Analysis and Performance Evaluation of Dwdmand Conventional WDM

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Abstract

The need of increasing the capacity of data transmitted within the fiber transmission links became a challenge for researcher. Even though optical fiber communication is the best communication system in transmitting high data rate but still users are hungry thus the researchers are pushing to get the highest bit rate. While the fiber channel may be capable of transmitting terabit-per-second data rates, no existing single communication system can make complete use of this speed. One of the main concerns in an optical network is the high cost of installation of components. The global network is made of a large submarine cable network that is expensive to modify and repair. An alternative solution to this is Wavelength Division Multiplexing (WDM) where each modulated signal is transmitted at an individual frequency, allowing full duplex data transmission. In WDM systems the available fiber bandwidth is divided into separate channels with each channel carrying one signal, thus increasing the overall data rate without increasing the number of fibers. The data rate of each channel can be limited, but with many channels the total data rate is considerably higher.WDM has not always been a popular choice. The invention of Erbium-doped fiber amplifiers (EDFA) with large bandwidth is largely responsible for popularizing this technique. In terms of multiwavelength signals, so long as the EDFA has enough pump energy available to it, it can amplify as many optical signals as can be multiplexed into its amplification band. These properties of EDFAs have enabled us to use Dense WDM (DWDM) technique, which uses denser channel spacing in order to achieve even higher bit rate. It is an interesting solution is to double the capacity of each fiber by using a duplexer. It is a system capable of duplex communication over a single fiber in contrast to two fibers required in the present scenario. The capacity can be further doubled by the application of DWDM techniques as opposed to conven

Index terms— wavelength division multiplexing, WDM, dense wavelength division multiplexing, DWDM, optical fiber.

Introduction n optical communications system is similar to other communication systems in that it consists of the three main parts: transmitter, medium and the receiver. In optical communications system the transmitter is a light source whose output acts as the carrier wave. Although frequency division multiplexing (FDM) techniques are used in longer broadcast systems, most optical communication links use time division multiplexing (TDM) techniques. The easiest way to modulate a carrier wave with a digital signal is to turn it on and off, where that is called on-off keying, or amplitude shift keying. In optical systems this is commonly achieved by varying the source drive current directly, so causing a proportional change in optical power.

The components that are used to transmit or receive the optical signal are usually semiconductors devices. For transmission the most common light source used are laser diode (LD) and light emitting diode (LED) where they have different specification according to power spectrum and fabrication. At the receiving end of the optical link a PIN photodiode or Avalanche photodiode (APD), acts as a photo detector and converts the modulated light back into an electrical signal. The photodiode current is directly proportional to optical power.

The transmitter block consists of three major parts: the modulator, the carrier source, the channel coupler. First a transducer converts a non-electrical message into an electrical signal. This signal is called the message origin. Then the modulator converts it into proper message format. For long length transmission, laser diodes are used because of the narrow spectral width and high optical power that is used as carrier source to carry data over long distance. The light is then coupled into the transmission channel via the channel coupler to the optical fiber cable, where most of the dispersion and attenuation takes place. The receiver block which is the last part of the system which converts the optical signal back into the replica of the electrical signal using photo detectors like the Avalanche photodiode (APD) or PIN-type photodiode then to the amplification stage before reaching the end user.

1 Conventional Wdm

The traditional or conventional, passive WDM systems are wide spread with 2, 4, 8, 12, and 16 channel counts being the normal deployments using the 3rd transmission window (C band, wavelengths around 1550 nm) of silica fibers. This technique usually has a distance limitation of less than 100 km. Modern WDM system can handle up to 160 signals and can thus expand a basic 10 Gb/s fiber system to a theoretical total capacity of over 1.6 Tb/s over a single fiber pair.

A WDM system uses a multiplexer at the transmitter to join the signals together and a demultiplexer at the receiver to split them apart. With the right type of fiber it is possible to have a device that does both simultaneously, and can function as an optical add-drop multiplexer. After the new generation amplifiers were developed, it enabled us to accomplish high-speed repeater less single-channel transmission. However, the 25 THz optical fiber can accommodate much more bandwidth than the traffic from a single lane. To increase the system capacity we can transmit several different independent wavelengths simultaneously down a fiber to fully utilize this enormous fiber bandwidth. Therefore, the intent was to develop a multiple-lane highway, with each lane representing data traveling on a different wavelength. Thus, a WDM system enables the fiber to carry more throughputs. By using wavelengthselective devices, independent signal routing also can be accomplished. Attempts to alleviate the vast traffic on the network included using time-division multiplexing (TDM) techniques and increasing the operating speed of the system. However, due to the chromatic dispersion of the fiber, the baud rate for a single optical channel eventually reached its limit. Furthermore, the transformation from the existing network, the 2.5 Gbps (OC-48 or STM16) transmission system, to the 10 Gbps (OC-194 or STM64) would prove costly seeing that the transmitting and receiving terminal of the network would have to be replaced.

2 III.

3 Dense Wdm (dwdm) System

Dense wavelength division multiplexing, or DWDM for short, refers originally to optical signals multiplexed within the 1550 nm band so as to leverage the capabilities (and cost) of erbium doped fiber amplifiers (EDFAs), which are effective for wavelengths between approximately 1525-1565 nm (C band), or 1570-1610 nm (L band). EDFAs were originally developed to replace SONET/SDH optical-electricaloptical (OEO) regenerators, which they have made practically obsolete. EDFAs can amplify any optical signal in their operating range, regardless of the modulated bit rate. In terms of multi-wavelength signals, so long as the EDFA has enough pump energy available to it, it can amplify as many optical signals as can be multiplexed into its amplification band (though signal densities are limited by choice of modulation format). EDFAs therefore allow a single-channel optical link to be upgraded in bit rate by replacing only equipment at the ends of the link, while retaining the existing EDFA or series of EDFAs through a long haul route. The EDFAs cost is thus leveraged across as many channels as can be multiplexed into the 1550 nm band. A basic DWDM system contains several main components: A DWDM terminal multiplexer, an intermediate optical terminal or Optical Add-drop multiplexer, A DWDM terminal demultiplexer, Optical Supervisory Channel (OSC). IV.

4 Fiber Dispersion a) Chromatic Dispersion

The interaction between an electromagnetic wave and bound electrons of a dielectric medium is in general dependent on the optical frequency, ?, of the signal. This property of optical transmission through a dielectric medium manifests itself in optical fiber primarily due to the frequency dependence of the refractive index of the core. It is referred to as chromatic dispersion. The refractive index of optical fiber is well approximated by the Sellmeier equation:n 2 (ð ??”ð ??”) = 1 + ? ?? ?? ð ??”ð ??” ?? 2 ð ??”ð ??” ?? 2 ?ð ??”ð ??” 2 ?? ?? =1

Where ? j is the resonance frequency and ß j is the Sellmeier parameter, synonymous to the strength of the J th resonance. Chromatic dispersion plays a significant role in pulse propagation in fiber optics Depends on the fiber design parameters such as the core radius and the core-cladding index difference Î?”. The contribution of D w to ß 2 is considered negligible except near the zero dispersion wavelength, where the two are comparable. The total dispersion is the mathematical addition of D w and D mat.D crom = D w + D mat

The numerical aperture (NA) of the fiber is parameter that is solely defined by the refractive indices of the core and the cladding of the fiber. The acceptance angle is defined as the largest possible angle that could ensure light coupling into the waveguide. The relation between the NA and the launch angle can be defined as: NA = n i sin? i Where, ? i is the largest acceptance angle. ? i is determined from TIR conditions at the interface between n 1 and n 2 .

V.

5 Selection Criteria of System Components

Selection of system components includes the choice of the operating wavelength, type of optical light sources, photo detectors available and the kind of fiber to be used.

Selection an optical fiber usually depends upon the type of light source used: 1. LEDs usually connect to multi-mode optical fibers in order to launch an acceptable amount of light power. 2. LDs can connect to either multi-mode or singlemode fibers. 3. Multi-mode fibers generally have a larger core diameter, and are used for short-distance communication links and for applications where high power must be transmitted.

6 a) Carrier Wavelength Choice

In short wavelength systems applications, like data bus on premises, the fiber loss and dispersion are not very critical. Hence, sources emitting in the 820 to 900 nm region are used, to limit the overall cost of the system. In long-haul systems, where the transmitting distance exceeds 30 km, a source that operates at long wavelengths is required. Typically wavelengths in region of 1300 to 1600 nm are used. More recently the 1550 nm wavelength has been often used in long-high-bit-rate system because of the small attenuation at this particular wavelength.

7 b) The LED or LD Choice

The laser is a threshold device, which is significantly influenced by ambient temperature, it is necessary to operate at driving currents only 10-30% above the threshold. Consequently, the laser driving circuits are intrinsically more expensive than those of an LED. In systems operating in the 820 to 900 nm region, the LED spectral width in combination with the wavelength dispersion of silica fiber yields a bit rate distance product of about 140 Mbits/km. This is adequate for on-premises applications.

8 c) The Detector Choice

The photo detector is typically a semiconductorbased photodiode. Several types of photodiodes include p-n photodiodes, a p-i-n photodiodes, and avalanche photodiodes. Silicon type detectors, operating between 0.8-0.9 µm, provide useful quantum efficiency and are available in both the PIN and APD (avalanche photodiode) type. The germanium detectors are also available for long wavelength systems.

9 d) Choice of Optical Amplifiers

Erbium-doped fiber amplifiers (EDFA) are the by far most important fiber amplifiers in the context of longrange optical fiber communications; they can efficiently amplify light in the 1500nm wavelength region, which coincides with the third transmission window of silicabased optical fiber, where telecom fibers have their loss minimum. The pump light, which most often has a wavelength around 980 nm and sometimes around 1450 nm, excites the erbium ions (Er3+) into the 4I13/2 state (in the case of 980-nm pumping via 4I11/2), from where they can amplify light in the 1.5-?m wavelength region via stimulated emission back to the ground-state manifold 4I15/2.

10 VI.

11 Link Design Consideration a) System Crosstalk

Crosstalk occurs in multi-channel optical transmission systems. There are two types of crosstalk noise discussed and analyzed in this work. First is the inter band crosstalk and it's a known also by "out of band" crosstalk. Second is intraband it's known by "inband". The use of the same wavelength in both directions causes these problems for Full Optical Duplex system. The effect of Crosstalk due to non-ideal circulator characteristics and the fiber Rayleigh backscattering is degrading to the transmitted data and raising the noise floor. It is known that when an optical signal enters a fiber strand of virtually infinite length it will experience back scattering effect due to the glass material itself and the light guiding properties of the fiber. Crosstalk can be caused by the following: 1) the spectral skirts of one channel entering the demultiplexing and filtering pass-band of another cause 2) Practical limits on selectivity and isolation cause crosstalk. 3) Non-linear effects within the fiber at the high power densities possible in single mode systems can cause crosstalk or cross modulation. The mechanism is Raman scattering, which is a non-linear stimulated scattering effect that allows the optical power at one wavelength to affect scattering and thus the optical power in another wavelength.

12 b) System Power Penalty

In optical communication the receiver sensitivity is defined with respect to the receiver noise for several basic detection scenarios. The highest sensitivity means the lowest value of the received optical power that is needed. The sensitivity of the photo detector of real receiver is degraded due to the impact of two principal noise contributions, the thermal noise (in PIN photodiodes) and quantum shot noise (in APD).

13 VII. Simulations and performance

Comparisons between Wdm and Dwdma) Mathematical Model

This topic is mainly concerned with the caused by the optical crosstalk, the penalty can be regarded as the reduction of optical power level differences between the ”one” and the ”zero” states and this is represented in the following equation: In general terms, the spectral emission from a conventional LD conforms reasonably well to a Gaussian distribution, which then provides a simple analytical expression for use in any model. According to Gaussian distribution in the mathematical model, the mean and variance for a random variable will be:? ? ? ? ? ? = ? = = 2 / 0) (|) (1) (|) (2 0 0 1 1 A t d t P t d t P s s x ? Where 1) (|) (1] [= x E ? ? = N i i x ? ?] var[

With Gaussian distribution, considered the following:9 1 10 6 1 ? = = ? N i i x prop ? ?

Here the use of 10 -9 as a figure of merit for establishing the confidence for the penalty analysis. But this is not necessarily a confidence requirement for actual system design, as this figure does not really have to coincide with the commonly used BER figure of merit at 10 -9 . However, with this level of confidence for calculating crosstalk penalty:P x = ? 10 log ?1 ? 6?? ?? ?? ?? ??=1 ? (I)

Where (P X) represents the power penalty of the receiver optical signal,(N) is the number of crosstalk elements and (? i) is the crosstalk coupling coefficient. Equation (I) represents the power penalty to the received optical signal in the case where the optical receiver noise is dominated by thermal noise. But for more accurate estimate if the detection is signal spontaneous beat noise dominated the equation will be:P x = ? 5 log ?1 ? 6?? ?? ?? ?? ??=1 ? (II)

The above two equations have been used for analyzing the simulation results as models for power penalty of the optical fiber duplexer.

From the equations notes that the relationship between the power penalty and the crosstalk must be directly proportional to each other, and obviously that relationship between the signal power received and the power penalty is inversely proportional. The curve one in the figure 7.1 above represents the power penalty when the optical received signal is dominated by thermal noise (I). The curve two represents the optical received signal spontaneous beat noise dominated (II) and it is more accurate than the previous one. From the curves, it is observed that the crosstalk that dominated by the thermal noise always The topology setup consists of 8 channels launched into a single fiber span. Channel spacing is 50 GHz and they are generated in groups of odd and even channels by two PRBS generators, Electrical Signal Generators, and CW laser sources (each with four 100 GHz-spaced wavelengths). Initially all channels have the same polarization state. All even channels before being multiplexed with odd channels are passed through the Polarization Shifter, which rotates the polarization state by a fixed angle. After multiplexing, the signal is launched into a fiber, and then is demultiplexed and sent to 8 receivers followed by BER Testers to measure channel performance (BER and Q-factor) for given polarization state difference between adjacent channels. Two conditions are considered in this example. Both of them have the same settings and the only difference is in polarization angle treatment in parameter scan setting.

14 a. WDM orthogonal polarization

Here the polarization angle is scanned from 0 to 180 degrees with 10 degrees step and Q-factor is measured versus polarization angle. Fig. 7.2 shows results for one odd (ch.3) and one even channel (ch.6). In both cases the Q-factor is minimal for polarization angles equal to 0 or 180 degrees, i.e. when all channels have parallel polarization states; and Q has maximum at 90 degrees, i.e. when adjacent channels polarization state is orthogonal to each other. Difference between max and min Q's is 0.4-0.6 dB for these cases. ii.

15 Simulation for DWDM

This simulation simulates a realistic scenario of a 40 Gbps DWDM link with inter-channel spacing of 50 GHz. Forty individual channels carrying PRBS data are transmitted over a 50 km length of ITU-T G.652 single mode dispersive fiber. The design objective is to utilize distributed Raman amplification to compensate for the link attenuation thereby effectively increasing the inter-EDFA span in a longer haul link.

Since backward pumping helps in averaging out power ripples at the receiver end, we choose a backward pumping scheme that employs eight CW pump signals with carefully chosen nominal wavelengths and power values. The following figures show various parameters of a 40-channel DWDM link. In the figure 7.4 above it is seen that the gain of the link is zero or very low in most of the parts but around wavelengths of 1550 nm the gain is much higher. This is because; the DWDM operates close to this region. As mentioned earlier, the DWDM method uses the C band and L band with a wavelength span from 1530 nm to 1625 nm. That is why the DWDM link has gain near the 1550 nm wavelength mark. Due to lack of ideal amplifier and filters, the gain varies somewhat and it does not change instantaneously or abruptly like a step signal. The signal to noise ratio (SNR) of the system is depicted in figure 7.5. As the wavelength region outside about 1500 to 1600 nm range is not under concern, it is not included in the graph For similar reasons to the SNR plot, the region outside the 1500 to 1600 nm range has not been included in the plot.

The following figures 7.7 and figure 7.8 shows the input channel wavelength spectrum and the output channel wavelength spectrum respectively. The slight distortion in the output signal due to uneven gain in the region of operation is visible here. 7.9 shows the signal power and forward and backward noise power of the system over the length of the fiber. It is seen that as the signal travels in the forward direction, the signal accumulates further noise and the forward noise power increases. The reflected or backward noise power is similarly high at the beginning of the fiber for obvious reasons. As the length of the fiber is increased further, the forward noise undergoes a sharp increase near the 40 to 50km distance. The system discussed here could not be used to send signal any farther, the noise would be too high and the reconstruction of the signal would not be possible. Cost effective way of increasing system capacity without introducing more fibers to the system. iv.

With selective wavelength spacing, four-wave mixing is possible. v.

Higher number of wavelengths (up to 8) supported. vi.

Higher distance capability with Erbium Doped Fiber Amplifier (EDFA). Maximum link distance of ~30 km. vii.

Repeater or amplification sites are reduced, resulting in a large savings of funding. viii.

Maximum number of channels is up to ~40 as of today (theoretically hundreds of channels are possible). ix.

For long haul applications, optical amplification is well proven. x.

Very useful as upgrades to already installed systems. xi.

Multiple channels of information carried over the same fiber, each using an individual wavelength. xii.

Improved noise figure for same given specifications. xiii.

Signal distortion is less than conventional WDM systems. xiv.

Secondary market systems are available which can significantly reduce costs.

e) Disadvantages of DWDM over WDM i.

Requires more space than conventional WDM ii.

Higher power consumption (typically 3 times than WDM systems for every transmitter card) iii.

High dependence on the dispersion of the deployed fiber iv.

Optical multiplexers and demultiplexers require custom wavelengths, challenging vendor specifications. v.

Allowed wavelength variation due to temperature change of laser diodes is much lower than WDM vi.

Installation costs are higher than WDM systems.

VIII.

16 Conclusion

In early WDM systems, there were two IR channels per fiber. At the destination, the IR channels were demultiplexed by a dichroic (two-wavelength) Filter with a Cutoff Wavelength approximately midway between the wavelengths of the two channels. It soon became clear that more than two multiplexed IR channels could be demultiplexed using cascaded dichroic filters, giving rise to coarse wavelength-division multiplexing (CWDM) and dense wavelength-division multiplexing (DWDM). In CWDM, there are usually eight different IR channels, but there can be up to 18, whereas in DWDM, there can be dozens. Because each IR channel carries its own set of multiplexed RF signals, it is theoretically possible to transmit combined data on a single fiber at a total effective speed of several hundred Gb/s. The use of WDM can multiply the effective Bandwidth of a fiber optic communications system by a large factor. But its cost must be weighed against the alternative of using multiple fibers bundled into a cable. Multichannel WDM exists in two flavors, one is called Dense WDM (DWDM) and the other is called Coarse or Conventional WDM (CWDM) or simply, WDM. When it comes to transporting lots of data, say, digital video over a single fiber, DWDM as a technology is unrivalled. If on the other hand, a short fiber span requires a few more channels, CWDM with its lower cost per channel can be a good alternative to laying new fiber cable. DWDM uses temperature-stabilized lasers in order to fix the center wavelength and narrow band filters, giving many densely spaced channels. Typical channel spacing is 100GHz, corresponding to a channel spacing of approximately 0.8nm. CWDM on the other hand uses non-stabilized lasers in combination with broadband filters, which then gives a coarse channel spacing of 20nm between channels. CWDM transmitter cards have lower power consumption than DWDM transmitter cards, since there is no need for temperature control of the laser diodes. If the future bandwidth need may exceed 8 channels per fiber, DWDM will be a better solution with several tens of available channels in the range from 1530-1610nm. The uniformity of the fiber attenuation over the DWDM wavelengths is better than the CWDM, so for medium and long haul applications DWDM will be the best solution even for low channel counts. Current DWDM research is going on increasing the capacity and distance of future DWDM products. Wide spectrum DWDM is on the future horizon and will offer more channels. The electronics and chip industry is constantly increasing quality yield which will drive cost lower and

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Figure 1: Figure 3 . 1 :

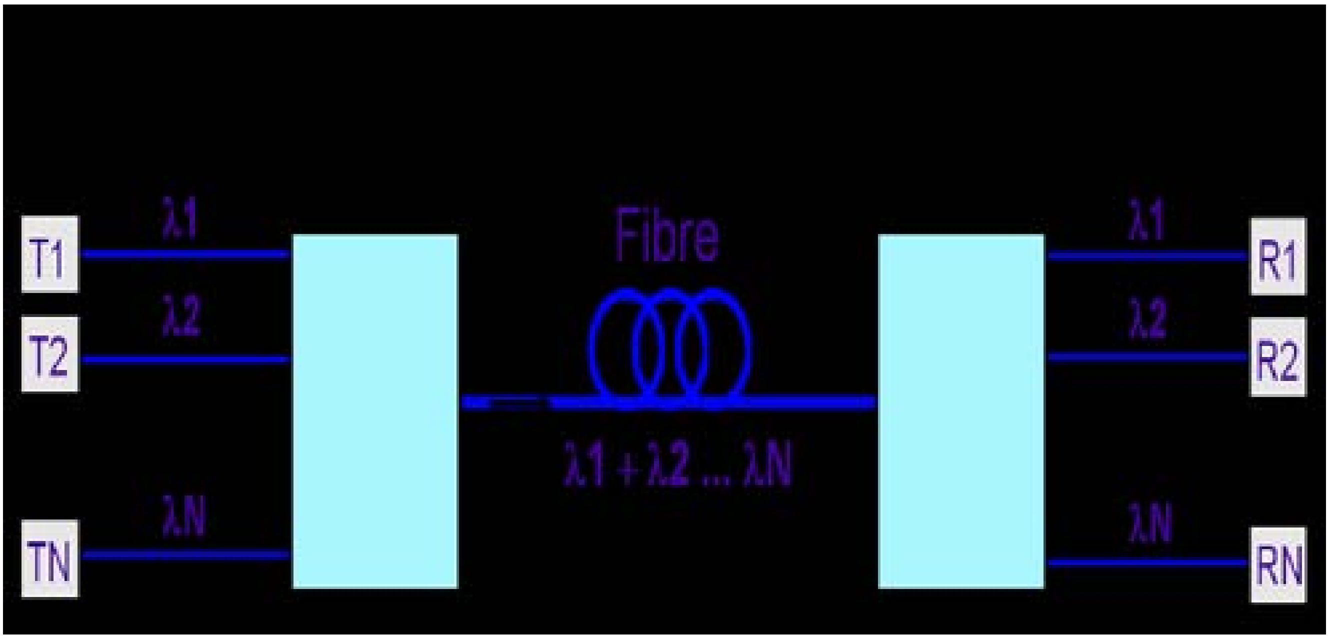

Figure 2:

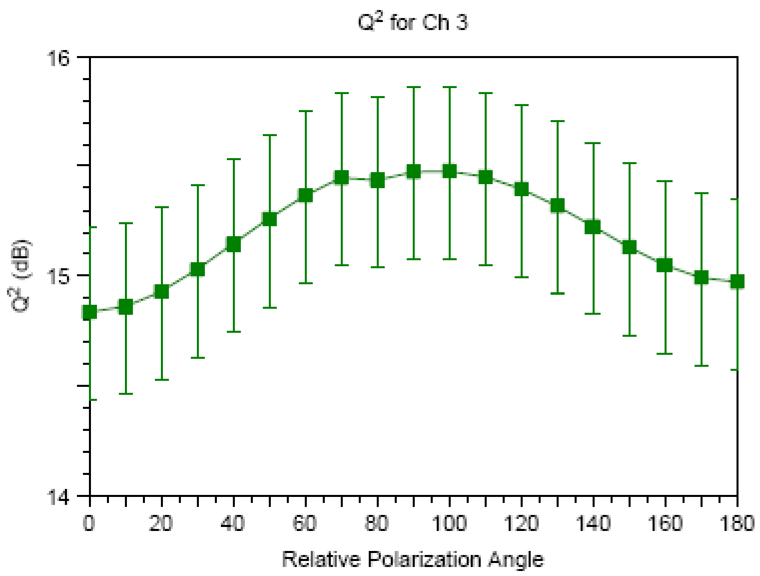

Figure 3: -

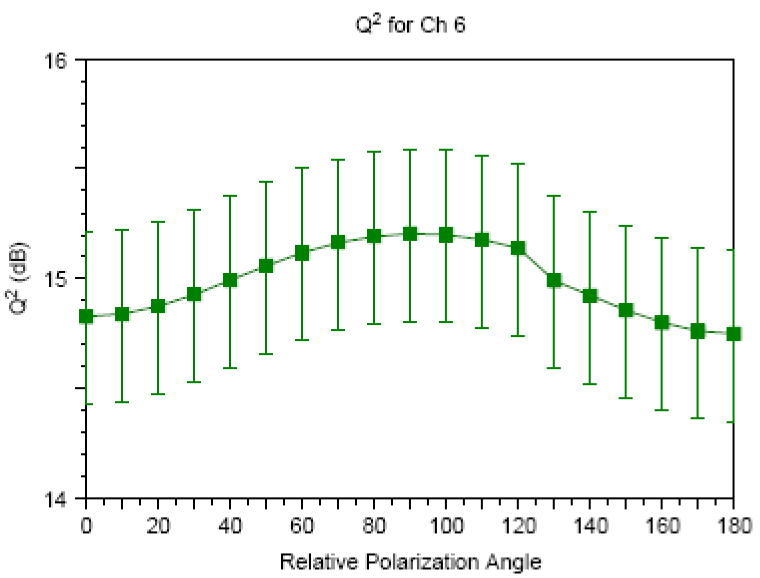

Figure 4:

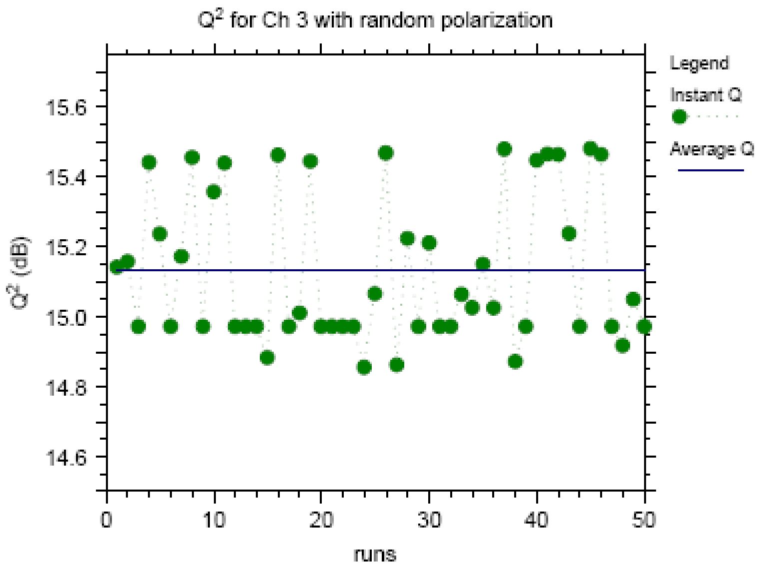

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Figure 5: Figure 7 . 1 :

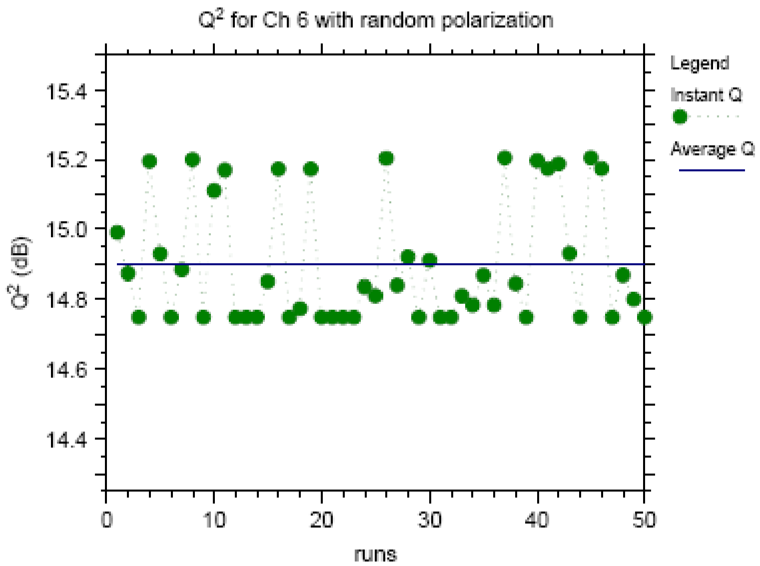

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Figure 6: Figure 7 .

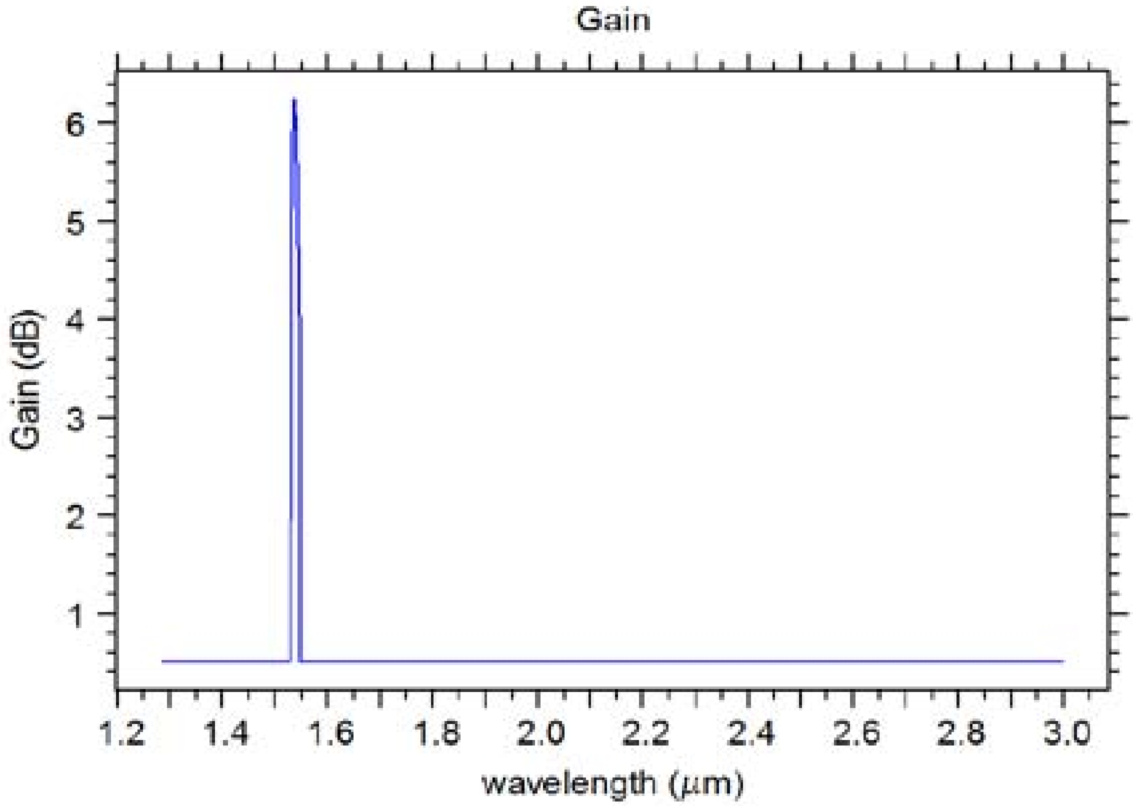

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Figure 7: Figure 7 .)Figure 7

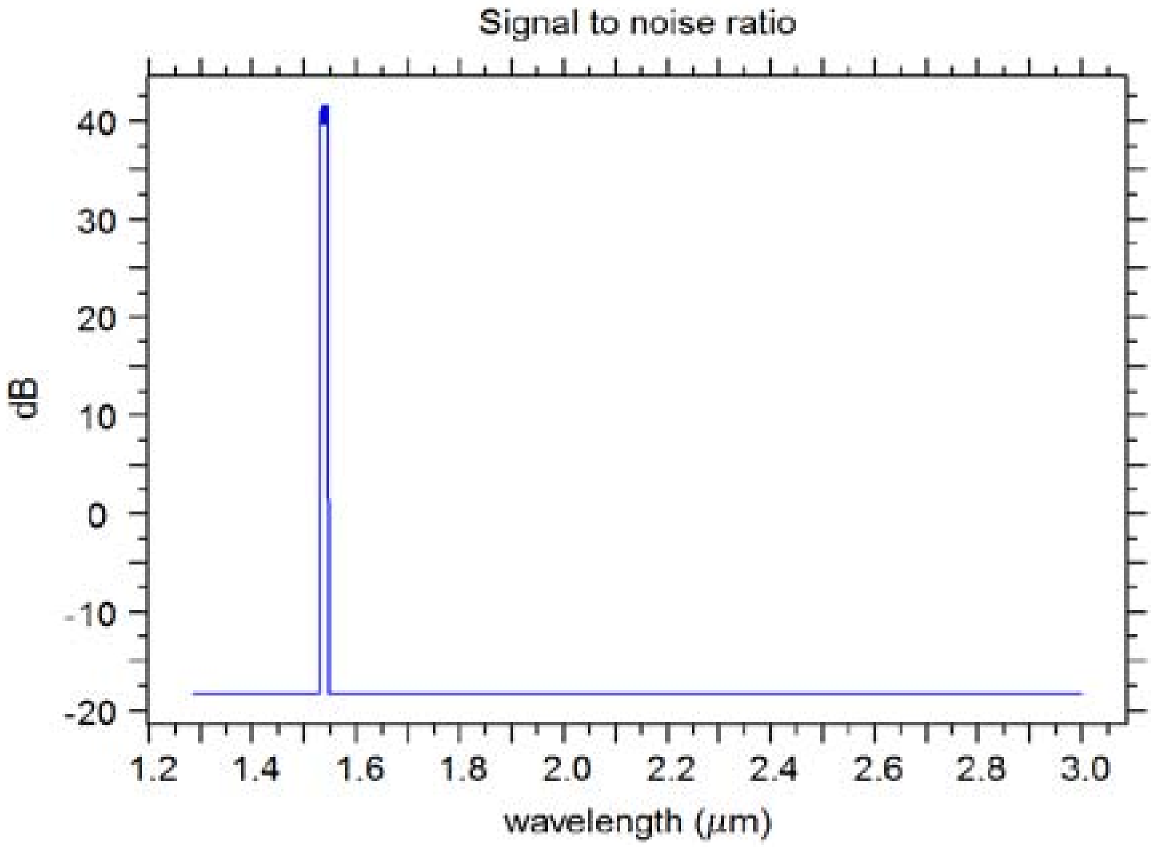

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Figure 8: Figure 7 . 4 :Figure 7 . 5 :Figure 7 . 6 :

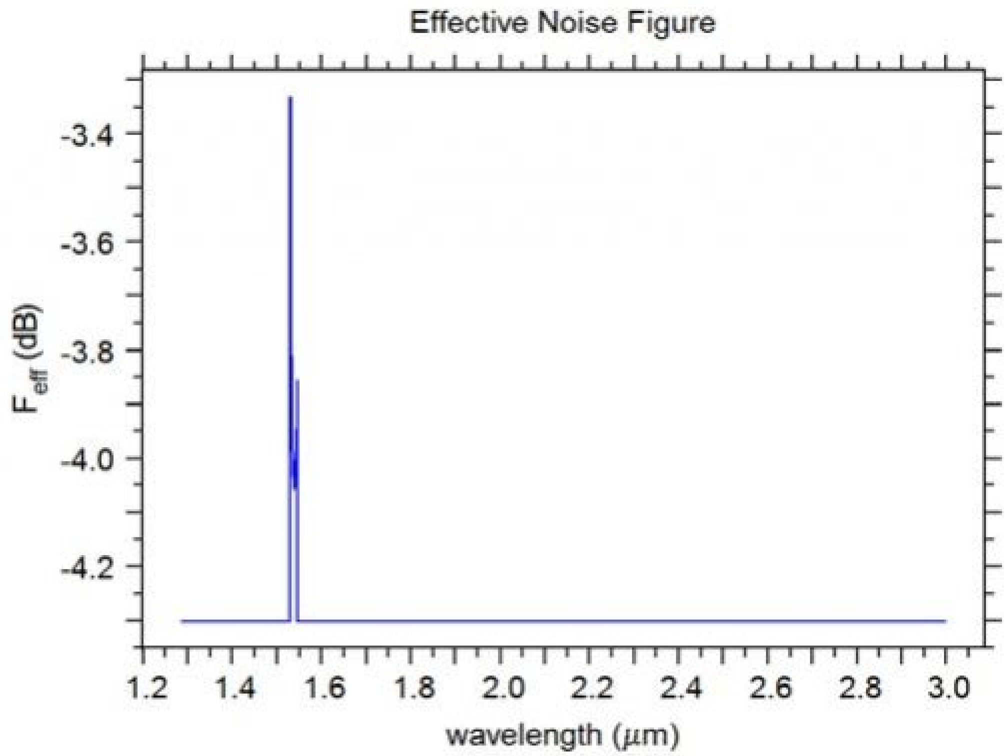

Figure 9:

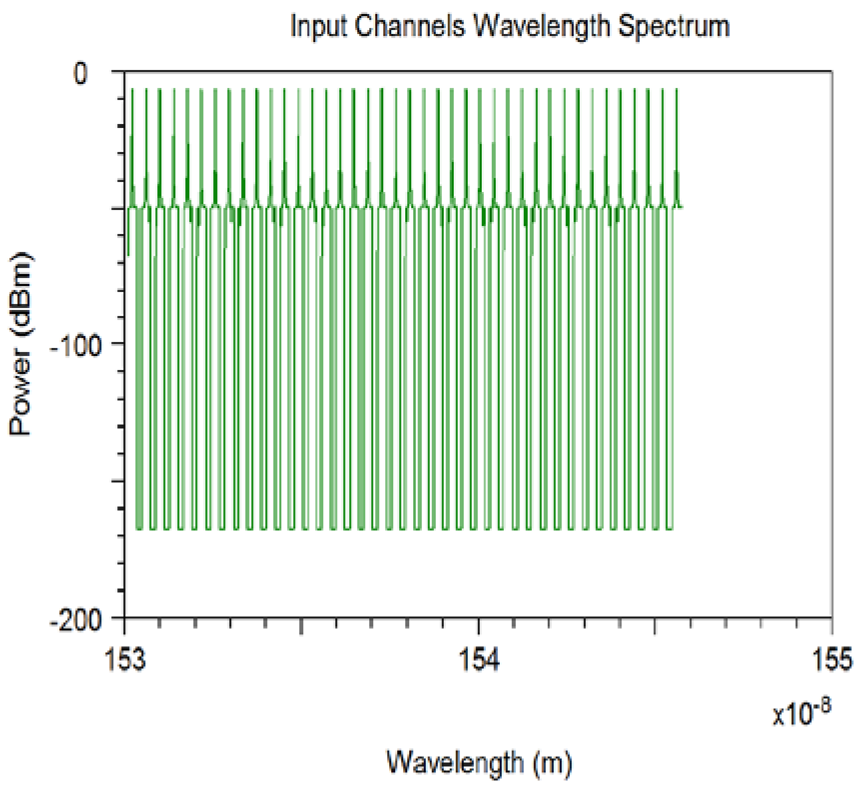

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Figure 10: Figure 7 . 7 :Figure 7 . 8 :

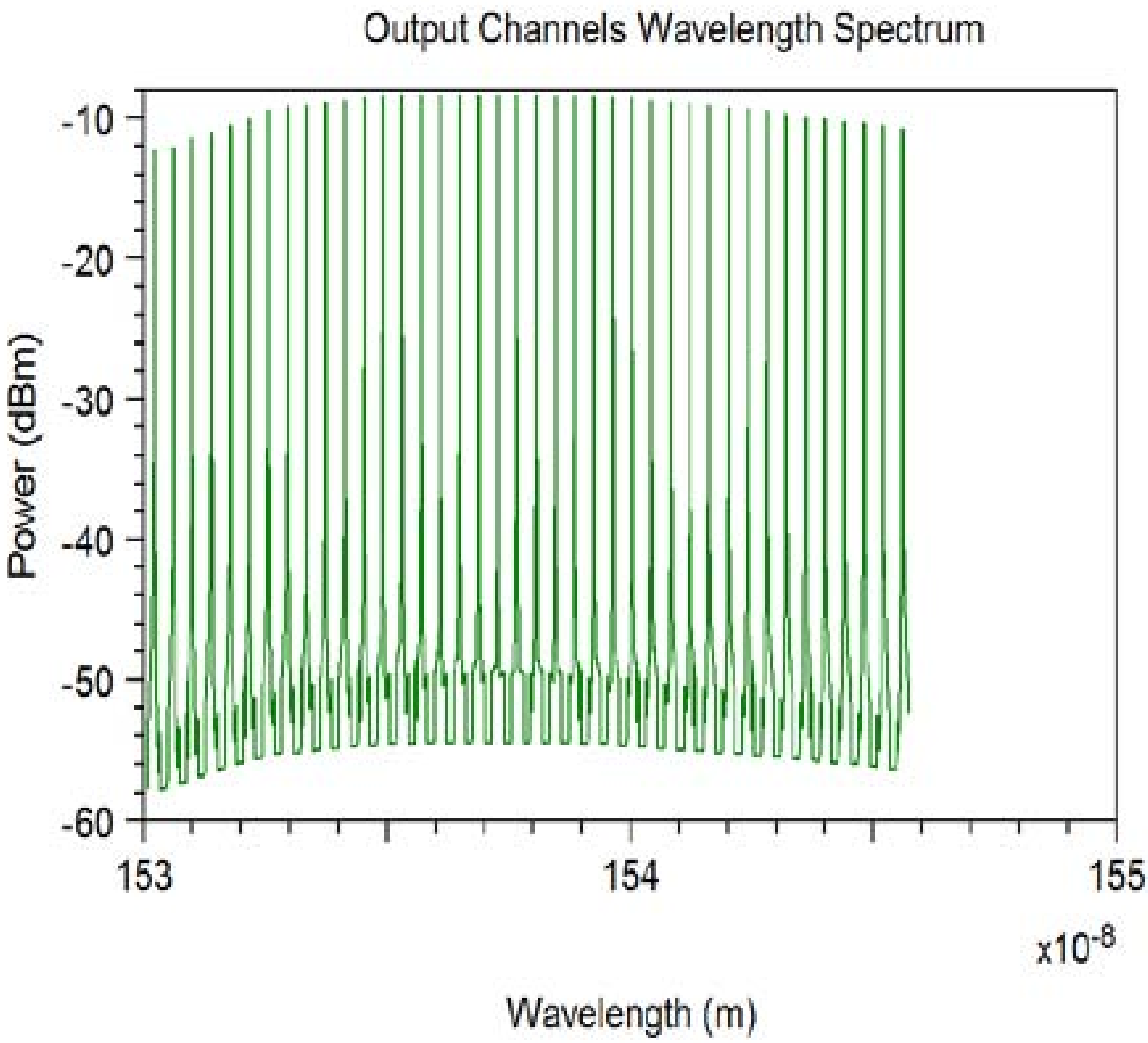

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Figure 11: Figure 7 . 9 :

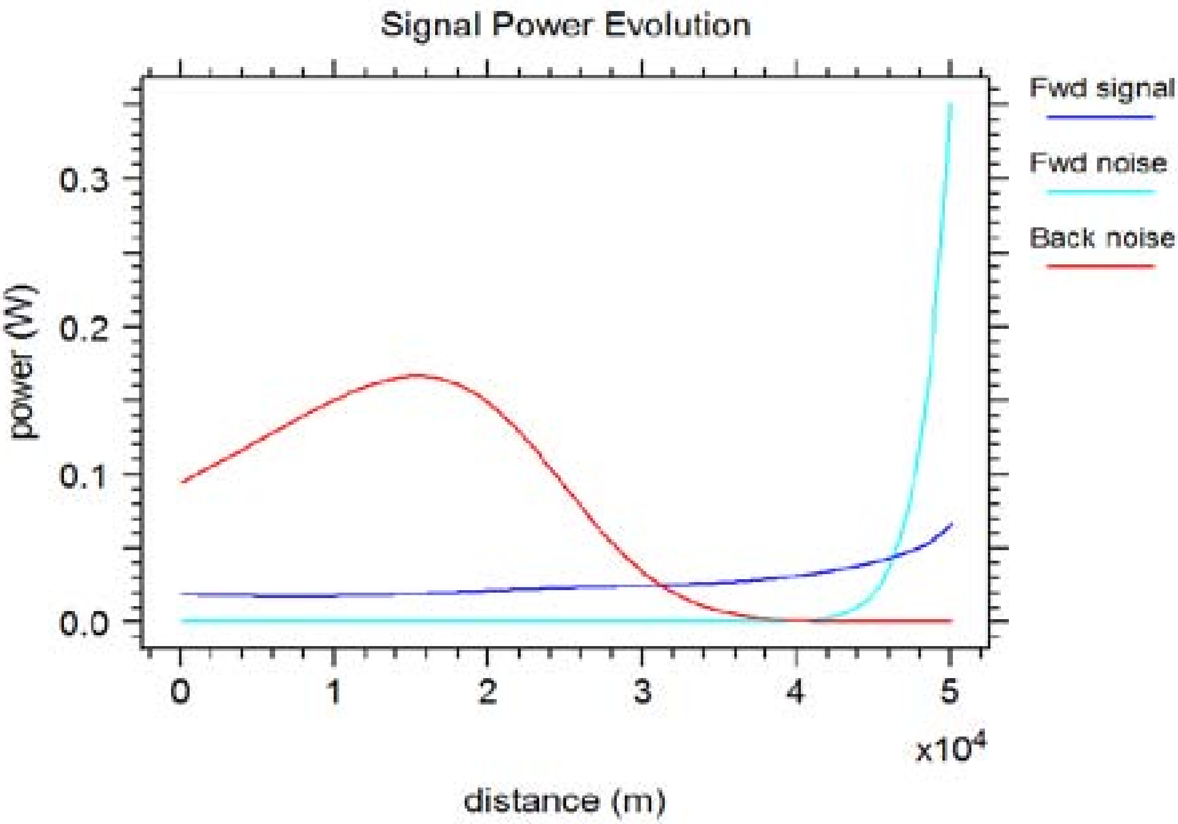

Figure 12:

increase capability. Combination systems of CWDM and DWDM are being produced now. Fiber to the Premises (FTTP) technology intends to expand capacity with a "wavelength per home". [1] [2] [3] [4] [5]

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[3]Analysis and Performance Evaluation of Dwdmand Conventional WDM
[4]Analysis and Performance Evaluation of Dwdmand Conventional WDM

[Delavaux et al. (1995)] ‘10 Gb/s 150 km. a. Bidirectional Repeater less Optical Fiber Transmission’. J.-M P Delavaux , O Mizuhara , P D Yeates . *IEEE Photonics b. Technol. Lett* September 1995. 7 (9) p. .

[Laude (2002)] ‘Artech House’. Jean-Pierre Laude . *DWDM Fundamentals, Components, and Applications*, January, 2002.

[Basics of Wavelength Division Multiplexing (WDM) Dense WDM Grameenphone Limited] ‘Basics of Wavelength Division Multiplexing (WDM) & Dense WDM’. *Grameenphone Limited*,

[Suzuki et al. ()] ‘Bidirectional 10-channel 2.5Gbit/s WDM transmission over 250 km using 76nm (1531-1607nm) gain-band bidirectional erbium-doped fiber amplifiers’. K I Suzuki , H Masuda , S Kawai , K Nakagawa . *Electronic Letters. vol33*, 1997. 1997. p. . (no 23.)

[Ings and Morthier (1999)] ‘Crosstalk Analysis of Multiwavelength Optical Cross Connects’. G Ings , Morthier . *IEEE journal of Light wave Technol* June, 1999. 14 p. .

[Basak and Chowdhury] *Design and Simulation of DWDM in Fiber Optic Communication and Performance Comparison with Conventional WDM System*, A Basak , S A Chowdhury . Rajshahi, Bangladesh. Rajshahi University of Engineering& Technology (RUET)

[Antony (2002)] *DWDM Network Designs and Engineering Solutions*, Ashwingumaste , Tony Antony . December, 2002. Cisco Press.

[Kim and Gnauck (2003)] ‘Experimental Investigation of the Performance Limitation of DPSK Systems Due to Nonlinear Phase Noise’. Hoon Kim , Alan H Gnauck . *IEEE Photonics Technology Letter* February 2003. 15 (2) p. .

[For ITU-T activities and some of the PON standards] `http://www.itu.int/ITU-T` *For ITU-T activities and some of the PON standards*,

[GP ()] *Non-linear fibre optics*, GP . 1995. New York.: Academic Press. (2nd edition)

[Senior ()] *Optical Fiber Communications Principle and Prentice*, J Senior . 1985. Prentice Hall. (2nd ed. Cambridge)

[Ramaswami and Sivarajan ()] *Optical Networks*, R Ramaswami , K N Sivarajan . 1998. San Francisco, CA: Morgan Kaufmann Publishers.

[Cvijetic ()] *Optical Transmission Systems Engineering” Artech House*, Milorad Cvijetic . 2004.

[Wilson and Hawkes ()] *Optoelectronics*, J Wilson , J F B Hawkes . 2001. Prentice-Hall International (UK) Ltd.

[Petruzzellis (1997)] ‘Optoelectronics, Fiber Optics, and Laser Cookbook’. Thomas Petruzzellis . *McGraw-Hill* May, 1997.

[Headley ()] *Raman Amplification in Fiber Optical Communication Systems*, Clifford Headley , GovindP . 2005. San Diego, CA: Elsevier Academic Press.

[Tai ()] ‘Wavelength-Interleaving Bidirectional Circulators’. K Tai . *IEEE Photonics Technol. Lett* 2001. 13 (4) p. .