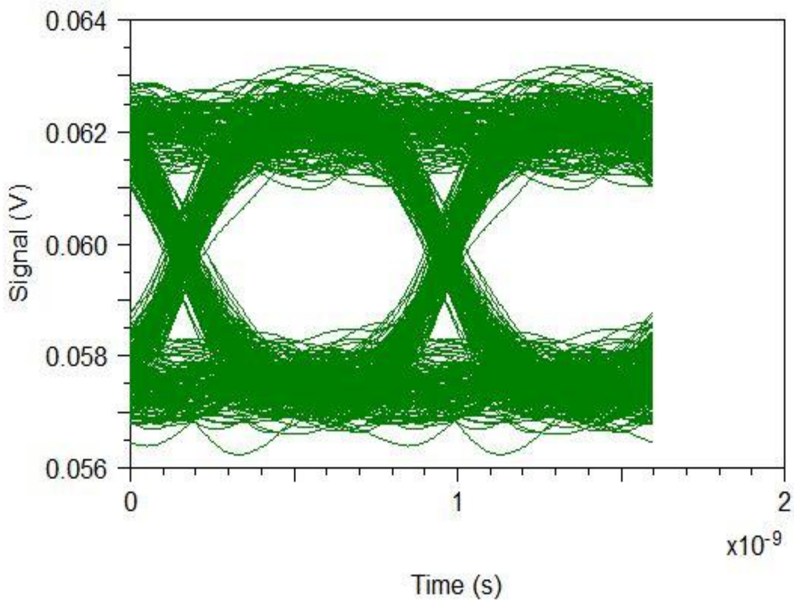
(b)

Figure 4.3 Eye diagrams at 1490 nm (a) without Raman pump (b) with Raman pump

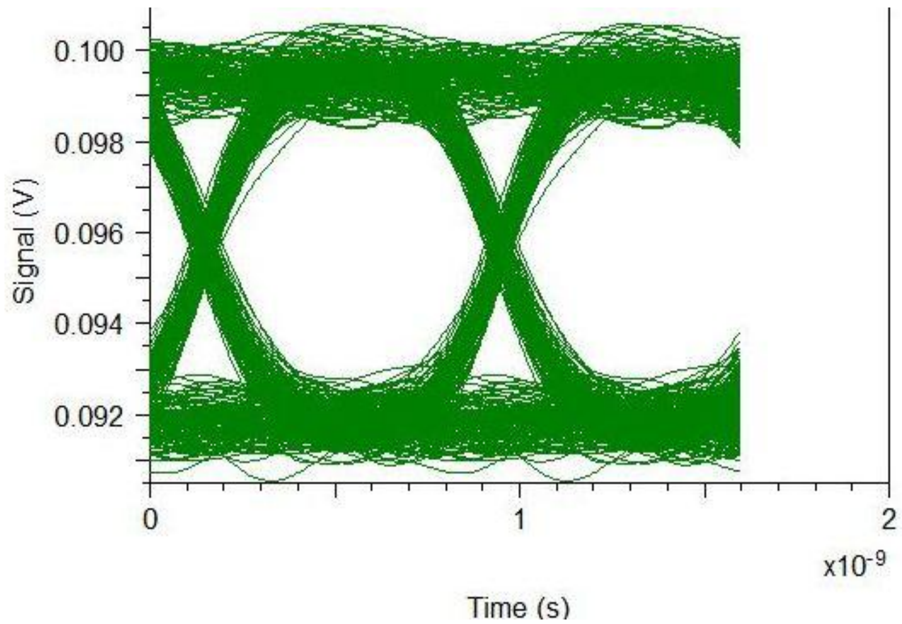
We observe signal quality of signal using eye diagram as shown in figure 4.2 (a) is poor. It can improve by using Raman pump. In this simulation we used pump power 180 mW. It is evident from the optical spectra figure 4.1(b) that we obtain ~7dB amplification in power. Quality of signals can observe from figure 4.2, 4.3 and observe that with pump power signal has good quality. Here we observe quality of signal for both wavelength i.e. 1482 nm, 1490 nm and concluded from comparison of eye diagram that eye opening for higher wavelength signal is wide. So we can say higher wavelength signal are less effective from SRS.

4.1.2 Fibre length 60 Km with pump power 180 mW

Now we carried our simulation for increasing fibre length 60 Km and observe the signal quality using Eye Diagram and BER. Eye diagram for different wavelength are shown below.



(a)



(b)

Figure 4.4 Eye diagram at (a) 1482 nm (b)1490nm

Figure 4.4 shows the Eye diagram for different wavelength signal after the Raman pump and measure the BER. From comparison of eye height of 4.4(a) or 4.4(b) then found that signal 1490 nm have wide eye opening. This shows the signal quality of 1490 nm is good compare to 1482 nm. We measure BER of the signal using BER tester then 1490 nm have BER is less than 1482 nm. BER for 1482 nm is in the range of acceptable range.

The resulting amplified signal evolution suggests that reach or distribution can be increased. It verifies the fact that we obtain a much wider eye opening for the case of Raman amplified WDM-PON with a BER«1×10^{-12}, as compared to the regular WDM-PON. The fact to be noted is that we have not introduced any extra components, such as an SOA or highly nonlinear fibre or EDFA into the mix besides the pump. The pump wavelength was varied from 1405 to 1425 nm with best result obtained at 1415 nm (±2 nm). Hence, the Raman pump wavelength is chosen data signal. A pump for video signal was not used, but if deemed necessary, that can also be easily added to the topology. As the channel separation between the pump and the upstream signal (in either 1310-nm or 1550-nm band) is 100 nm (Stokes' shift of silica fiber), they have minimal interaction between each other.

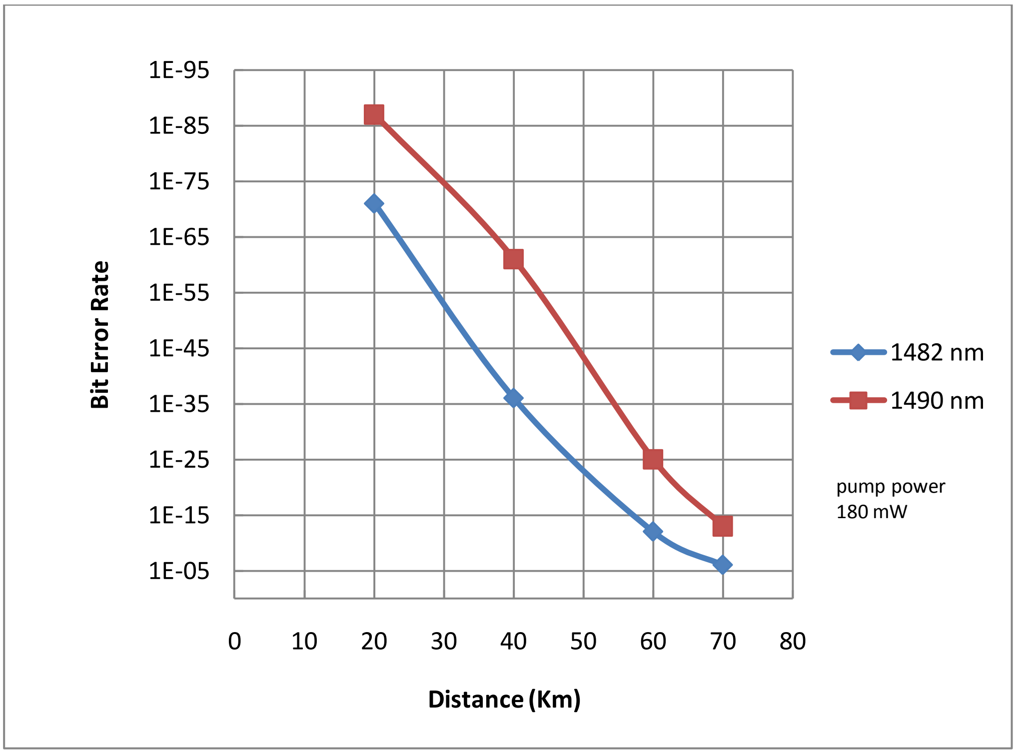


Figure 4.5 Effect of distance on BER for digital signal

Figure 4.5 displays the effect of distance on the bit-error rate (BER) of the system. It is evident from Fig. 4.5 less than 60 Km the BER always remains $<1\times10^{-9}$ which is the minimum requirement for any optical communication system. But, the limitation is imposed by the optical input at the receiver. In our simulations at 60 km, the optical input at the ONU for digital data signals reaches that value. Also, beyond 60 km, the BER goes in the regime of 1×10−8 to 1×10−9. Hence, one can conclude that by using remote Raman-amplified WDMPON the reach of a 32-split-wide WDM-PON can be extended up to 60 km.

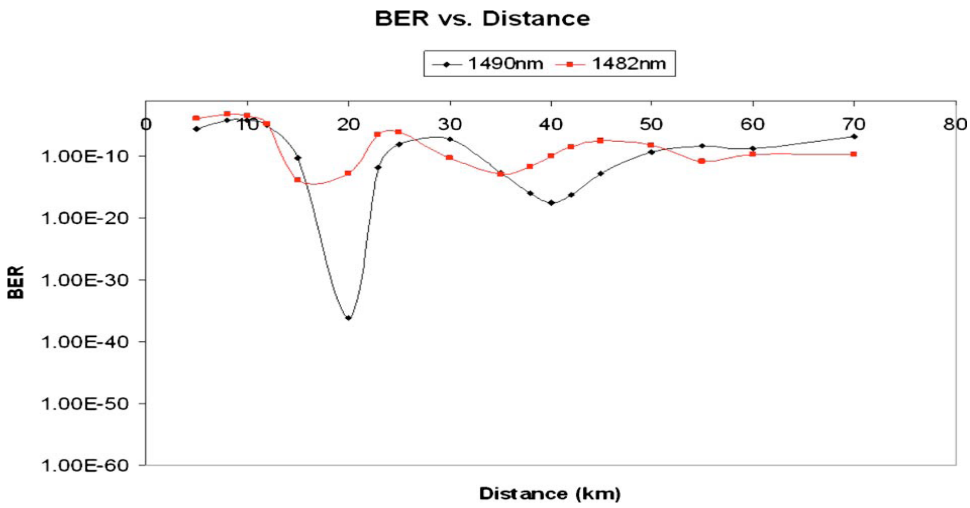


Figure: 4.6 Effect of distance on BER is illustrated. A significant improvement in the BER in the 15–20 km range is shown. BER remains ≪1×10−12 in the 38–40 km range, suggesting that the reach of WDM-PON can be increased to ~40 km (except the region between25 and 30 km) by using remote Raman amplification as the proposed [15].

In our proposed scheme using BPSK technique, we compensate the problem associated with region between 25 and 30 km. As shown in figure 4.5 that we get approximate linear relation between the distance & BER values and can used all the distance given by extended reach . Here we compare the BER vs Distance (Km) for both techniques with Raman pump power 180mW . After observing figure 4.5, 4.6 then conclude that using BPSK modulation technique we can transmit signal up-to 60km with better quality analysis.

4.2 Extended Reach using Raman pump power 400 mW

We have also simulated the results for 400mW pump power and get the reach extension up-to 100Km.

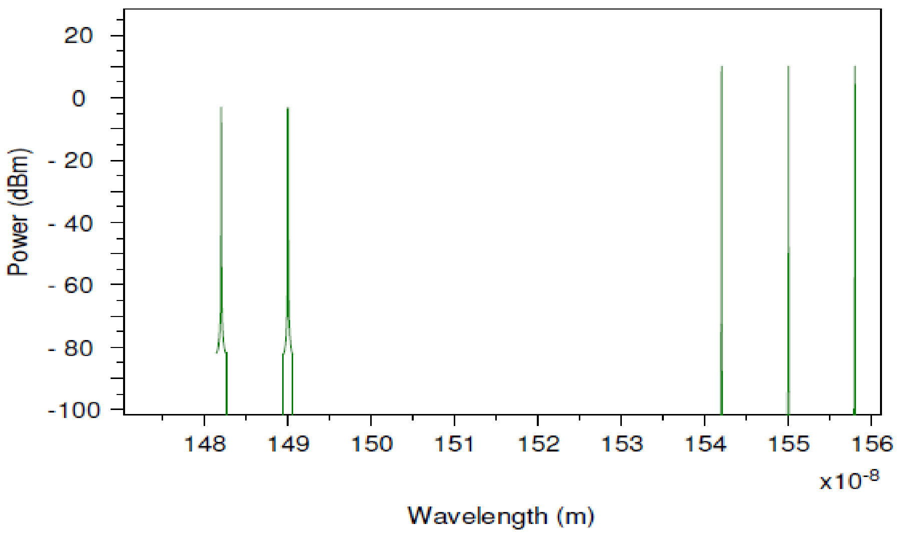


Figure 4.7 (a) input signal spectrum

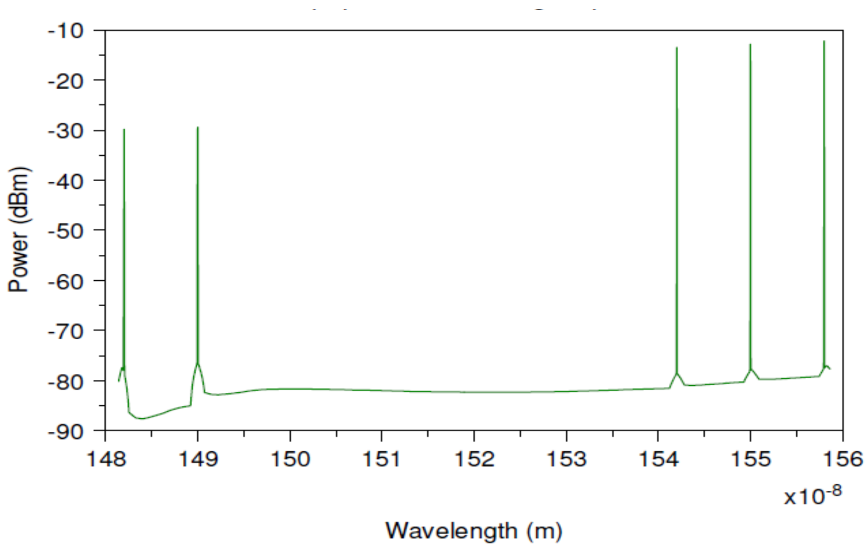


Figure 4.7 (b) Signal after Raman scattering

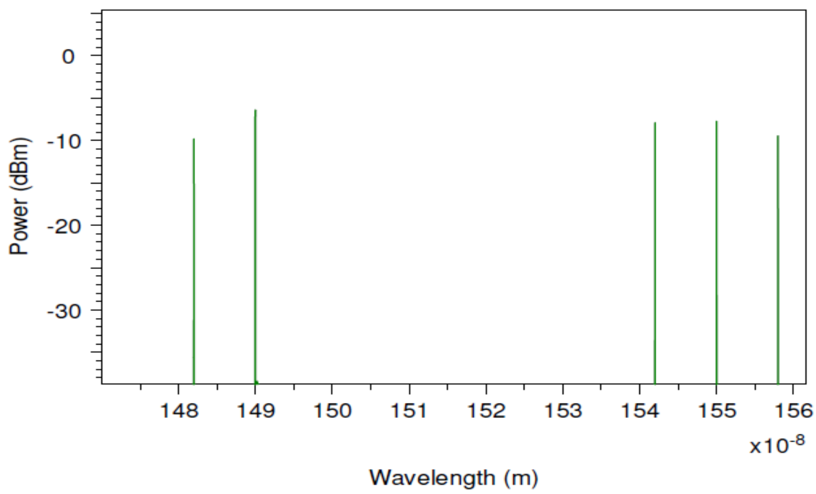
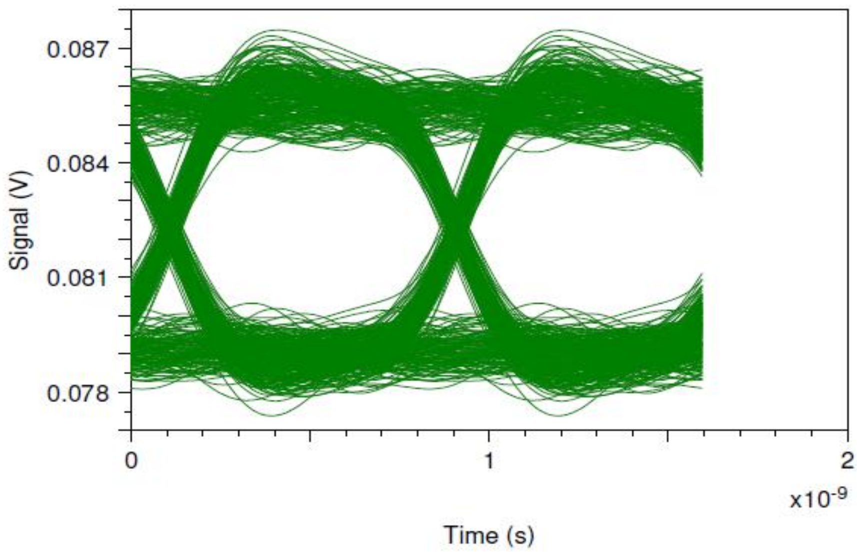
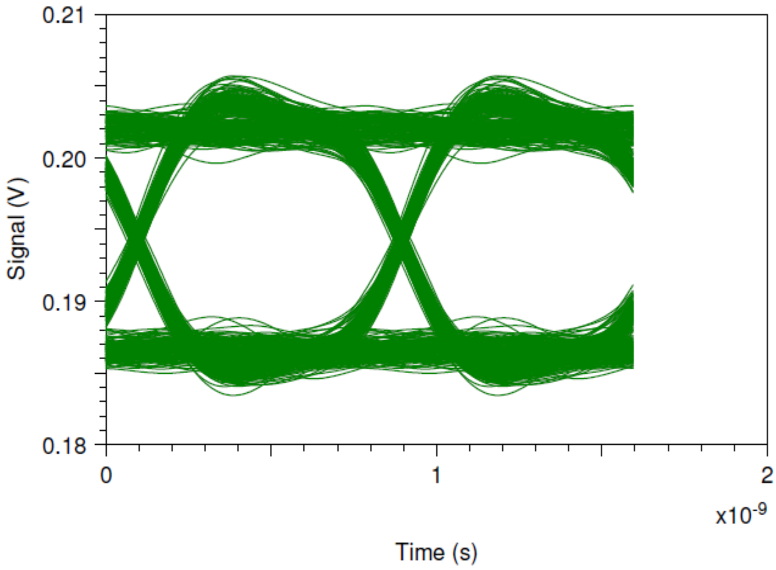


Figure 4.7(c) signal spectrum after raman pump



(a)



(b)

Figure 4.8 eye diagram for 400 mW pump power (a) for 1482 nm (b) for 1490

Figure 4.9 BER vs distance using 400 mW

Figure 4.7 (a) shows the input signal spectra and 4.7(b) shows the spectra After scattering . If we measure signal quality using eye diagram then find completely closed eye ,BER is high. Figure 4.7(c) shows the spectrum after Raman pump, and observe that signal power gets increased. We observe from figure 4.8(a) 4.8(b) a wide opening eye diagram. Figure 4.9 shows the bit error rate is for 100 km is in the acceptable range. . finally we can say reach can be extended to 100 Km fibre span.

CHAPTER 5

CONCLUSION & FUTURE WORK

Conclusion and future work

We proposed and simulated a Raman-amplified WDM-PON network topology. It can be used for potential applications in compensation of SRS cross-talk penalty and additional amplification for reach extension. In this simulation we used five channels, two data channels and three video channels, which are multiplex in WDM, transmitted through a bidirectional optical fibre. A counter propagating Raman pump is used to amplifying the downstream data signals. We used phase modulation techniques with 180 degree phase-shift for video signal which helps to mitigate the Raman scattering effect of signal. In this simulation we observe 2.6 dBm degradation of data signal.

We used Raman pump (180 mW), A ~7 dB of data signal amplification was observed for a 60-km fibre span. Simulations show that with the amplification, it is possible to increase the link length approximately (~60 km) for 32 splits and up to 40 km for 64 splits. In our proposed scheme using BPSK technique, we compensate the problem associated with region between 25 and 30 km as we get approximate linear relation between the distance & BER values. This property shows the reach extension for the WDM-PON. Here we compare the BER vs Distance (Km) for both techniques for 180mW pump laser. In BPSK modulation technique we can transmit signal up-to 60km with better quality analysis.

Now in another simulation we use Raman pump power 400 mW and observe that link length can further increase upto 100 Km for 32 splitter. Hence, using Raman amplification serves two purposes: it compensates for the attenuation of data signal due to SRS cross-talk as well as it helps extending the reach of PON.

This work can be extended by using signal-compensation technique such as widely used forward error correction (FEC) or dispersion compensation or advanced modulation , orthogonal frequency division multiplexing (OFDM) for the video signals . these techniques have not been used in this simulation. Use of FEC can lead to a further signal amplification of about 3–6 dB. This results in significant improvement of the BER of the system. Hence, if FEC is employed, better signal quality and further extension of reach can be obtained.

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