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Nonlinear Evaluation of Passive Optical Networks (PON) Based on Optical Nonlinearity

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Abstract:- In this paper, we evaluate the performance of the passive optical network (PON) based on optical nonlinearity which is presented. Here, performance measure criteria are decided by the cost and the power constraint of passive optical networks. Also the power constraint is affected by the nonlinearity that are arises due to the changes in refractive index and scattering. We consider only the nonlinear effect of optical fiber such as cross phase modulation (XPM), four wave mixing (FDM), and Stimulated Raman Scattering (SRS). Here, the effect of cross phase modulation (XPM), four wave mixing (FDM), and Stimulated Raman Scattering (SRS) nonlinearity is analysed in passive optical networks. Simulation result shows the performance of the passive optical network which is bound to a limited range of the transmitting power. Simulation results are presented for the combination of the nonlinearities such as SRS-FWM, SRS-XPM and XPM-FWM. Experimental results concluded that SRS-FWM, SRS-XPM and XPM-FWM can limit the performance of the optical passive network to a limited transmitting power. Small Transmitting power limits network expansion including length, distance, covered areas, and number of users accessing the network, unless suitable precautions are taken to reduce the effects of these nonlinearities in PONs.

Keywords: **Passive optical network (PON), SRS-FWM, SRS-XPM and XPM-FWM.**

I. INTRODUCTION

A PON is a fiber network that only uses fiber and passive components like splitters and combiners rather than active components like amplifiers, repeaters, or shaping circuits. Such networks cost significantly less than those using active components. The main disadvantage is a shorter range of coverage limited by signal strength. EPON and GPON are popular versions of passive optical networks (PONs). These short-haul networks of fiber-optical cable are used for Internet access, voice over Internet protocol (VoIP), and digital TV delivery in metropolitan areas. Other uses include backhaul connections for cellular base stations, Wi-Fi hotspots, and even distributed antenna systems (DAS). The primary differences between them lie in the protocols used for downstream and upstream communications.

Due to the rapid development of fiber optic communication systems requires higher transmission data rate and longer reach. This paper deals with the limiting factors in design of long-haul fiber optic communication systems and the techniques used to suppress their resulting impairments. These impairments include fiber chromatic dispersion, the Ker nonlinearity and nonlinear phase noise due to amplified spontaneous emission. We focus on the impact of transmission impairments in high speed optical networks.

The optical passive networks (PONs) communication system suffers from performance degradation due to fiber attenuation, chromatic dispersion and fiber nonlinear effects including stimulated Raman scattering (SRS), stimulated Brillouin scattering, four wave mixing, self- and cross-phase modulation [1-2]. Among all these effects, stimulated Raman scattering (SRS) and four waves mixing are the major limitations of system performance. One of the non-linear effect is four wave mixing (FWM) in which two signals at different wavelengths interact resulting in generation of "sum and difference" wavelengths [2]. The generated FWM components give rise to interference. The number of FWM components generated increases with the increase in number of users [3].

The Raman scattering effect is the inelastic scattering [4] of a photon with an optical phonon, which originates from a finite response time of the third order nonlinear polarization [5] of the material. When a monochromatic light beam propagates in an optical fiber, spontaneous Raman scattering occurs. It transfers some of the photons to new frequencies. The scattered photons may lose energy or gain energy. If photons at other frequencies are already present then the probability of scattering to those frequencies is enhanced. This process is known as stimulated Raman scattering.

In this paper, we evaluate the performance of the passive optical network (PON) based on optical nonlinearity is presented. Here, performance measure criteria are decided by the cost and the power constraint of passive optical networks. Also the power constraint is affected by the nonlinearity that are arises due to the change in refractive index and scattering. We consider only the nonlinear effect of optical fiber such as cross phase modulation (XPM), four wave mixing (FDM), and Stimulated Raman Scattering (SRS). Here, the effect of cross phase modulation (XPM), four wave mixing (FDM), and Stimulated Raman Scattering (SRS) nonlinearity is analysed in passive optical networks.

The rest of the paper is organized as follows: In section II, explain the basic of passive optical networks (PONs). In Section III, detail of the four waves mixing is given and how this affects the performance of PONs. Section IV explains the scattering based nonlinearity stimulated Raman scattering. In Section V, detail of the cross phase modulation is given and how this affects the performance of PONs. In Section V, shows the simulation results of optical passive networks in the presence of the nonlinearities such as four wave mixing, stimulated Raman scattering and cross phase modulation. Combine effect of four wave mixing, stimulated Raman scattering and cross phase modulation nonlinearity are analysis. Result also shows the comparative analysis of PONs with respect to this nonlinearity. Finally, a conclusion is put forward.

II.   PASSIVE OPTICAL NETWORKS (PONS)

A PON is a fiber network that only uses fiber and passive components like splitters and combiners rather than active components like amplifiers, repeaters, or shaping circuits. Such networks cost significantly less than those using active components. The main disadvantage is a shorter range of coverage limited by signal strength. While an active optical network (AON) can cover a range to about 100 km (62 miles), a PON is typically limited to fiber cable runs of up to 20 km (12 miles). PONs also are called fiber to the home (FTTH) networks [6-7].

In a PON network, data signals are carried from one to many in the downstream direction and from many to one in the upstream direction. Thus the power of the downstream signal is divided in a splitter and delivered to all ONUs, connected via fibre links to the splitter. The number of ONUs that can be connected to a splitter is limited by the power loss, introduced in the splitter and on the OLT-to-ONU fibre links. When the power is divided uniformly between the ONU-links, the longest link sets the limit, because the power loss is a function of the transport distance. One could use Linear Divider Combiner (LDC) components to adjust the signal power to be equal at each ONU input interface.

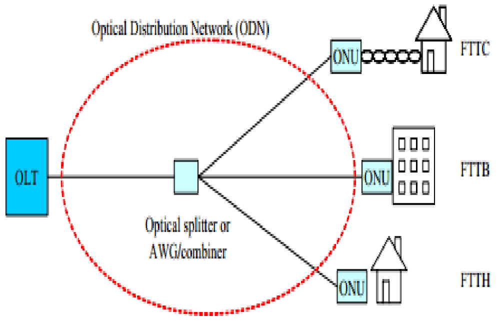

Fig. 1 Passive optical Network

The typical PON arrangement is a point to multi-point (P2MP) network where a central optical line terminal (OLT) at the service provider’s facility distributes TV or Internet service to as many as 16 to 128 customers per fiber line In fig. 1. Optical splitters, passive optical devices that divide a single optical signal into multiple equal but lower-power signals, distribute the signals to users. An optical network unit (ONU) terminates the PON at the customer’s home. The ONU usually communicates with an optical network terminal (ONT), which may be a separate box that connects the PON to TV sets, telephones, computers, or a wireless router. The ONU/ONT may be one device [8]. In the basic method of operation for downstream distribution on one wavelength of light from OLT to ONU/ONT, all customers receive the same data. The ONU recognizes data targeted at each user [9-10].

III. FOUR-WAVE MIXING (FWM)

Four-wave mixing is an intermodulation phenomenon in non-linear optics, whereby interactions between two wavelengths produce two extra wavelengths in the signal. It is similar to the third-order intercept point in electrical systems. Four-wave mixing is a nonlinear effect arising from a third-order optical nonlinearity, as is described with a $X_{(3)}$ coefficient. It can occur if at least two different frequency components propagate together in a nonlinear medium such as an optical fiber [11]. Assuming just two input frequency components f_1 and f_2 (with $f_2 > f_1$), a refractive index modulation at the difference frequency occurs, which creates two additional frequency components. In effect, two new frequency components are generated: $f_3 = f_1 - (f_2 - f_1) = 2f_1 – f_2$ and $f_4 = f2 + (f2 - f1) = 2f2 - f1$. Furthermore, a pre-existing wave the frequency f_3 or f_4 can be amplified.

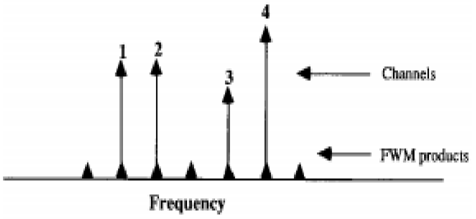

Fig.2 Effect of four wave mixing

The simplest picture of the four-wave mixing process in fibers can be illustrated by the transmission and cross-phase modulation of four equally spaced channels shown in Fig. 2 Channels 1 and 2 interfere, producing an index of refraction which oscillates at the difference frequency. This modulation in refractive index modulates channel 4, producing sidebands at channels 3 and 5. This is only the simplest combination of frequencies. Four-wave mixing allows any combination of three frequencies beating together to produce a fourth. If the fourth frequency lies within a communication band, that channel can be rendered unusable [12].

This channel interference can affect either closely spaced channels, as one encounters with coherent communications, or the rather widely separated channels of a PONs system [8]. Efficient four-wave mixing requires phase matching of the interacting waves throughout the interaction length widely separated channels will therefore be phase matched only in a region of low-fiber dispersion [18].

IV. STIMULATED RAMAN SCATTERING (SRS)

SRS is due to interaction of incident light wave with vibrational modes of silica molecule i.e., if two or more optical signals at different wavelengths are injected into a fiber, SRS causes energy from lower wavelength channels to be transferred to the higher wavelength channels [13]. This in turn reduces the signal-to-noise ratio of the lower wavelength channels and introduces crosstalk on higher wavelength channels which can lower the information carrying capacity of the system [14]-[17]. The threshold power in case of SRS can be estimated as

$$P_{th} \approx 16 A_{eff} / g_R L_{eff} \qquad (1)$$

where g_R is the Raman gain and L_{eff} the effective length of the fiber. If the fiber is sufficiently long, then $L_{eff} \cong 1/\alpha$. In that case

$$P_{th} \approx 16 A_{eff} \alpha / g_R \qquad (2)$$

The value of g_R is 1 x 10^{-13} m/W for silica at λ =1550 nm. The value of α as 0.2 dB/km and A_{eff} as 55 2 μm, results in P_{th} equal to 570 mW. Hence, the effect of SRS is insignificant in case of single channel.

In case of N equally spaced channels with frequency separation between adjacent channels Δf Hz, assuming scrambled polarization and Raman gain g_R to be linear, the power loss due to SRS by the shortest wavelength (i.e., first) channel is given by

$$D = \sum_{i=2}^{N} (m_i) \frac{P_i \gamma_i L_{eff}}{2A_{eff}} \qquad (3)$$

where m_i is the modulation of i^{th} channel, P_i the power injected in i^{th} channel in watts and γ_i the Raman gain coefficient coupling the i^{th} channel and first channel. Assuming the Raman gain profile to be triangular, γ_i is given by

$$\gamma_i = \begin{cases} \frac{(i-1)\Delta f}{1.5x10^{13}} \gamma_p & \text{for } i\Delta f < 1.5x10^{13}\, Hz \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

where γ_p is the peak Raman gain coefficient. Since m_i are independent random variables, power depletion D converges to a Gaussian random variable [19].

V. CROSS PHASE MODULATION (XPM)

XPM originates from the intensity dependence of the refractive index, which results in intensity dependent phase-shift as signal propagates through the fiber. When there is more than one optical signal propagating through the fiber as in multichannel WDM, the non-linear phase shift of a signal not only depends upon its own power but also on the power of other signals . For example, if there are four signals, the non-linear phase shift of the first signal is given by

$$\phi_1 = \gamma L_{eff} (P_1 + 2P_2 + 2P_3 + 2P_4) \qquad (5)$$

where P_i i =1 to 4 are the powers of the four signals and L_{eff} the effective length of the fiber. The first term in above equation is due to SPM while other terms are due to XPM [8] that represents the phase-modulation (PM) process. In presence of group velocity dispersion (GVD), this PM is converted into IM (intensity modulation), which degrades the quality of the signal [10]. The XPM-induced phase shift can occur only when two pulses overlap in time due to which the intensity-dependent phase shift and consequent chirping is enhanced, leading to asymmetric spectral broadening and distortion of the pulse shape. Cross-phase modulation can be relevant under different circumstances:

- It leads to an interaction of laser pulses in a medium, which allows e.g. the measurement of the optical intensity of one pulse by monitoring a phase change of the other one (without absorbing any photons of the first beam). This is basis of a scheme for quantum nondemolition (QND) measurements.
- The effect can also be used for synchronizing two mode-locked lasers using the same gain medium, in which the pulses overlap and experience cross-phase modulation.
- In optical fiber communications, cross-phase modulation in fibers can lead to problems with channel cross-talk.
- Cross-phase modulation is also sometimes mentioned as a mechanism for channel translation (wavelength conversion), but in this context the term typically refers to a kind of cross-phase modulation which is not based on the Kerr effect, but rather on changes in the refractive index via the carrier density in a semiconductor optical amplifier.

VI. SIMULATION RESULTS

In this section, simulation results are presented for the evaluation of the passive optical networks (PON). To analysis the performance of the system is presented based on these parameters as thermal and short noise, four wave mixing, cross phase modulation (XPM) and Stimulated Raman Scattering. Fig: 3 indicate the efficiency of passive optical networks varied with transmitted power, XPM-FWM and SRS-FWM. Fig: 4 shows the efficiency of passive optical networks varied with transmitted power, XPM-FWM and SRS-XPM. Fig: 5 depict the efficiency of passive optical networks varied with transmitted power, SRS-FWM and SRS-XPM.

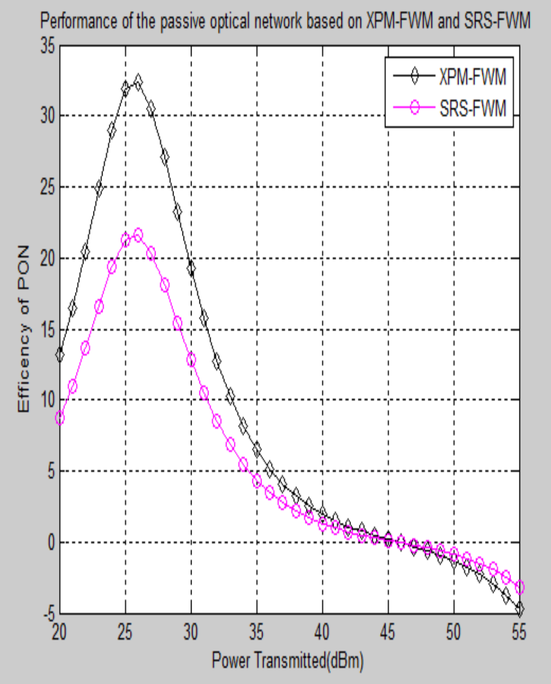

Fig: 3 Efficiency of passive optical networks varied with transmitted power, XPM-FWM and SRS-FWM

Fig: 6 shows the efficiency of passive optical networks varied with transmitted power, XPM-FWM, SRS-FWM and SRS-XPM. Fig: 7 demonstrates the efficiency of passive optical networks varied with transmitted power, XPM-FWM, SRS-FWM, SRS-XPM, four wave mixing, thermal shot noise and stimulated Raman scattering.

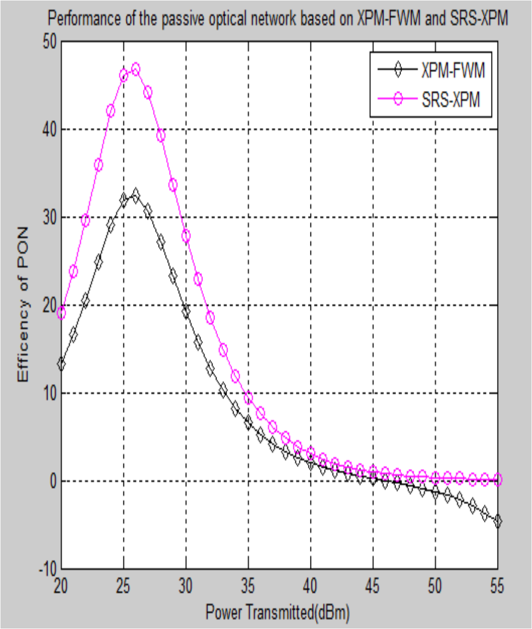

Fig: 4 Efficiency of passive optical networks varied with transmitted power, XPM-FWM and SRS-XPM

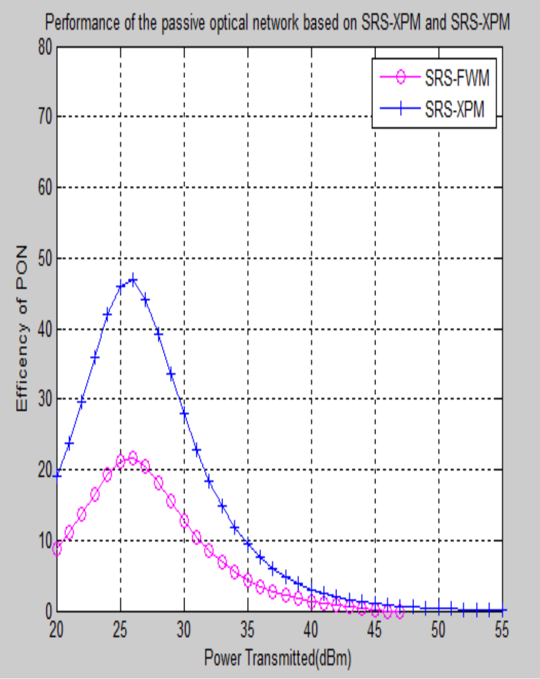

Fig: 5 Efficiency of passive optical networks varied with transmitted power, SRS-FWM and SRS-XPM

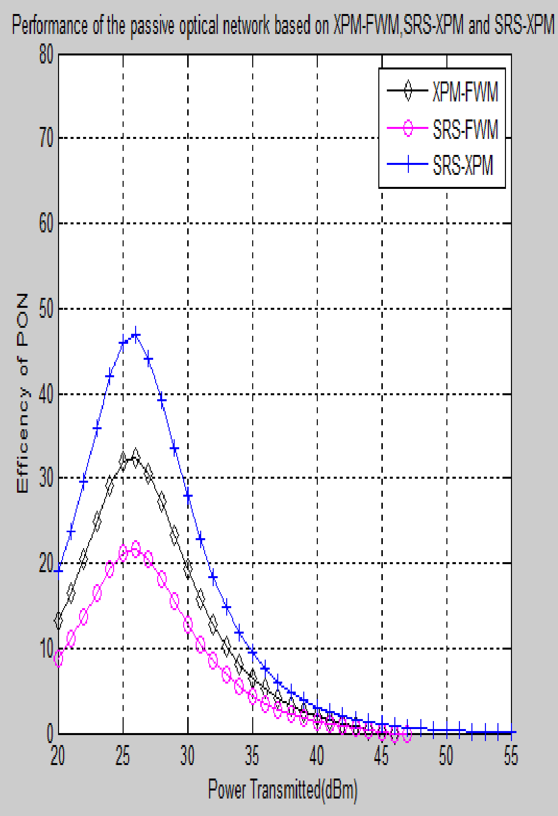

Fig: 6 Efficiency of passive optical networks varied with transmitted power, , XPM-FWM, SRS-FWM and SRS-XPM

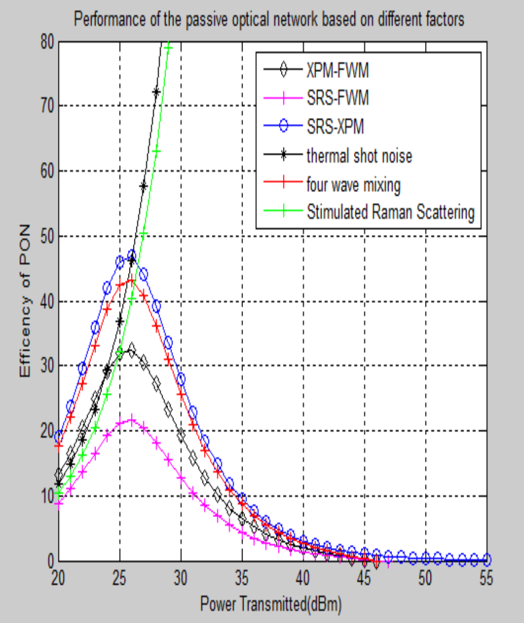

Fig: 7 Efficiency of passive optical networks varied with transmitted power,, XPM-FWM, SRS-FWM, SRS-XPM, four wave mixing, thermal shot noise and stimulated Raman scattering

VII. CONCLUSIONS

In this paper, we evaluate the performance of the passive optical network (PON) based on optical nonlinearity is presented. Here, performance measure criteria are decided by the cost and the power constraint of passive optical networks. Also the power constraint is affected by the nonlinearity that are arises due to the change in refractive index and scattering. We consider only the nonlinear effect of optical fiber such as cross phase modulation (XPM), four wave mixing (FDM), and Stimulated Raman Scattering (SRS). Here, the effect of cross phase modulation (XPM), four wave mixing (FDM), and Stimulated Raman Scattering (SRS) nonlinearity is analysed in passive optical networks. Simulation result shows the performance of the passive optical network is bound to a limited range of the transmitting power. Simulation results are presented for the combination of the nonlinearities such as SRS-FWM, SRS-XPM and XPM-FWM. Experimental results concluded that SRS-FWM, SRS-XPM and XPM-FWM can limit the performance of the optical passive network to a limited transmitting power.

REFERENCES

[1]. F. Vanholsbeeck, S. Coen, P. Emplit, M. Haelterman, and T. Sylvestre, “Raman-Induced Power Tilt in Arbitrarily Large Wavelength-Division-Multiplexed Systems,” IEEE Photon. Technol. Lett, vol. 17, no. 1, pp. 88-90, 2005.

[2]. A. R. Chraplyvy, “Limitations on Light wave Communications Imposed by Optical-fiber Nonlinearities,” J. Lightw. Technol., vol. 8, no. 10, pp. 1548-- 1557, 1990.

[3]. M. W. Maeda, W.B.Sessa, W.I.Way, A.Yi-Yan, R.Spicer, and R.I. Laming. The effect of four-wave mixing in fibers on optical frequency-division multiplexed systems. J. of Light wave Tech., 8(9):1402-1408, September 1990.

[4]. R. W. Byod, “Nonlinear Optics,” Academic Press, SanDiego, CA, 1992.

[5]. G.L. Lan, P. K. Banerjee, and S. S. Mitra, “Raman scattering in optical fibers,” J. of Raman Spectrosc., Vol. 11, 416–423, 1981.

[6]. Grobe, K. ; Roppelt, M. ; Autenrieth, A. ; Elbers, J.-P. ;Eiselt, M., “Cost and energy consumption analysis of advanced WDM-PONs”, IEEE Communications Magazine, Vol: 49 , Issue: 2 , Page: s25 - s32, 2011.

[7]. Skubic, Bjorn ; De Betou, E.I. ; Ayhan, T. ; Dahlfort, S., “Energy-efficient next-generation optical access networks”, IEEE Communications Magazine, Vol: 50 , Issue: 1 , Page: 122 – 127, 2012.

[8]. Kantarci, B. ; Mouftah, H.T., "Availability and Cost Constrained Long-Reach Passive Optical Network Planning", IEEE Transactions on Reliability, Vol: 61 , Issue: 1 , Page: 113 – 124, 2012.

[9]. Gu Rentao ; Liu Xiaoxu ; Li Hui ; Bai Lin, "planning", China Vol: 10 , Issue: 4 , Page: 59 – 69, 2013.

[10]. Kiaei, M. ; Fouli, K. ; Scheutzow, M. ; Maier, M. ;Reisslein, M. ; Assi, C., "Low-Latency Polling Schemes for Long-Reach Passive Optical Networks", IEEE Transactions on Communications, Vol: 61 , Issue: 7 , Page: 2936 – 2945, 2013.

[11]. Inoue K., K. Nakanishi, K. Oda, and H. Toba. Crosstalk and power penalty due to fiber four wave mixing in multichannel transmission. Journal of Light wave Tech.12 (8) , 1423, 1994.

[12]. Lin C., W. A. Reed, A. Pearson, and H.T.Shang. Phase-matching in a minimum chromatic dispersion region of single mode fibers for stimulated four-photon mixing. Opt. Letter. 6: 493, 1981.

[13]. Tomita A. Crosstalk caused by stimulated Raman scattering in single mode wavelength division multiplexed systems. Optics Letters. 8(7): 412, 1983.

[14]. Ikeda M., Stimulated Raman amplification characteristics in long span single-mode silica fibers. Optical Communication. 39: 148, 1982.

[15]. G. P. Agrawal., Fiber-Optic Communication Systems. John Wiley and Sons. Pp.141-180, 1997.

[16]. Agrawal, G. P., Nonlinear Fiber Optics. Academic Press, New York, 2001.

[17]. Buck, J. A., "Fundamentals of Optical Fibers", Second Edition, John Wiley & Sons. 2004.

[18]. Senior, J. M., "Optical Fiber Communications", Second Edition, Prentice Hall. 1992.

[19]. Vivek Alwayn., "Optical Network Design and Implementation", Part of the Networking Technology series Cisco Press. 2004.