Analysis of 8 x 10 GB/s WDM System using Hybrid Amplifier + FBG in Presence of Fiber Non Linearities

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Abstract— This paper introduces the non linear optical effect known as four wave mixing (FWM). In wavelength division multiplexing (WDM) systems four wave mixing can strongly affect the transmission performance on an optical link. As a result it is important to investigate the impact of FWM on the design and performance of WDM optical communication systems. The main objective of this paper is to analyze the FWM power for different Raman gain length in presence as well as in absence of FBG by designing and simulating a model in Optisystem 7. In this paper, we have simulated the FWM design for eight waves.

Key words: Raman-EDFA, OSNR, RFA, BER, WDM, Q Factor

I. Introduction

Optical nonlinearities give rise to many ubiquitous effects in optical fibers. These effects can be detrimental in optical communication. In the Dense Wave length division multiplexing system (DWDM) the nonlinear effects plays important role. DWDM system carries different channels. Hence power level carried by fiber increases which generates nonlinear effect such as SPM, XPM, SRS, SBS and FWM [1]. Four wave mixing (FWM) is one of the most troubling issues. The FWM give rise to crosstalk in DWDM system whose channel spacing is narrow. Four-wave mixing (FWM) is one of the major limiting factors in wavelength division multiplexing (WDM) optical fiber communication systems. FWM is a third-order nonlinearity in silica fibers, which is analogous to inter-modulation distortion in electrical systems. It is due to change in the refractive index with optical power called the optical Kerr effect. FWM occurs when light of three different wavelengths is launched into a fiber; it gives rise to a new wave. This newly generated wave is a result of FWM which co-propagates with the originally transmitted signal and interferes with them. It causes severe degradation of the WDM channels and introduces the crosstalk and required power to reduce the crosstalk. Unlike the linear effects which can be compensated, the nonlinear effects accumulate and degrade the system performance. FWM is a major source of non-linear crosstalk since they interfere with the desired signals. The magnitude of FWM depends on channel power, channel spacing and fiber dispersion but is independent of the bit rate. The development of the next generation of optical communication networks is likely to rely strongly on fiber nonlinearities in order to implement all optical functionalities [2] [3].

II. Simulation Setup

In this model, eight channels are transmitted at 10 Gb/s speed with 100 GHz channel spacing. Each input signal is modulated in NRZ format and pre-amplified by a booster. The amplified signals are sent to the channel where these signals are transmitted over DS anomalous fiber of different transmission distance.

A transmitter compound component (Tx) is built up using eight transmitters. In transmitter compound each transmitter section consists of the data source, electrical driver, laser source and external Mach–Zehnder modulator. The data source is generating signal of 10 Gb/s with pseudo random sequence. The electrical driver converts the logical input signal into an electrical signal. The CW laser sources generate the 8 laser beams at 191.5–192.2 THz with 100 GHz channel spacing. These beams have random laser phase and ideal laser noise bandwidth. The signals from data source and laser are fed to the external Mach–Zehnder modulator (sin2_M for all configurations), where the input signals from data source are modulated through a carrier. The amplitude modulator is a sine square with an excess loss of 3 dB.

The simulation setup of transmission link using hybrid amplifier (EDFA-RAMAN) and FBG at different transmission distances is shown in Figure 1. The output optical signal of the modulator is fed to the channel where a booster is used to boost up the signal. This optical signal is transmitted and measured at 16.75 ps/nm/km dispersion. The reference wavelength and attenuation for this model is choosed to be 1550 nm and 0.2dB/km respectively.

The optical power meters and optical spectrum analyzers are used to measure the power and spectrum at different levels. The modulated signal is converted into original signal with the help of PIN photodiode and filters. A compound receiver is used to detect all the eight signals and convert these into electrical form. The various parameters for RFA are: Operating temperature is 300 K and pump wavelength is 1440 nm. The input power is kept constant for all distances and is taken as -25dBm.

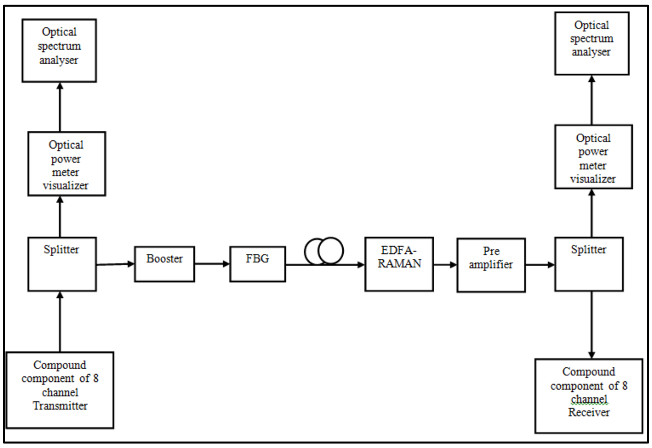

Fig. 1: Block diagram for simulation setup

III. Effect of RFA Length on FWM at Different Transmission Distances

The performance of long distance optical communication systems is limited by nonlinear effects of fiber, which interact and accumulate along the length of the optical link. One of the unique characteristics of optical fibers is their relatively low threshold for nonlinear effects. This can be a serious disadvantage in optical communications, especially in wavelength division multiplexing (WDM) systems, where many closely spaced channels propagate simultaneously, resulting in high optical intensities in the fiber [4]. Here, we have simulated the effect of FWM products in WDM environment by varying the fiber length parameter. Systems are operating in which the fiber carries such a high optical power density that signals can modify the transmission properties of the fiber leading to nonlinear effects. Nonlinearity in optical fiber essentially leads to the conversion of power from one wavelength to another. The system implications of this wavelength conversion depend on the type of channel or channels used to carry the data [5].

In the FWM simulation model layout, two types of tools have been used. The optical spectrum analyzer and the power meter have been fixed after MUX and at the end of the fiber optic. The nonlinear effect occurs only during the propagation of signals through the fiber. The optical spectrum analyzer has been used to show the waveform.

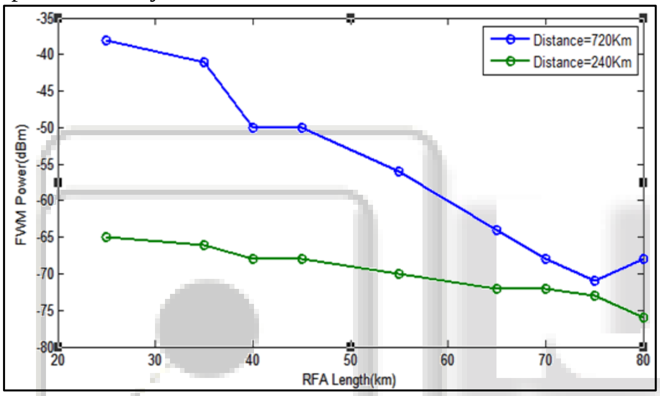

Fig. 2: Raman-gain length versus FWM Power

The above graph shows that the power level of forward wave mixing components drop down with increase in Raman-gain length for both the transmission distances. This is because the process of amplification occurs in Raman-gain length and more the length, longer the signal will be indulged in amplification. Hence no non linear processes will occur in that particular piece of length. For 240km the power is sinking gradually almost at a constant rate but for 720km the power is falling steeply. At 75km of RFA length the FWM power is nearly same for both the 240 and 720km. This implies that no matter how larger or smaller distance the signal has travelled, the same RFA length (75 km in this case) will compensate the non linear effect carried by signal at the same level. But there is always one optimum RFA length for every Raman pump power. Here it is 75km for 100mW of pump power.

The reason being as the optical power from pump travels upstream (from the receiver towards the transmitter), the SRS effect progressively transfers power from shorter pump wavelength to longer signal wavelengths. Thus, both the signal power level and the pump power level vary along the characteristics Raman-gain length $L_G=g_{RP}/A_{eff}$, where P is the pump laser power and A_{eff} is the effective area of transmission fiber. At any point excessive increase in Raman pump power or RFA length will take simulated Raman Scattering process (SRS) in degrading direction and therefore we can only achieve a finite gain (and a finite maximum power) per unit length of the amplifier. In an amplifier designed for single wavelength operation the optimal amplifier length is a function of the signal power, the pump power and the amount of gain required.

IV. EFFECT OF FBG ON FWM

The Fiber Bragg Grating (FBG) is a fiber optic passive component exhibiting basic functional attributes of reflection and filtering. FBG's are relatively simple to manufacture, small in dimension, low cost and exhibit good immunity changing ambient conditions and EM radiation [6]. FBG's have replaced bulk optic mirrors & beam splitters in equipment which has increased system stability and portability. A fiber Bragg grating is region of periodic refractive index perturbation inscribed in the core of an optical fiber such that it diffracts the propagating optical signal at specific wavelengths. The parameter dispersion is varied in this component to get desired results [7]. Using FBG along with hybrid amplifier has enabled to design a long haul system by increasing the amplifier span.

The two parameters of FBG which effects the transmission of signal are dispersion and bandwidth. Bandwidth of FBG is adjusted to get all the eight channels at receiver but dispersion of FBG decides the signal strength [8]. For 80km optical span, -1500ps/nm/km dispersion of FBG is giving acceptable results. But figure 3 shows that the FWM power is less for the link without FBG. It means forward wave mixing effect is enhanced by FBG. This is because FWM arises from intensity dependent variations in refractive index in silica fiber and we are using here a chirped FBG in which there are so many refractive index perbutations. FBG is just helpful in compensating the dispersion along the transmission link. But this limitation of FBG can be neglected as it is compensating dispersion to a larger extent and its contribution in non linearities is less significant.

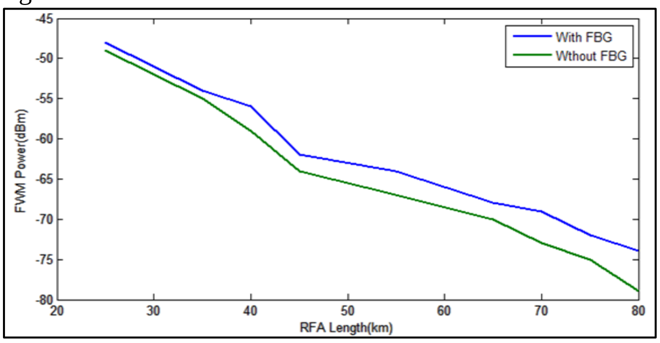

Fig. 3: Effect of FBG on FWM Power

V. EFFECT OF CHROMATIC DISPERSION ON Q FACTOR

Although chromatic dispersion broadens the pulses but low chromatic dispersion enhances some nonlinear effects of fibers like four wave mixing. FWM can be suppressed through special arrangements of fibers having different dispersion characteristics. In this chromatic dispersion compensation technique various fiber segments are tailored in WDM link to have high local dispersion, but an overall low dispersion. The low average dispersion minimizes pulse spreading giving good quality of eye diagram, whereas the high local dispersion destroys the carrier frequency phase relationships that give rise to FWM intermodulation products. The following figure describes it well.

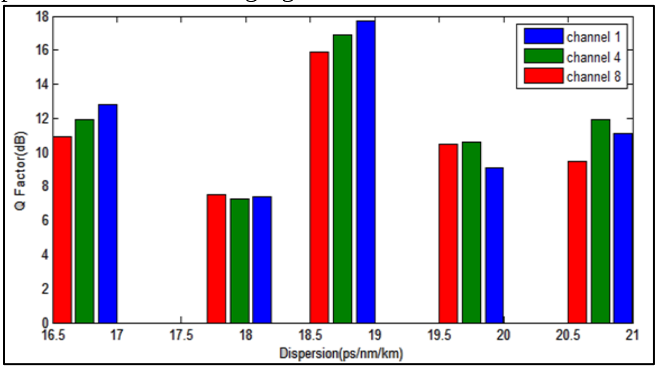

Fig. 4: Effect of chromatic dispersion on Q factor

Figure 4 shows that Q factor varies with variation in chromatic dispersion of fiber. Here Q factor is observed at dispersions 16.75, 17.95, 18.75, 19.75, 20.75ps/nm/km for channel 1, 4 and 8 corresponding to frequencies 191.5, 191.8 and 192.2 THz. It is seen that Q factor is maximum at dispersion 18.75ps/nm/km and minimum at 17.95ps/nm/km. There is not any regular interchannel or intrachannel Q Factor variation observed in above figure. We can just say that in this design link different dispersions give different values of Q factor. It is not like at every dispersion the same channel is affected worstly, but the crosstalk among channels is diverse for all values of dispersion. In figure 4 it is clearly visible that at 16.75ps/nm/km due to crosstalk interference, channel 8th is experiencing more degradation, at 17.95ps/nm/km crosstalk among channels is less effective, at dispersion 18.75ps/nm/km again channel 8th suffers signal degradation, at 19.75ps/nm/km first channel is having Q factor of 9.1 which is lesser than channel fourth and eight whose Q factor is 10.6 and 10.5 respectively and at dispersion 20.75ps/nm/km signal at channel eighth is experiencing more impairment. Last channel among all the channels is affected on whole for most of the values of dispersions. So an appropriate value of dispersion must be choosed at which we should obtain a good Q factor as well as where FWM effect is mitigated to an extent and where crosstalk among channels is less severe.

VI. Crosstalk Analysis of the 8 x 10 Gb/s WDM System

Four-wave mixing (FWM) is one of the phenomena that may lower the effectiveness of the transmitted signal in wavelength division multiplexing (WDM) systems under dense channel spacing and low chromatic dispersion. In a WDM system with equally spaced channels, the new frequencies generated by FWM will drop at the channel frequencies and will introduce crosstalk. The FWM effect is a result of the change in the intensity dependence of the refractive index of optical fiber.

Depending on the sources, two type of crosstalk mainly exists, namely, inter-band crosstalk and intra-band crosstalk. The inter-channel or inter-band crosstalk is the crosstalk situated in wavelengths outside the channel slots and this can be removed with narrowband filters. The crosstalk within the same wavelength slot is called intra-channel crosstalk [11].

The non-linear effects that produce inter-channel crosstalk are SRS and XPM. The crosstalk can also be induced by several nonlinear phenomenon such as cross gain saturation and FWM in optical amplifiers. Here the crosstalk is calculated between eight channels.

$$\text{Crosstalk} = \frac{P_{out}^{all\ channel} - P_{out}^{reference\ channel}}{P_{out}^{reference\ channel}}$$

Where $P_{out}^{all\ channel}$ is the output power of a calculation with all channels at the input and $P_{out}^{reference\ channel}$ is the output power of a calculation with only the channel under study and the adjacent channels being off [12].

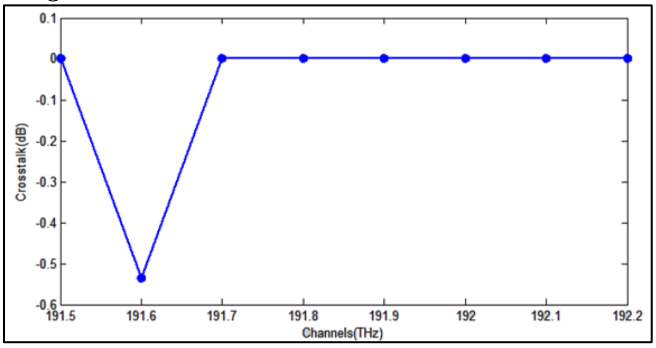

Fig. 5: Crosstalk between 8 channels at 100GHz channel spacing with NRZ pattern

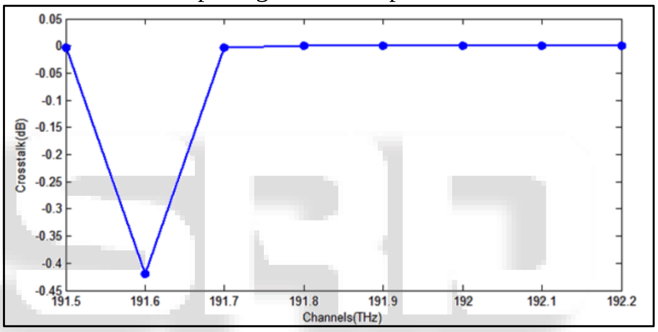

Fig 6: Crosstalk between 8 channels at 100GHz channel spacing with RZ pattern

Crosstalk is calculated for all the 8 channels of WDM network for both NRZ and RZ format and on comparing figures 5 and 6 it is clear that the graphs are same for both the patterns with minor variation in the values. Minimum crosstalk is observed for second channel and for all other channels the crosstalk is nearly same. This shows that the new components arised due to FWM effect have not fallen in 191.6THz frequency band and hence power of this channel has not been robbed by the new products formed. For other channels too the value of crosstalk is quite less which means that the new frequency components generated are not sharing the channel's frequencies due to which the power of channels is not affected much.

VII. Conclusion

Here, firstly the effect of RFA length on FWM is examined which shows that the power of FWM components decreases with increase in RFA length. Here that RFA length is 75km. Also the FWM power of signals covering different distances is equally reduced.

The study shows that FWM effect is enhanced by FBG. The reason being, FWM arises from intensity dependent variations in refractive index in silica fiber and we are using here a chirped FBG in which there are so many refractive index perbutations.

The effect of chromatic dispersion on FWM is observed by noting down the Q factors of first, fourth and eight channels. The effect is seen at dispersions 16.75, 17.95, 18.75, 19.75 and 20.75ps/nm/km and results show that Q factor is maximum at dispersion 18.75ps/nm/km for all the three channels and minimum at 17.95ps/nm/km. This concludes that FWM is minimum at 18.75 and maximum at 17.95ps/nm/km and also, increasing chromatic dispersion to some extent is an effective way of mitigating FWM.

Crosstalk of all the eight channels is studied. The crosstalk for this model is very less and within eight channels it is minimum for second channel. This shows that the new products generated due to FWM effect are not falling in the frequency band of WDM channels and hence the signal power is not robbed by the new produced components.

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