

Simulation Analysis of Four Wave Mixing Effect in WDM Optical System

Vivek Kumar Malik, Amit Kumar Garg

Abstract— The nonlinear effect degrades the system performance. Because nonlinear effects tend to manifest themselves when optical power is very high, they become important in WDM. Four-wave mixing (FWM) is one of the dominating degradation effects in wavelength division-multiplexing (WDM) systems with dense channel spacing and low chromatic dispersion on the fiber. Four wave mixing (FWM) is a parametric process in which different frequencies interact and by frequency mixing generate new spectral components. FWM can have important deleterious effects in optical fiber communications, particularly in the context of wavelength division multiplexing where it can cause cross-talk between different wavelength channels, and /or an imbalance of channel powers. The paper presents the design and performance analysis of four-wave mixing effect on the basis of output spectrums, eye diagrams, BER, eye opening and Q-factor for different values of channel spacing.

Keywords— Channel spacing, Eye diagram, FWM, nonlinear effects, WDM

I. INTRODUCTION

In order to meet the huge capacity demands imposed on the core transmission network by the explosive growth in data communications the number of optical channels in dense-WDM optical networks is being increased. Since the gain bandwidth of EDFAs is limited, these requirements for a very large number of channels mean that the channel spacing will have to be small. The current ITU grid specifies 100 GHz channel spacing, but systems are being considered with 50 GHz to 25GHz channel spacing. At these spacing, the non-linear effects of the optical fiber can induce serious system impairments. Four-Wave-Mixing (FWM) is another non linear effect that can limit the performance of WDM systems [1]. For long distance light wave communication larger information transmission capacity and longer repeater-less distance are required. When new frequencies fall in the transmission window of original frequency it causes severe cross talk between channels propagating through an optical fiber. When new frequencies fall in the transmission window of original frequency it causes severe cross talk between channels propagating through an optical fiber. Degradation becomes very severe for large number of WDM channels with small spacing. In this paper, we have simulated the effect of FWM products in WDM environment by varying the channel spacing.

II. FOUR WAVE MIXING

Optical fiber nonlinearities can lead to interference, distortion, and excess attenuation of the optical signals,

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resulting in performance degradation. The most common nonlinear optical effect of importance in optical fiber communication systems results from the fiber nonlinear refractive index. The nonlinearity in the refractive index is known as Kerr nonlinearities. The Kerr nonlinearity gives rise to different effects, such as self-phase modulation (SPM), cross-phase modulation (XPM), and four-wave mixing (FWM) [2,6]. FWM may induce light path BER fluctuations in dynamic networks that can affect the optical signal to noise ratio and quality of service in transparent networks under highly complex nonlinear effect Four-wave mixing (FWM) is one of the dominating degradation effects in wavelength-division-multiplexing (WDM) systems with dense channel spacing and low chromatic dispersion on the fiber. If in a WDM system the channels are equally spaced, the new waves generated by FWM will fall at channel frequencies and, thus, will give rise to crosstalk. In case of full in-line dispersion compensation, i.e., 100% dispersion compensation per span, the FWM crosstalk becomes of a maximum level since the FWM products add coherently in each span. Four-wave mixing (FWM) is a parametric process in which different frequencies interact and by frequency mixing generate new spectral components [3]. Four-wave mixing (FWM) is a type of optical Kerr effect, and occurs when light of two or more different wavelengths is launched into a fiber. Generally speaking FWM occurs when light of three different wavelengths is launched into fiber, giving rise to a new wave (know as an idler), the wavelength of which does not coincide with any of the others. FWM is a kind of optical parametric oscillation. Figure 1 is a schematic diagram that shows four-wave mixing in the frequency domain. As can be seen, the light that was there from before launching, sandwiching the two pumping waves in the frequency domain, is called the probe light (or signal light). The idler frequency fidler may then be determined by

$$f_{idler} = f_{p1} + f_{p2} - f_{probe} \quad (1)$$

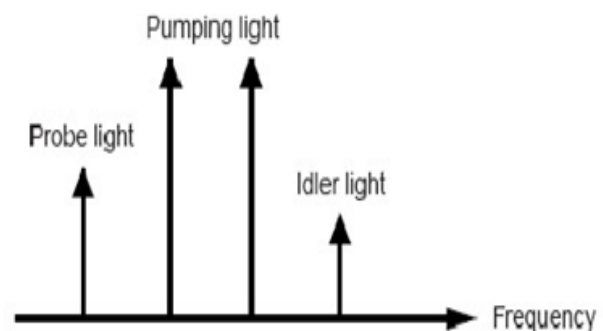


Figure 1: Two channel pump wave

Where f_{p1} and f_{p2} are the pumping light frequencies, and f_{probe} is the frequency of the probe light[3]. This condition is called the frequency phase-matching condition. FWM can have important deleterious effects in optical fiber communications, particularly in the context of wavelength division multiplexing where it can cause cross-talk between different wavelength channels, and/or an imbalance of channel powers [4]. FWM can transfer data to a different wavelength. A continuous wave pump beam is launched into the fiber together with the signal channel. Its wavelength is chosen half-way from the desired shift. FWM transfers the data from signal to the idler beam at the new wavelength [5, 7, 9].

III. SCHEMATIC MODEL

This schematic model is the general setup for an optical communication system. The transmitter section consists of a laser, modulator driver, pn-sequence generator i.e. data source and modulator. The wavelength of various channels is set by keeping the difference equal to the spacing required. Then all these transmitted signals are combined/multiplexed together. Then the combined signal is amplified so that it can be transmitted over long distances without its degradation. Then the signal is transmitted over the non linear fiber which adds the nonlinearities into the signal. At the receiver side, the signal is demultiplexed. The receiver consists of a photodiode and a filter.

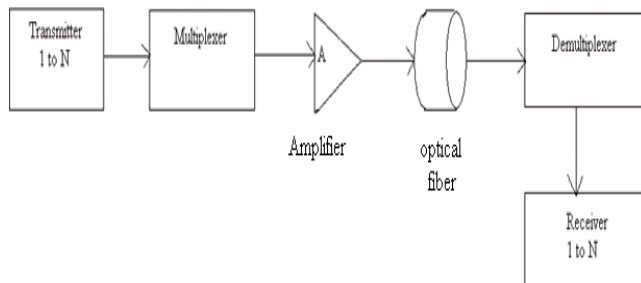


Figure 3: Schematic model for WDM communication system

IV. SIMULATION AND DESCRIPTION

The simulation setup for showing the effect of changing spacing between the input channels on four-wave mixing is shown in figure 4. The continuous wave laser is used to create the carrier signal. In this setup, eight users are taken in account whose wavelengths have a specific difference i.e. spacing between them. The data source is used to generate the random input data bit sequence at the rate of 10 Gbps. The light signal modulates the input data. The modulator is driven by the modulator driver which decides the input data format. The input data format used here is NRZ raised cosine. The modulated data from all the users is combined using a combiner. The post amplifier amplifies the signal before allowing it to enter into the fiber to avoid losses. Then this signal is sent over the fiber. At the receiver, the signal is demultiplexed by using optical splitter which splits this signal into the same number of signals as were transmitted. The photodiode is used for optical to electrical conversion. Then the signal is passed through the Raised cosine filter and the final output signal is received. An

optical scope is attached at the output of combiner to examine the input signal. Another optical scope is placed at the output of splitter to examine the four wave mixing effect in frequency spectrum. An electrical scope is kept at the receiver output to examine the eye diagram. The four wave mixing effect has been compared for different values of channel spacing and the performance has been evaluated in terms of output spectrums, eye diagrams, BER, eye opening and Q-factor. Here, all the channels are spaced evenly but at different values like less than 30GHz, between 40GHz to 70GHz, and more than 80GHz.

Table 1: performance parameters of 8 channel WDM communication system

Name of component	Type	Parameter value
Laser	CW-lorentzian	Center Frequency 1550nm, (193.4 Thz), Power is varied from 10 to 16.5 dbm
Amplitude modulator	Sine square	2 db excess loss
Driver	NRZ	-2.5, +2.5 as levels
Detector	PIN	Responsivity 0.875
Electrical filter	Bessel's type	-
Optical filter	Raised cosine type	-
Optical fiber	100 km length	Dispersion 0.2 ps/nm/km

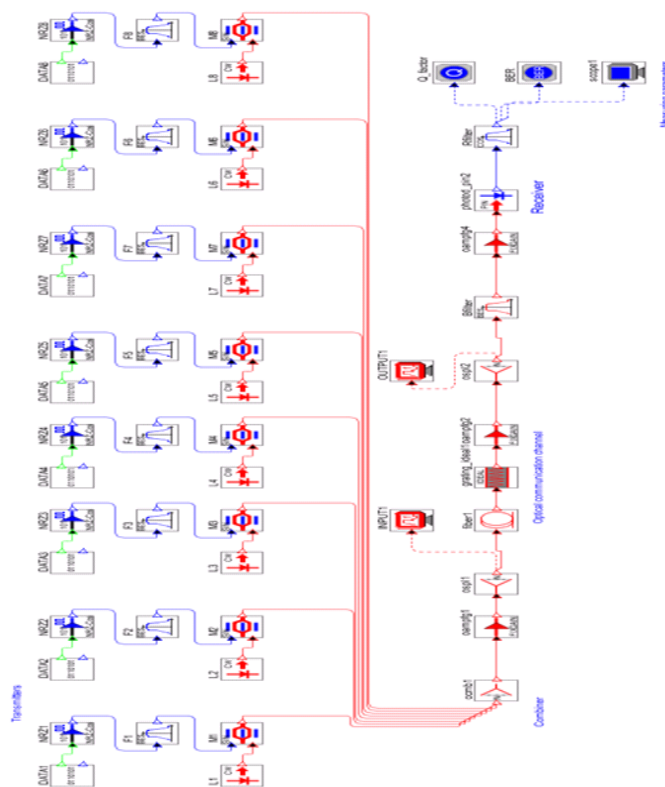


Figure 4: Simulation setup for 8 channel WDM communication system

V. SIMULATION RESULTS

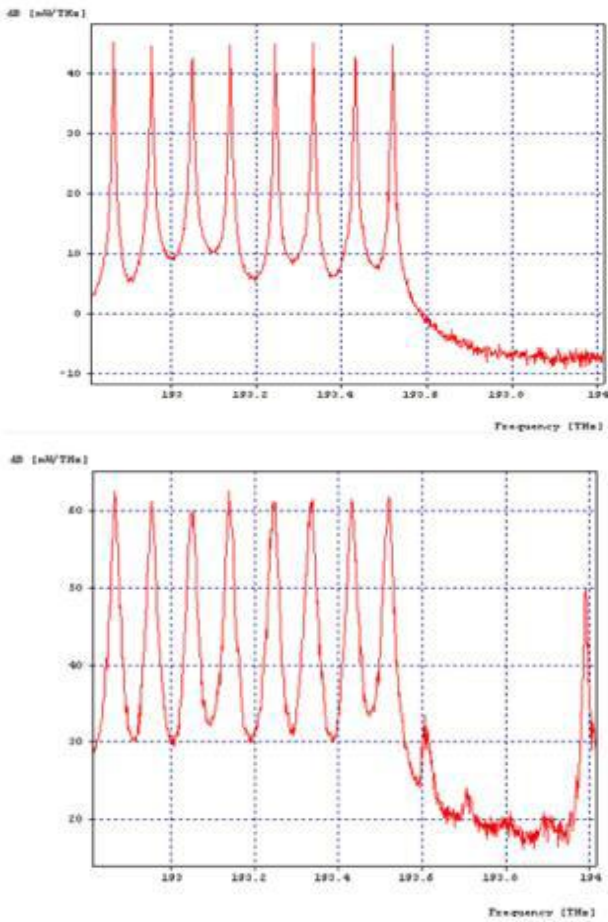


Figure 5: (a) Input pattern for more than 80 GHz channel spacing and (b) Output pattern

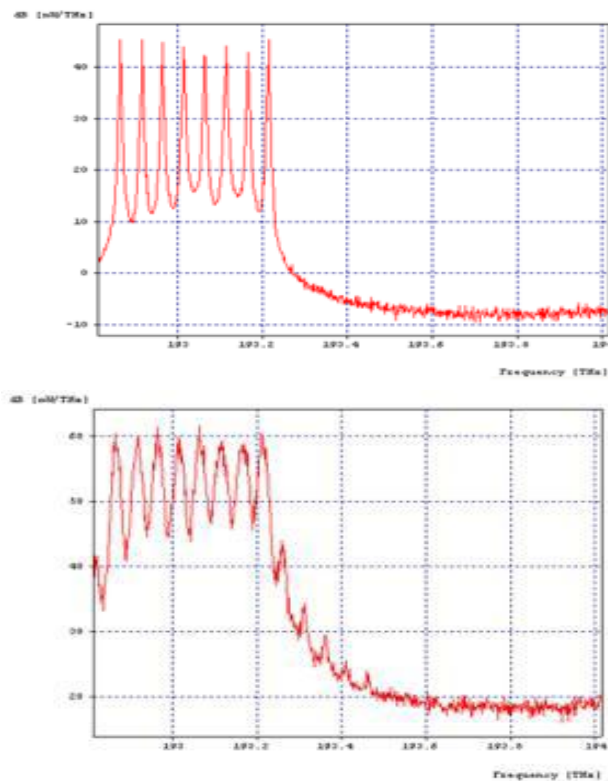


Figure 6: (a) Input pattern for between 40 GHz to 70GHz channel spacing and (b) Output pattern.

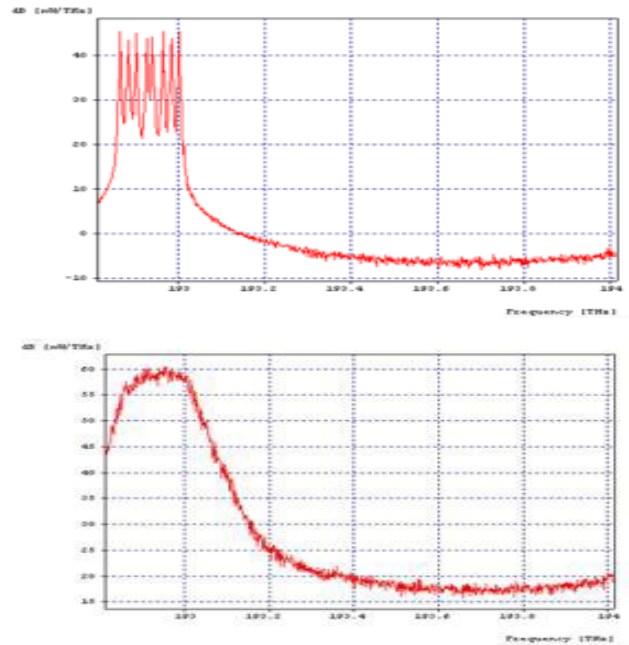


Figure 7: (a) Input pattern for less than 30GHz channel spacing and (b) Output pattern

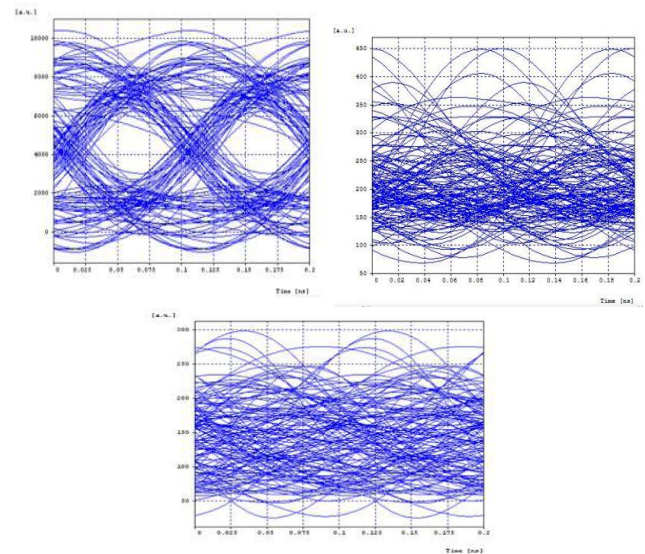


Figure 8: (a) Eye pattern for more than 95GHz channel spacing, (b) Eye pattern for between 40 to 70 GHz channel spacing, (c) Eye pattern for less than 30GHz channel spacing.

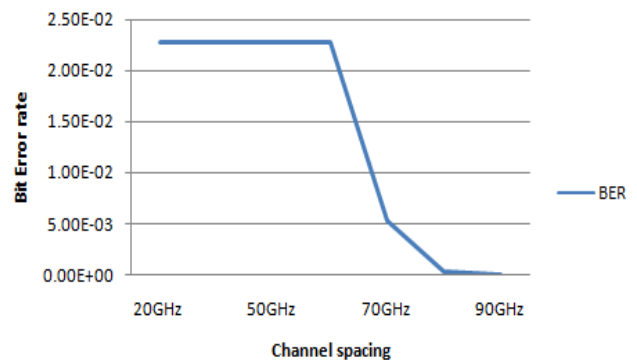


Figure 9: BER vs. channel spacing.

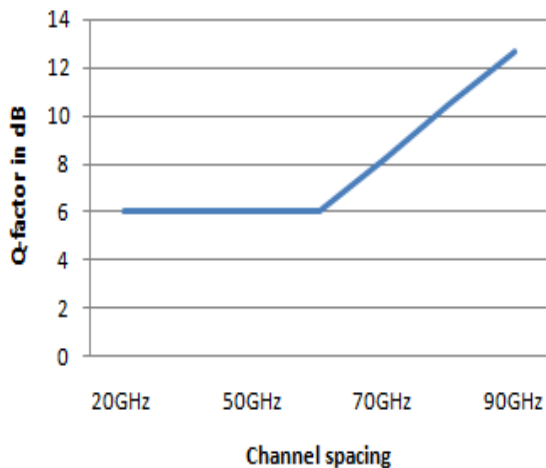


Figure 10: Q-FACTOR vs. channel spacing.

Using simulation setup, the value of BER, Q-factor, eye diagrams, input and output optical spectrums are measured. Optical scope measures the input and output wavelength spectrums. BER, eye diagrams and Q-factor is measured at the receiver output by using an electrical scope, Q estimator and BER estimator. Figure 5(a) shows the input optical spectrum for the spacing more than 80 GHz between input channels. On changing the spacing between the different users, the peaks get shifted to the frequencies as specified in the laser. It is observed that there are no unnecessary side peaks at the input of the fiber. There are eight input channels so eight peaks appear in the input spectrum. Figure 5 to Figure 7 represents the input and output spectrum for the various values of spacing between the input users. The four wave mixing effect is clearly seen in the above output spectrum for less than 30GHz spacing as unnecessary peaks at various frequencies are occurring at the sides of the input spectrum. Moreover, the peaks at the input frequencies have also diminished due to four wave mixing occurred after crossing the non linear fiber. The above spectrums shows that as the spacing between the input channels/users increases, the four wave mixing effect goes on decreasing. The unwanted peaks are maximum when the spacing is less than 30GHz and are minimum when the spacing is more than 80 GHz. This shows that lesser the spacing between different input users/channels, more is the interference between the input frequencies i.e. more is the four wave mixing effect. On increasing the spacing between the input channels, the four wave mixing decreases. Figure 8 shows the eye diagrams for the various values of channel spacing. The above eye diagrams show that the eye diagram clarity goes on increasing with the increasing spacing between the input channels. This shows that the interference between the input frequencies and hence the four wave mixing effect decreases with the increasing channel spacing. Figure 9 shows the variation of BER on the basis of spacing between the input channels. The figure shows that BER goes on decreasing with the increasing spacing. Figure 10 shows the variation of Q-factor with the spacing between the input channels. The graph shows that the Q-factor increases as the channel spacing increases. The comparative study of all the measured parameters for different channel spacing is given in Table 1 below.

Table 1: Comparative study of measured parameters.

Parameter	CHANNEL SPACING		
	Less than 30GHz	Between 40GHz to 70GHz	More than 80GHz
Q-factor (dB)	6.02060	8.27636	12.75983
BER	0.22750E-01	0.227681E-02	0.86281E-05
Eye opening	0.22340E+03	0.42204E+03	0.75052E+04

VI. CONCLUSION

In this paper, the design, implementation and performance analysis of four waves mixing in optical communication system for different values of spacing between input channels is presented. The comparison of four wave mixing effect at various values of channel spacing revealed that more than 80 GHz channel spacing has the edge over less than 30 GHz channel spacing in optical communication system. It is found that channel spacing of more than 80GHz has the lowest BER and higher Q-factor and gives better system performance. Hence, the higher channel spacing values between the input channels are recommended for long distance transmission without four wave mixing. Hence, it is concluded that higher channel spacing is best suitable to be employed in the optical communication systems minimizing the four wave mixing effect.

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