Investigation of Various Optical Amplifiers in Optical Communication System

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Abstract- **Optical wavelength converters are the key components provide wavelength conversion in optical domain without distortion of input signal. For wavelength conversions semiconductor optical amplifiers can be used in cross gain modulation mode, cross phase modulation and four wave mixing mode. Extinction ratio degradation for conversion to longer wavelengths can be overcome using cross phase modulation in semiconductor optical amplifiers with MZI configuration. With increase in average receiver power BER value decreases and Q factor increases. Raman amplifier utilizes Stimulated Raman Scattering to create optical gain. Raman amplification can be achieved in every region of transmission window of the optical transmission fiber and thus push a fiber's capacity beyond C-band, offers more stability and insensitivity to reflections. Use of Raman Amplifier with multi pump reduces the bit error rate and increases Q factor in a better way.Erbium Doped Fiber Amplifiers (EDFAs) amplifies optical signals in an optical fiber directly in high bit rates. Erbium-doped fiber is usually pumped by semiconductor lasers at 980 nm or 1480 nm.On analysis,compared to 1480 nm laser, higher gain and lower noise values are possible to achieve by 980nm. Along with the stimulated emission that creates gain, the gain medium also produces spontaneous emission, which gives rise to the amplified spontaneous emission (ASE) spectrum of the amplifier. The ASE power increases with increase in pump power and EDFA length, increasing the doping radius reduces ASE power. The ASE spectrum peak is shift to longer wavelengths with increased number of fiber spans. Simulations have been done using Optsim 5.3 software and Optisystem ver.12 for Raman Amplifier.**

***IndexTerms*—Amplified Spontaneous Emission (ASE),Cross Gain Modulation (XGM), Cross Phase Modulation (XPM), Erbium Ytterbium Co-Doped Fiber Amplifier (EYCDFA), Four Wave Mixing (FWM), Mach-Zehnder Interferometer (MZI), signal-to-noise ratio (SNR), Stimulated Raman scattering (SRS)**

I.INTRODUCTION

Optical fiber is the only transmission medium offering such large bandwidth with low loss communication links. With growing transmission rates, electronic regeneration becomes more and more expensive. Optical amplifiers are in general bit rate transparent and can amplify signals at different wavelength simultaneously [14].

Optical wavelength converters provide wavelength conversion in optical domain without distortion of input signal. WCs increase the flexibility and capacity of networks for a fixed set of wavelength. All optical wavelength converters are expected to become key components in the future broadband networks. Electro-optic converter, Cross Gain Modulation (XGM), Cross Phase Modulation (XPM), and Four Wave Mixing (FWM) are the techniques for wavelength conversion [1][12].

The electro-optic converter is a straight forward solution for conversion, but electro-optic converter has limitations such as large power consumption and complexity.Cross gain modulation (XGM) wavelength conversion is based on the SOA gain nonlinearity. XGM based wavelength conversion is very simple to implement, as it requires only a single SOA device. The process of wavelength conversion is polarization independent, depending on the design of the SOA gain medium.XGM of SOA with high conversion efficiency but requires a large input optical power to saturate the gain of the SOA and shows extinction ratio degradation for conversion to longer wavelengths and this can be overcome using cross phase modulation in SOA. The XPM scheme relies on the dependency of the refractive index of the carrier density in the active region of the SOA. An incoming signal that depletes the carrier density will modulate the refractive index and thereby result in phase modulation of a CW signal[7-9].

This work proposes an interferometric mode for wavelength converters based on XPM.The phase modulated CW signal can be demultiplexed after the converter or even better the SOA can be integrated into an interferometer so that intensity modulated signal format results at the output of the converter.In a Mach-Zehnder interferometer, the CW signal is split between the two branches of the interferometer. The bias of the SOAs in the branches determines the gain of the signal, as well as relative phase of the signal at the output of the two branches. For non-inverting mode of operation, the output of the interferometer is turned off by adjusting the bias of the SOA in one branch of the interferometer in order to achieve π relative phase shift between the two branches. The output of the MZI can be modulated by the data signal, which compresses the gain of the SOA in the common branch and swings the phase difference ideally between 0 and π.The MZ1 wavelength converter show good performance for both up and down converted signals [4][13].

Fiber based Raman amplifier uses stimulated Raman scattering (SRS) occurring in silica fibers when an intense pump beam propagates through it. In SRS, incident pump photon gives up its energy to create another photon & remaining energy is absorbed by the medium in the form of molecular vibrations (optical phonon).The principal advantage of Raman amplification is its ability to provide distributed amplification within the transmission fiber, thereby increasing the length of spans between amplifier and regeneration sites. The amplification bandwidth of Raman amplifiers is defined by the pump wavelengths utilized and so amplification can be provided over wider, and different, regions than may be possible with other amplifier types which rely on dopants and device design to define the amplification window[5].The main features of the Raman amplification were that it realized as continuous amplification along the fiber, bidirectional in nature and offers more stability, insensitivity to reflections. The main disadvantage of this amplifiers that pump power requirement is relatively high in comparison with SOAs and EDFAs [2].

The capacity of fiber optical communication systems has undergone enormous growth during the last few years in response to huge capacity demand for data transmission. Because of signal absorption when transmitting optical signal at long distances it is necessary to use an optical amplifier. Choosing a signal amplification method for wavelength division multiplexing (WDM) systems, preference is given to one of amplifier class - Erbium-Doped Fiber Amplifier (EDFA). EDFAs consist of erbium-doped fiber having a silica glass host core doped with active Er ions as the gain medium .Erbium-doped fibre is usually pumped by semiconductor lasers at 980 nm or 1480 nm. Signal propagates along short span of a special fibre and is being amplified at that time.EDFA amplifiers insert small noises; they are almost insensitive to the polarization of Signal and can be relatively simply realized.Commercially available in C-band & L-band, insensitivity to light polarization state, high gain low noise figure: 4.5 dB to 6dB,no distortion at high bit rates, simultaneous amplification of wavelength division multiplexed signals, immunity to cross talk among wavelength multiplexed channels [15].

Incoming signal photons will trigger the excited ions to drop to the ground state and emit a new photon of the same energy, wave vector and polarization as the incoming signal photon. This process is called stimulated emission. Sometimes the excited ions can fall back to the ground state without any trigger, resulting in photons being re- leased that do not amplify the signal. These photons are then amplified by the remaining erbium doped fibre. This spontaneous emission is referred to as Amplified Spontaneous Emission (ASE) noise and is un-desirable [16].

This spontaneous emission reduces the amplifier gain by consuming the photons that would otherwise be used for stimulated emission of the input signal. This ASE noise limits the optical signal-to-noise ratio (SNR) of a cascade of amplifiers and is quantified in the amplifier's noise figure (NF)[17-18].

II. SYSTEM ARCHITECTURE

A. XPM Wavelength Conversion

The intensity modulated data signal, produces variation in carrier density within the SOA. The carrier density variation gives rise to a change in the refractive index which is proportional to amplitude of the input signal and inversely proportional to carrier density variation. These refractive index variations produce a phase modulation when a continuous wave probe signal is coupled to SOA.A great advantage of this approach is that the output from thewavelength converter is not inverted.Similar to XGM wavelength converters, in most XPM configuration, thewavelength conversion can be performed in both co and counter-propagatingmodes of operation.For high speeds of operation, co-propagating is the methodof choice.Counter-propagating one requires no optical filteringat the output, but its speed is limited by the transit effects [11].

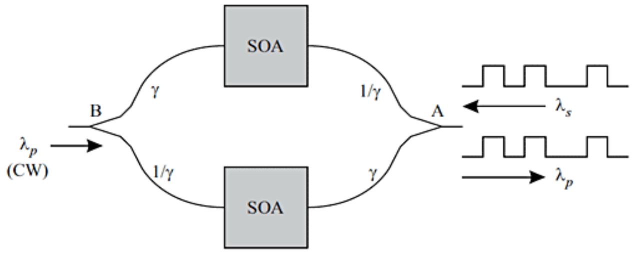

Figure 1 : XPM Basic Diagram

B. SOA-MZI Based XPM

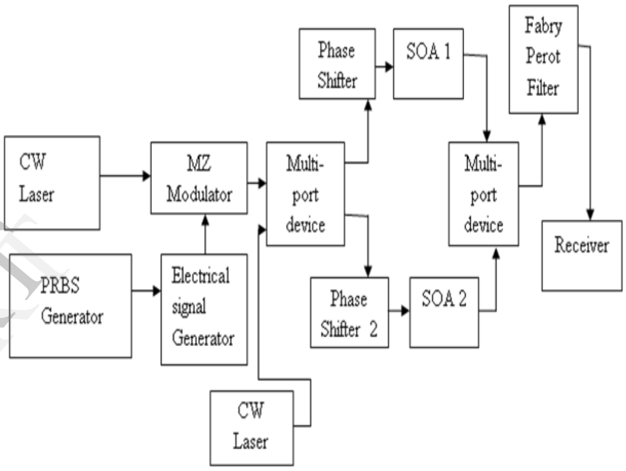

Figure 2: SOA-MZI Based XPM Basic Block Diagram

As the carrier density in the amplifier varies with the input signal, it produces a change in refractive index, which in turn modulates the phase of the probe.When the light from the upper and lower arm of the SOA-MZI interfere in the output coupler, their phase difference causes the output light to re-direct from one port to the other, this phase difference can be adjusted by the phase shifter in either arm of the SOA-MZI. This phase modulation can be converted into intensity modulation by using an interferometer such as a Mach-Zehnder interferometer (MZI) [4]. The upper semiconductor optical amplifier is represented by SOA1 and lower is represented by SOA2. Transmitter section consists of PRBS generator, NRZ Pulse Generator, CW laser, electrical signal generator, modulator. Signal is generated with the help of PRBS generator and then it changes into the electrical signal with the help of electrical signal generator. The output from the electrical generator can be seen with the help of electrical signal analyzer. The output of the electrical signal generator is applied to the modulator. Here used Mach-Zehnder type modulator. The output waveform of modulator can be seen with the help of modulator signal analyzer.

PRBS generators provide the generation of high fidelity pseudo-random binary sequence data signals for testing high speed communications components. The NRZ

Generator pulse generators source creates a sequence of non-return to zero pulses coded by an input digital signal. CW Laser produces the optical signal output of one or more CW lasers. It is most commonly used in conjunction with the external modulator model to encode a binary signal upon the CW source. A phase modulating EOM (Electro-optic modulator) can also be used as an amplitude modulator by using a Mach-Zehnder interferometer. The modulated signal will have the same polarity as the original binary sequence. This is important for increased numerical accuracy in simulation.Nonlinear fiber provides a detailed implementation of propagation of one or more optical channels in a single mode fiber. It takes into account attenuation, dispersion, polarization mode dispersion (PMD) and nonlinearities including Raman effects.

The two multi-port devices are used to set up the MZI configuration, one SOA in each arm of the MZI configuration. The upper semiconductor optical amplifier is represented by SOA1and lower is represented by SOA2. MZI can also transfer matrix data file for the multi-port device model. Actually the multi-port devices here can be easily replaced by optical couplers. The first multi-port device functions as a coupler, its transfer matrix data file name is multiport coupler. The second multi-port device functions as a summer, its transfer matrix data file name is multiport summer. Can find different coupling ratios in the two arms used, which will make the phase change in each amplifier different. Unlike in the cross-gain modulation wavelength conversion, in the cross-phase modulation wavelength conversion the added signal is in-phase with the original signal. In the two arms of the MZI, two optical phase shifters are used to monitor the influence of the phases on the performance of the system [10].

The output of the SOA-MZI is applied to the Fabry-Perot filter. Output spectra waveform of filter with the help of filter spectrum analyzer and signal at the output port of receiver can be taken with the help of signal receiver .Eye diagrams of the simulation result can be seen with the help ofeye diagram analyzer. Input wavelength is taken in lower port and converted wavelength chosen is in upper arm for the validation of SOA for both up and down conversion.

C. Transmission System Using Raman Amplifier

An optical fiber transmission system consists of three basic parts, transmitter, fiber optic cable and receiver. Depending on the application, the transmitter and receiver circuitry can be very simple or quite complex.

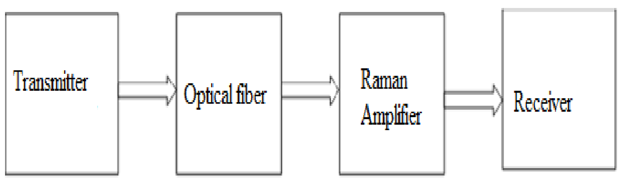

Figure 3: Block diagram of transmission system using Raman Amplifier

Transmitter consists of CW Laser, PRBS Generator, NRZ pulse Generator, Mach-Zehnder Modulator. Optical Fiber Cable, Receiver, BER Analyzer and Eye Diagram Analyzer are the other components. Raman Amplifier with single and multi-pump is used here to check the transmission efficiency compared with a common and simple transmission system [3][6].

Optical receiver component is an optical receiver subsystem built using a PIN or APD photodetector, a Bessel filter and a 3R regenerator. Good sensitivity (responsivity) at the desired wavelength and poor responsivity elsewhere, fast response time, compatible physical dimensions, low noise, insensitive to temperature variations, long operating life and reasonable cost etc are the requirements of a photodetector.

D. EDFA Analysis

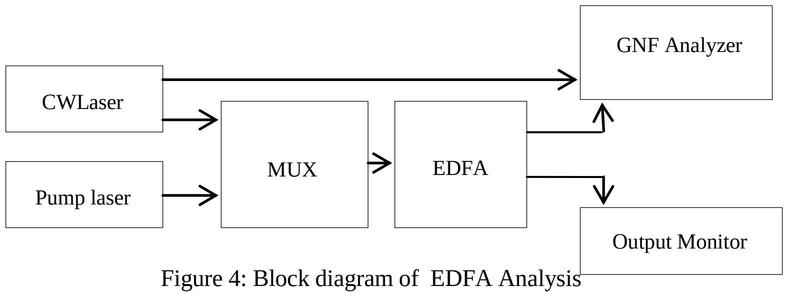

Figure 4: Block diagram of EDFA Analysis

EDFA scheme consist of one channel and can be divided into three main parts: transmitter, amplifier, and receiver section. Pump is provided to EDFA in copropagating method.Both pump and input signal are provided to EDFA via a multiplexer.Gain and noise figure can be analyzed by the GNF analyzer [18].

E.Measurement of ASE in an in-line EDFA

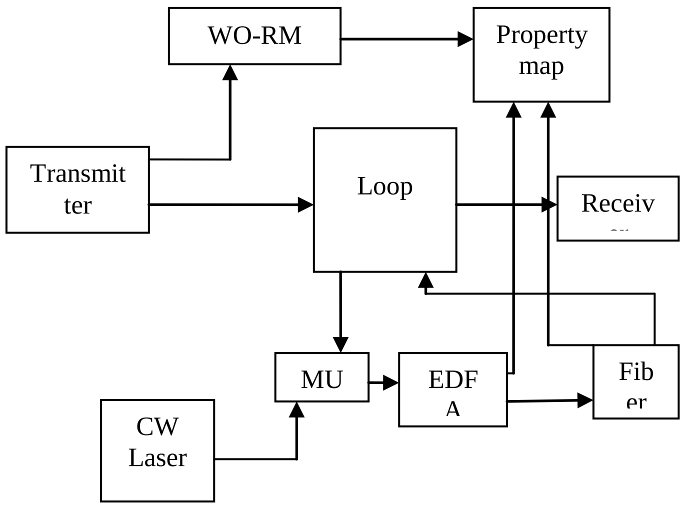

Figure 5: Block diagram of Measurement of ASE in an in-line EDFA

Write once read many (WORM) describes a data storage device in which information, once written, cannot be modified. This write protection affords the assurance that the data cannot be tampered with once it is written to the device.This model produces maps of dispersion and power along a fiber link.Frequently we construct links consisting of a series of fibers and amplifiers and it is useful to monitor the power evolution along the link.The repetition loops are used to indicate a section of the topology which is to be repeated during the simulation thespecified number of times as if it were actually that many sets of component models connected together. The first input at the left hand of the icon above is used to indicate the start of a repetition loop, while the output at the right of the icon is used to indicate the end of a repetition loop. The number of times the loop is to be executed is defined by the NumReps parameter.

III. SIMULATION MODELING

A. Simulation of SOA-MZI Based XPM

Wavelength conversion performance is carried out by using Opstsim ver.5.3. Figure 6 shows the simulation layout of SOA-MZI Based XPM.Detectors in the receiver are PIN and APD.Positive-Intrinsic-Negative (*pin*) photodiode has no internal gain. Avalanche Photo Diode (*APD*) has an internal gain due to self-multiplication.

Bessel filter is an optical filter with a Bessel frequency transfer function. Bessel filter is a type of linear filter with a maximally flat group delay (maximally linear phase response). Bessel filters are often used in audio crossover systems..3R regenerator component regenerates an electrical signal.3R regeneration preserves data quality and allows for improved transmission distances, thus enhancingtransparency, scalability and flexibility of optical networks.

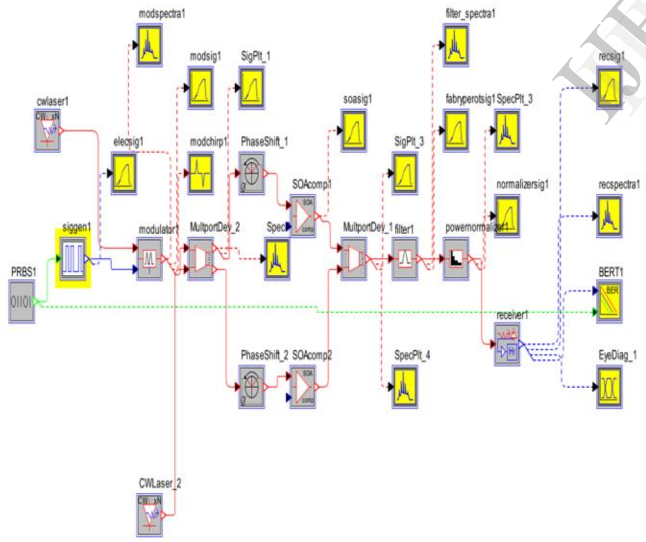

Figure 6: Simulation layout of *SOA-MZI Based XPM*

Up conversion and down conversions are possible using this simulation.For up conversion input wavelength is 1550nm and chosen is 1555nm.For down conversion 1555nm as input and output is taken as 1550nm.Filter used, Fabry Perot filter with optimized bandwidth of 0.12 x 10^-9Hz. The sensitivity of the receiver is -27 dBm and absorption coefficient 0.68 x106 luminous/m. The quantum efficiency of receiver is 0.8. The simulation is carried out at centre frequency of 193.1THz.

B. Transmission System Using Raman Amplifier

Signal degradation, which is a major problem in fiber communication system. Boosters or amplifiers amplify the signal transmitting through the fiber. Analysis is by comparing the transmission system with and without using Raman Amplifier. Single and multi-pumps are used in case of with using Raman Amplifier

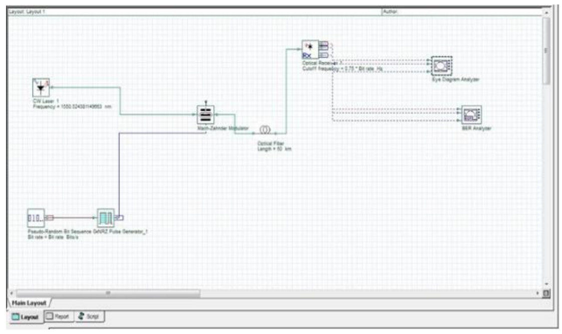

Figure 7: Transmission system without using Raman Amplifier

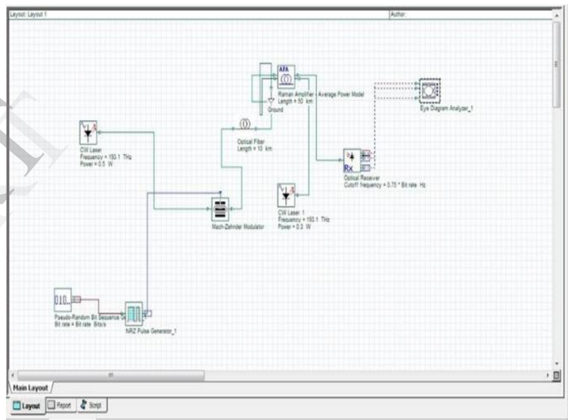

Figure 8: Transmission system with using single pump Raman Amplifier

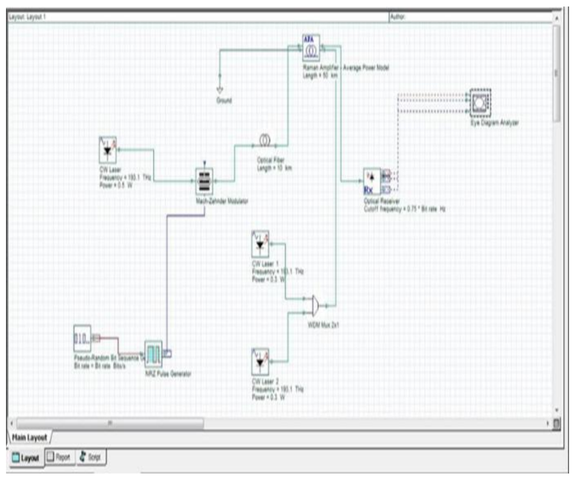

Figure 9: Transmission system with using multi pump Raman Amplifier

C. EDFA Analysis

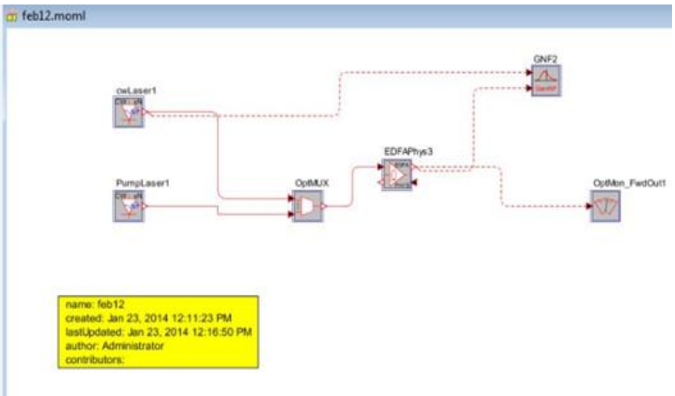

Figure 10:Simulation layout of EDFA Analysis

The transmitter section consists of binary data source and non-return to zero (NRZ) on/off keying optical signal source. Data source generate 2.5 Gbit/s data stream. NRZ was chosen because it is most popular code method in the fibre optical transmission systems and due to its simple realization. Amplifier part consists of EDFA physical model itself along with optical multiplexer and 980 nm copropagating continuous wavelength pumping laser. No optical fibre was used in this solution. It was done to simplify simulation process and to accentuate on EDFA part.

D. Measurement of ASE in an in-line EDFA

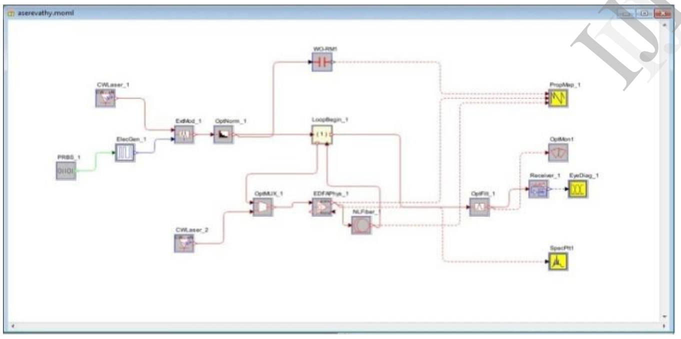

Figure 11: Simulation layout of measurement of ASE

The data source is a PRBS generator with a bit rate of 10Gbps. The input signal is cached inside the model and is read as many times as requested inside the loop. Loop indicates the number of repetitions during the simulation. Electrical generator is on-off ramp type with NRZ modulation format. CW laser1 has a peak power of 1mW and operates at wavelength 1550nm in single mode with random intensity noise of -150dB/Hz. External modulator1 is MZ type with on-off ratio 30dB.An optical normalizer is used to normalize the average power output of -40dBm. CW laser2 has wavelength of 980 nm. It operates in single mode with random intensity noise (RIN) -150dB/Hz. The Write-Once/Read-Many model is a special model that is used in cases where connection branches into a repetition loop.

IV. RESULTS AND DISCUSSIONS

A. SOA-MZI Based XPM

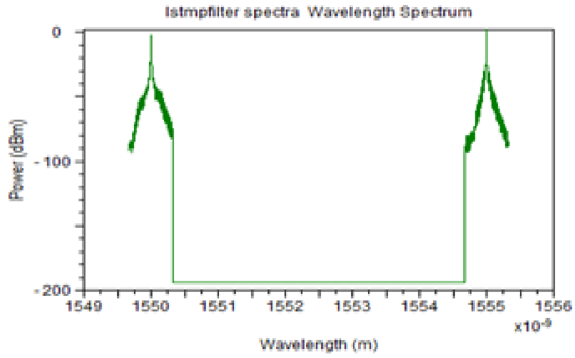

Figure 12: Converted wavelength spectra

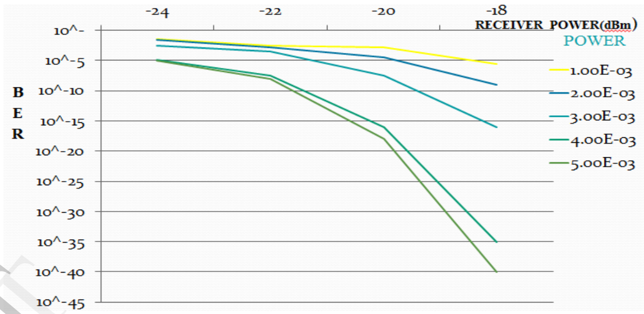

Figure 13: BER Vs Receiver power at various input powers

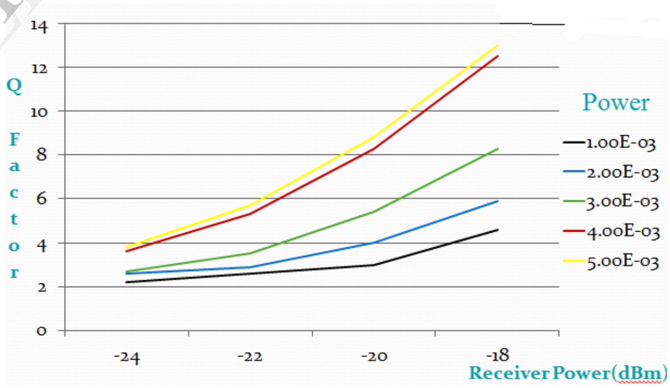

Figure 14: Q factor Vs Receiver power at various input powers

Figure 12 shows wavelength spectra for down conversion, it can be identified by using the power level. In figure 13, it can be seen that minimum BER is for -18dBm with a power of 5mW.With increase in input power and receiver power BER goes on decreasing. Figure 14, shows Q factor. With increase in input power and receiver power Q factor goes on increasing. Highest Q factor shown is 13.

B. Transmission System Using Raman Amplifier

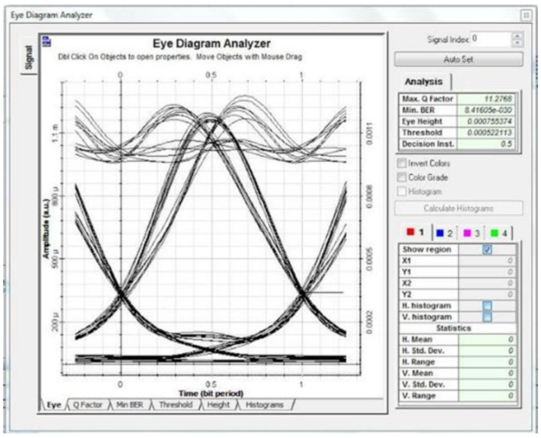

Figure 15: Eye diagram of transmission system without using Raman Amplifier

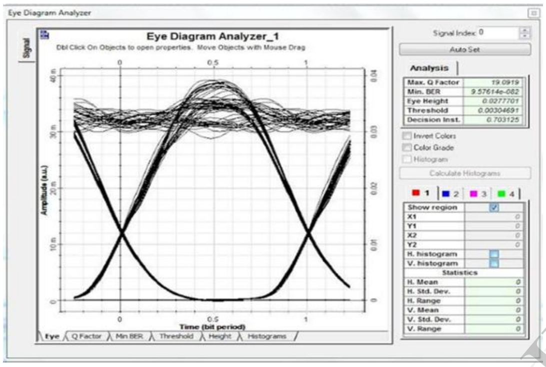

Figure 16:Eye diagram of transmission system using single pump Raman Amplifier

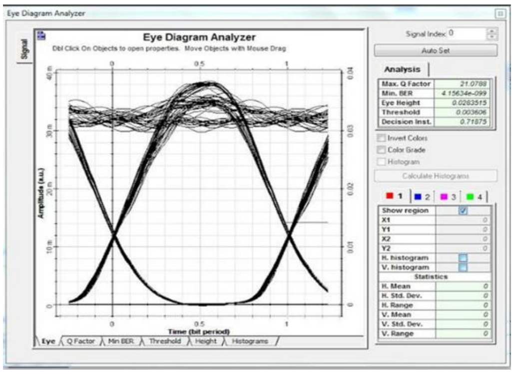

Figure 17:Eye diagram of transmission system using multi pump Raman Amplifier

In Raman amplifiers, the number of pumps, determination of powers, wavelengths and pumping schemes are main design criteria. On analyzing the eye diagrams transmission quality of signal is very much improved.Multiple-pump fiber Raman amplifiers (FRAs) can increase the transmission bandwidth. Raman Amplifier placed at various distances with multi pumps are also analyzed.

TABLE 1
Results obtained from the simulation of Raman Amplifier placed at various distances with multi pumps

Length(Km)	Q Factor	BER
10	28.1413	1.0031 E-174
20	26.9632	1.290 E-160
30	26.4504	1.16 E-154
40	25.5753	8.90 E-145
50	24.729	1.49 E-135

C.EDFA Analysis

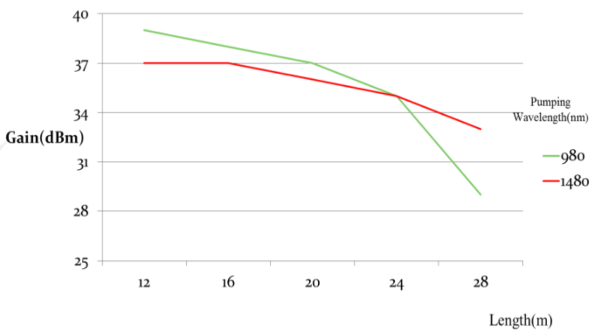

Figure 18: Gain Vs Length

In 980 nm laser usage case, erbium excite to higher energy state requires less energy than in the case of 1480 nm laser, and at the same laser power, the use of 980 nm wavelength will lead to greater gain then with 1480 nm. Lower noise values are also possible by 980nm.

D. Measurement of ASE in an in-line EDFA

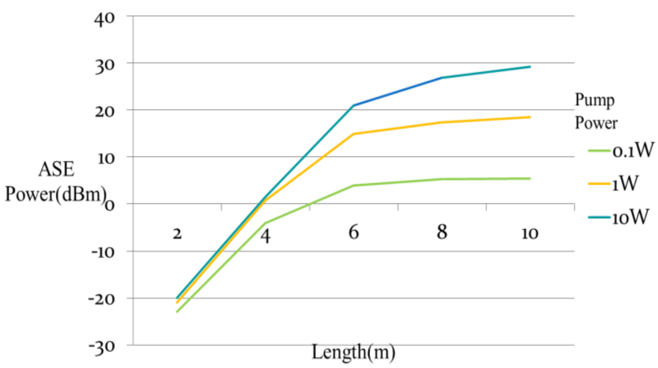

Figure 19: ASE power Vs EDFA length

According to the increase in length, ASE noise also increases.Considering the power,it shows larger ASE noise than lesser power.

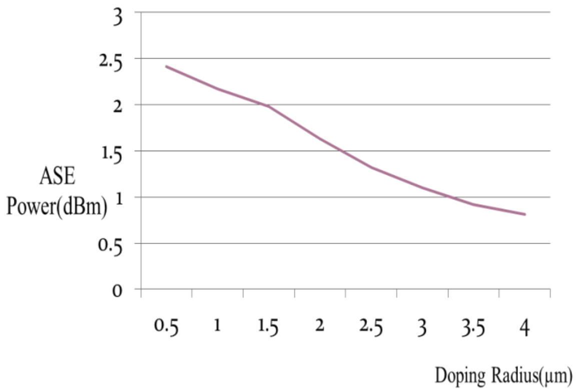

Figure 20: ASE Vs Doping Radius

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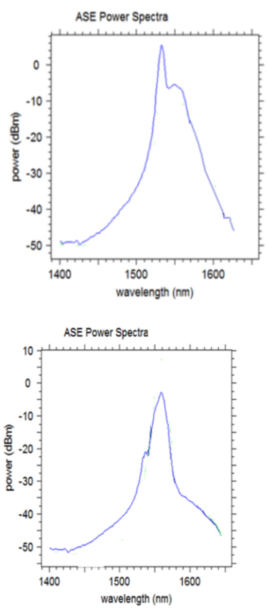
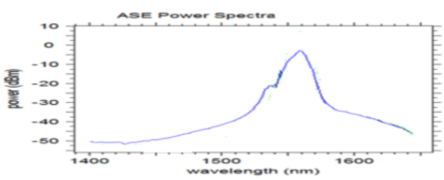


(a)(b)



(c)

Figure 21: ASE spectrum (a) after 1st span , (b) 4th span (c) 8th span

ASE noise power goes on decreasing with increasing radius. Although, it is desirable to have large doping radius for decreasing the ASE power, but at the same time signal gain increases as doping radius decreases, because the signal light does not suffer from additional absorption. The Er(3+) ions do not exist in the area where the pump power is small. So there is a trade-off between high gain and low ASE while deciding on the doping radius. ASE spectrum is observed by increasing the number of spans of nonlinear fiber (and amplifier). It is observed that ASE spectra peak is at 1532nm after first span, after fourth span ASE is peaked at 1558nm, ASE spectra peak after eighth span is 1561nm.

V.CONCLUSION

In this work, for wavelength conversion SOA-MZI based XPM is introduced. With increase the input power and receiver power, BER values continuously falls and corresponding to it Q factor increases. This technique for wavelength conversion is with better efficiency and wideband conversion range than other methods.

In the case of transmission system with Raman Amplifier, multi pump system provides better transmission performance. With multi pump system, with increase in distance bit error rate increases and quality of the signal decreases. In EDFA simulation results showedthe advantage of 980 nm co-directional laser usage inamplifier setup. Compared to 1480 nm laser, higher gain and lower noise values are possible to achieve by using the same pumping power.

ASE power in an EDFA increases with increase in pump power. So the pump power provided to an EDFA should be just enough to ensure population inversion.ASE power decreases with increase in doping radius, but at the same time with increase in doping radius gain decreases, so there is a trade-off between increasing gain and decreasing ASE. It is also observed that as the number of fiber spans increases in an optical link the ASE spectrum peak shifts to longer wavelengths or shorter frequencies.

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