Performance Analysis of WDM Optical Communication System in the Presence of Four Wave Mixing (FWM) Under the Impact of Channel Spacing with Variable Dispersion

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Abstract— Four Wave Mixing (FWM) is the parameter which restricts the transmission distance and bandwidth of optical communication systems. There are various factors which influence FWM, such as channel input power, spacing between channels, dispersion of fiber, operating wavelength and refractive index etc. The nonlinear effects tend to manifest themselves when optical power is very high and become important in WDM/DWDM systems. FWM suppression is required to overcome this problem. Techniques like, equal and unequal-channel spacing with varied laser power & alternate delay have been proposed to reduce the impact of FWM on Wavelength Division Multiplexing (WDM) optical communication system. Further the comparison of reduction of FWM for proposed techniques has been discussed by varying the dispersion of fiber from 0 to 16 ps/nm/km. Here, all the input channels have been spaced evenly at 100 GHz. The simulation results show that by increasing channel spacing, FWM reduces. It is observed that on increasing the channel spacing, the interference between the input frequencies decreases and hence the four wave mixing also decreases.

Keywords— BER, Channel Spacing, Dispersion, Four Wave Mixing, NRZ, Q Factor, SPM, WDM/DWDM, XPM.

I. INTRODUCTION

FWM is a phenomenon in which interactions between two wavelengths produces two extra wavelengths in the signal due to the scattering of the incident photons. Four-wave mixing (FWM) (also called four-photon mixing) is one of the major limiting factors in WDM optical fiber communication systems that use the low dispersion fiber or narrow channel spacing. Normally, multiple optical channels passing through the same fiber interact with each other very weakly. However, these weak interactions in glass can become significant over long fiber-transmission distances. FWM is due to changes in the refractive index with optical power called optical Kerr effect. The dispersion and fiber nonlinearities are the parameter which restricts the transmission distance and bandwidth of optical communication systems.

The nonlinear effects tend to manifest themselves when optical power is very high and become important in WDM/DWDM systems. It was assumed that four different frequency components interact via four-wave mixing. This is called non-degenerate four-wave mixing. However, there is also the possibility of degenerate four-wave mixing, where two of the four frequencies coincide. As optoelectronic technology moves forward, it is possible to have a high density of wavelengths in the same fiber. Thus, dense wavelength-division-multiplexing (WDM), a key technology, comes into picture to enable the very high-capacity photonic networks required by our communication thirsty society. Fiber nonlinearities become a problem, when several channels are co-propagating in the same fiber. Nonlinear effects arose as data rate, repeater-less transmission length, number of wavelengths, and optical power levels are increased. The interaction between propagating light and the fiber can lead to interference, distortion, or excess attenuation of the optical signals. The fiber nonlinearities fall into two categories. One the stimulating scattering (Raman and Brillouin) are responsible for intensity dependent gain or loss and generated due to stimulated process. Stimulated Raman scattering, an interaction between light and vibrations of silica molecules, causes frequency conversion of light and results in excess attenuation of short-wavelength channels in wavelength multiplexed systems. Stimulated Brillouin scattering, an interaction between light and sound waves in the fiber, causes frequency conversion and reversal of the propagation direction of light. The second types of nonlinearities are Self Phase Modulation (SPM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM). Cross-phase modulation is an interaction, via the nonlinear refractive index, between the intensity of one light wave and the optical phase of other light waves. Four-photon mixing is analogous to third-order intermodulation distortion whereby two or more optical waves at different wavelengths mix to produce new optical waves at other wavelengths.
In multi-channel systems, four-wave mixing (FWM) in optical fibers induces channel crosstalk and possibly degrades system performance. The FWM is one of the major and significant degrading factors in WDM and DWDM optical communication systems. There have been many reports on methods for solving these problems including the use of nonzero dispersion fibers, dispersion management and unequal-channel spacing techniques. However, these techniques require dispersion compensation or a complex system design. For example, to design a transmitter of unequal channel spacing is more complex as compared to equal channel spacing transmitter. Therefore, a novel fiber for suppressing FWM has been needed to increase the transmission capacity and simplify the system design. The FWM efficiency depends strongly on the phase matching condition, which is closely related to the chromatic dispersion for each signal in an optical fiber.

The various methods for suppressing FWM have been reported in the literature. Moreover, from the previous literature, it is concluded that the FWM is increased at low dispersion (zero dispersion), small and equal channel spacing as compared to unequal channel spacing.

In this paper, new methods have been proposed for the suppression of FWM and compared with the results with existing methods like: equal channel spacing and unequal-channel spacing at various dispersion values from 0 to 16 ps-nm\(^{-1}\)km\(^{-1}\). BER and Q-factor of 8 channel WDM system, each operating at 10 Gbps have been evaluated over an optical span of 360 km in the presence of FWM under the impact of equal channel spacing of 100 GHz in conjunction with the fiber-dispersion control by means of dispersion compensation fiber. Graphs have been plotted for equal & unequal channel spacing with varied laser power and alternate delay.

II. SIMULATION SETUP

The proposed setup is shown in figure 1. Here 8 WDM channels are multiplexed using ideal multiplexer. The optical transmitter consists of continuous wave (CW) semiconductor laser with externally modulated by 10 Gbps NRZ-raised cosine each having different central frequencies. The NRZ rectangular pulse format is transmitted with pseudorandom bit sequence. The eight channels are multiplexed and amplified with erbium doped fiber amplifier (EDFA). The optical fiber length is taken as 360 km having six spans of 60 km. The fiber loss is taken to be 0.2 dB/km and core effective area of fiber is \(64 \times 10^{-12} \text{ m}^2\). The dispersion is compensated by using dispersion compensation fiber. In order to observe the impact of suppression method the fiber dispersion value is varied from 0 to 16 ps/nm/km.

At the receiver side, demultiplexer is used to separate the WDM channels. Then the signal is passed through the photodetector followed by the low pass Bessel filter. Optical power meter is used to measure FWM power.

III. RESULTS & DISCUSSION

The study was undertaken with overall objective to investigate modified FWM suppression methods in WDM optical communication system. The proposed high speed data transmission over single mode fiber was successfully simulated using Opti system 12. The transmitted data bits are 8×10 Gbps i.e. transmitted over single mode fiber after multiplexing. Modulation is done by Mach Zehnder modulator in which carrier frequency is analog, which is generated by laser diode whose central frequency is 1550 nm.
The multiplexed signal is passed through the 360 km long optical fiber. At the receiver end the signal is demultiplexed and different results seen by the different visualizers.

A. BER (Bit Error Rate) Analyzer Showing Min BER for Channel 1:

BER is the ratio of no. of bits received in error to the total no. of bits transmitted. Figure 2 is the graph drawn between log of BER versus time and it shows that the Min.BER for channel 1 is $1.5869 \times 10^{-89}$, which is a very low BER.

B. BER (Bit Error Rate) Analyzer Showing Min BER for Channel 4:

Figure 3 is the graph drawn between log of BER versus time and it shows that the Min.BER for channel 4 is $2.60699 \times 10^{-87}$, which is a very low BER.

C. BER Analyzer Showing Q Factor for Channel 1:

Q factor is simply a ratio of the average received signal level to the RMS noise level at the input of the decision circuit in a receiver. Figure 4 is the graph drawn between Q factor versus time and it shows that the Max.Q Factor for channel 1 is 20.0256, which is a very good Q Factor.

D. BER Analyzer Showing Q Factor for Channel 4:

Figure 5 is the graph drawn between Q factor versus time and it shows that the Max.Q Factor for channel 4 is 10.0256, which is a very good Q Factor.
Figure 5 is the graph drawn between Q factor versus time and it shows that the Max.Q Factor for channel 4 is 19.7699, which is a very good Q Factor.

E. Eye Diagram Of Demultiplexed Signal:

Following figure shows the eye diagram of demultiplexed signal. From the figure 6 it is clear that the distortion is created at the receiver side. As the length of the optical fiber is increased, the signal becomes distorted. This distortion is created due to the presence of different dispersion in the fiber. Q factor is reduced. Eye opening is also reduced. For removing this filter is used at the receiver side. Figure 6 shows good eye opening that indicates good jitter.

F. Measurement of Power Penalty:

The optical power falling on the photo detector is defined as the time within the statistical nature of quantum detection process. The reduction in SNR is known as the power penalty for that effect and generally is expressed in decibels. Figure 7 shows that the power penalty decreases, when fiber length is increased means that the impairment effect is present in the link. So there is a reduction in the signal-to-noise ratio (SNR) of the system from the ideal case.

G. FWM Power Versus Dispersion (Comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with equal channel spacing with varied laser power):

Figure 8 shows the graphs between FWM powers for equal channel spacing, unequal-channel spacing and equal channel spacing with varied laser power versus dispersions. The results show that output power for equal channel spacing with varied laser power varies in the range from -11.5 to -20.6 dBm for dispersion varying from 0 to 16 ps/nm/km.
H. FWM Power Versus Dispersion (comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with equal channel spacing with alternate delay):

Figure 9 shows the graph for FWM power versus dispersion for equal channel spacing, unequal-channel spacing and equal channel spacing with alternate delay. The FWM power is less in equal channel spacing with alternate delay and lies in the range from -18.5 to -27.5 dBm as compared to equal channel spacing, -14 to -22.6 dBm and unequal channel spacing, -16.3 to -24.6 dBm for dispersion values varying from 0 to 16 ps/nm/km, respectively.

It is observed that the equal channel spacing with alternate delay gives better result at zero dispersion and at higher dispersion values. Moreover the results show the decrease in FWM power with the increase in dispersion.

I. Q Factor Versus Channels:
Q factor have been measured for all the simulated channels under the impact of equal and unequal channels pacing as shown in figure 10. The observation reveals out that unequal channel spacing improves the Q factor for 8×10 Gbps WDM system.

IV. Conclusion
In this paper, a vigorous and in-depth analysis of prominent contributing parameters was carried out by using opti system 12 simulator to observe that how FWM is influenced by these attributes. An implementation of 8×10 Gbps dispersion compensated WDM system have been investigated to evaluate BER, Q-factor and received power after an optical span of 360 km in the presence of FWM under the impact of equal and unequal-channel spacing with varied laser power and alternate delay & found that power penalty reduces by increasing fiber length.

It is also found that increase in input power, increases FWM & by increasing channel spacing, FWM reduces. Equal channel spacing with alternate delay is found suitable for FWM reduction. Further it has been studied that the FWM power reduces more as the dispersion is increased.
REFERENCES


