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Analysis of Four Wave Mixing Effect in WDM Communication System for Different Channel Spacing

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ABSTRACT

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.

General Terms

Analysis.

Keywords

Channel spacing, Eye diagram, Four Wave Mixing, nonlinear effects,Wavelength Division Multiplexing.

1. 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 WDMsystems [1]. For long distance light wave communication larger information transmission capacity and longer repeater-less distance are required.

When high power optical signal is launched into a fiber linearity of optical response is lost. Four-wave mixing is due to changes in the refractive index with optical power called opticalKerr effect. In FWM effect, two co-propagating wave produce two new opticalsidebands at different frequencies.Whennew frequencies fall in the transmissionwindow oforiginal 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.

2. FOUR WAVE MIXING

Optical fiber nonlinearities can lead to interference, distortion, and excess attenuation of the optical signals, 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 asKerr 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 Kerreffect, 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 afiber, giving rise to a new wave (know as an idler), the wavelength of which does not coincide with anyof 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 canbe seen, the light that was there from before launching, sandwiching the two pumping waves inthe frequency domain, is called the probe light (or signal light). The idler frequency f_{idler} maythen be determined by

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

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].

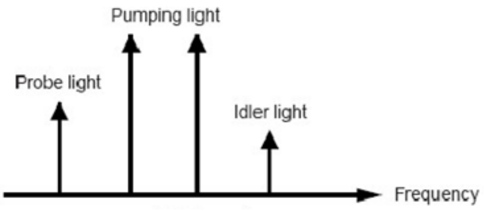


Figure 1: Two channel pump wave

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].

Applications of FWM:

1. Parametric amplification.
2. Optical phase conjugation.
3. Demultiplexing of OTDM channels.
4. Wavelength conversion of WDM channels.
5. Super-continuum generation.

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. In the FWM effect, three co- propagating waves produce nine new optical sideband waves at different frequencies. When this new frequency falls in the transmission window of the original frequencies, it causes severe cross talk between the channels propagating through an optical fiber.

The number of the side bands use to the FWM increases geometrically, and is given by,

$$M = \left[\frac{N^3-N^2}{2}\right] \qquad (2)$$

Where, N is the number of channels and M is the number of newly generated side bands. For example, eight (8) channels produce 224 side bands. The Figure 2 shows the FWM products due to increase in channels [5].

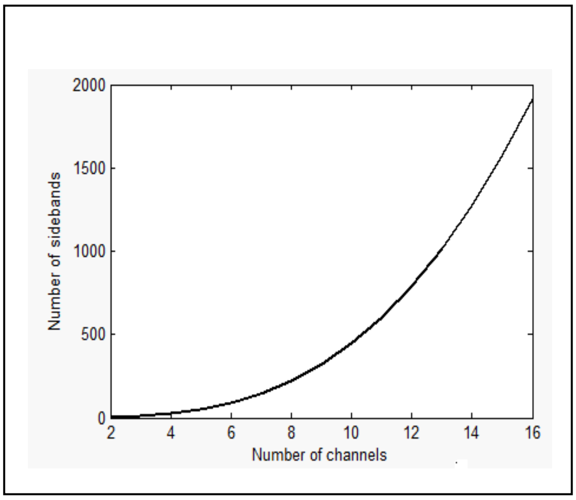


Figure 2: Number of FWM products.

3. 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.

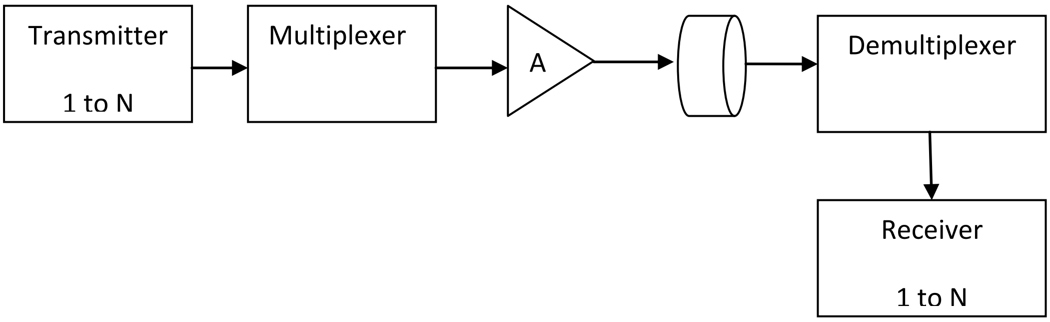


Figure 3: Schematic model for WDM communication system.

4. 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 thecarrier 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 arespaced evenly but at different values like 20 GHz, 30GHz, 50GHz, 70 GHz, 75 GHz, 90GHz and 95GHz.

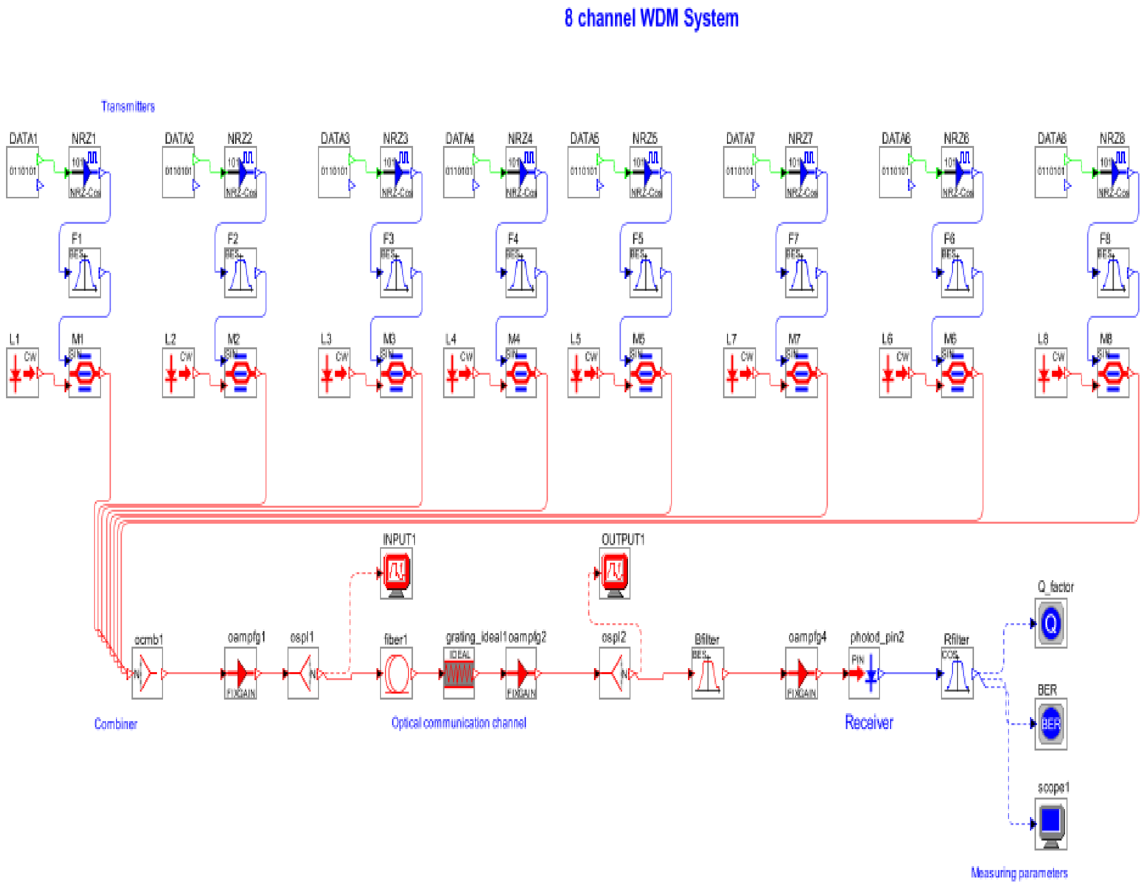


Figure 4: Simulation setup for 8 channel WDM communication system.

5. RESULTS AND DISCUSSION

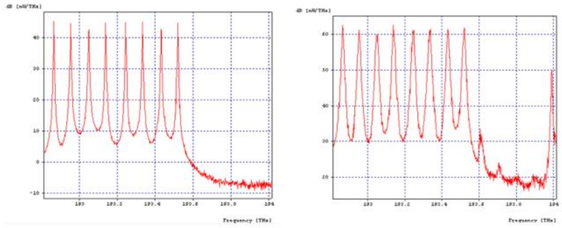


Figure 5: (a) Input pattern for 95GHz channel spacing and (b) Output pattern.

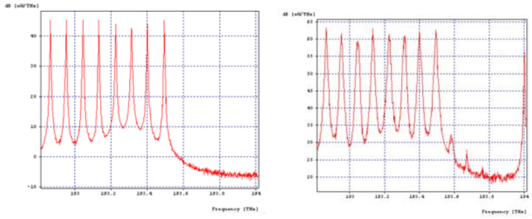


Figure 6: (a) Input pattern for 90GHz channel spacing and (b) Output pattern.

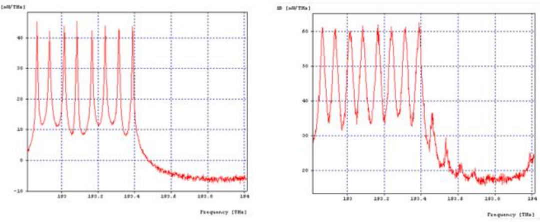


Figure 7: (a) Input pattern for 75GHz channel spacing and (b) Output pattern.

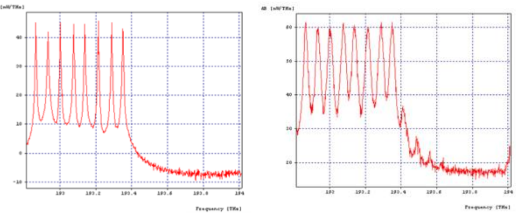


Figure 8: (a) Input pattern for 70GHz channel spacing and (b) Output pattern.

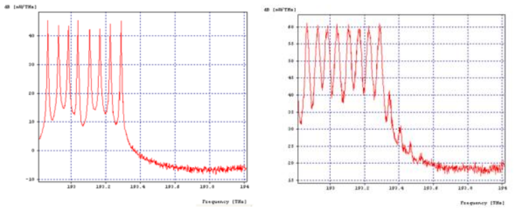


Figure 9: (a) Input pattern for 60GHz channel spacing and (b) Output pattern.

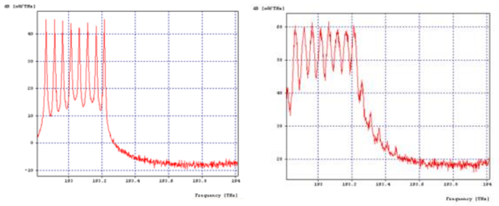


Figure 10: (a) Input pattern for 50GHz channel spacing and (b) Output pattern.

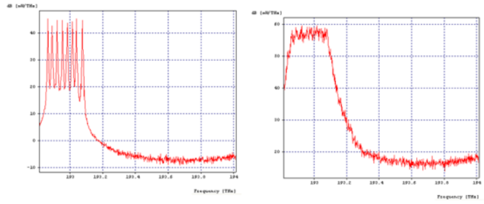


Figure 11: (a) Input pattern for 30GHz channel spacing and (b) Output pattern.

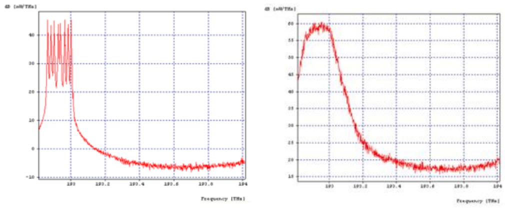
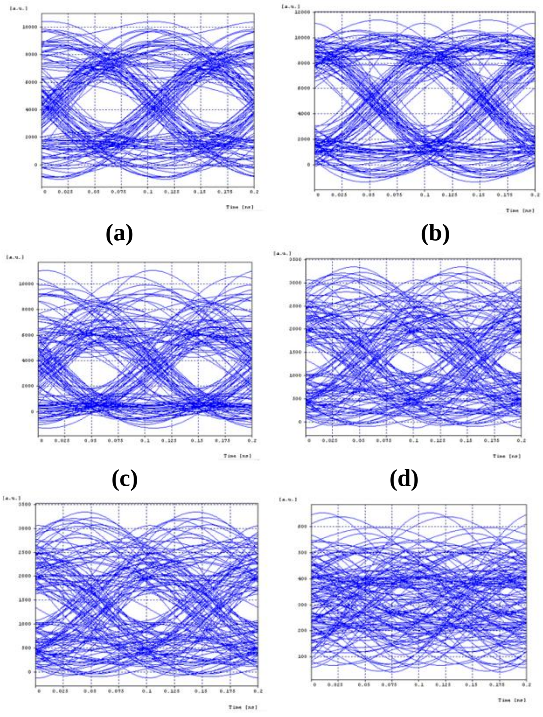


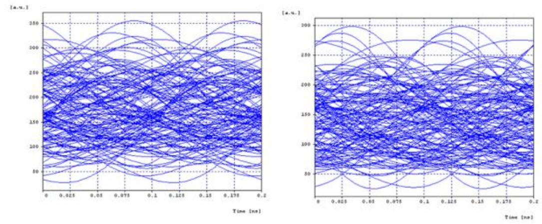
Figure 12: (a) Input pattern for 20GHz channel spacing and (b) Output pattern.



(a) **(b)**

(c) **(d)**

(e) **(f)**



(g) **(h)**

Figure 13: (a) Eye pattern for 95GHz channel spacing, (b) Eye pattern for 90GHz channel spacing,(c) Eye pattern for 75GHz channel spacing , (d) Eye pattern for 70GHz channel spacing ,(e) Eye pattern for 60GHz channel spacing , (f) Eye pattern for 50GHz channel spacing ,(g) Eye pattern for 30GHz channel spacing , (h) Eye pattern for 20GHz channel spacing.

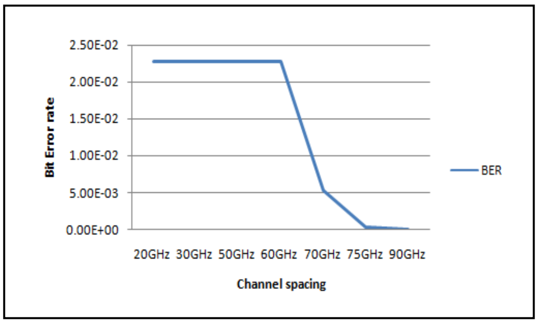


Figure 14: BER vs. channel spacing.

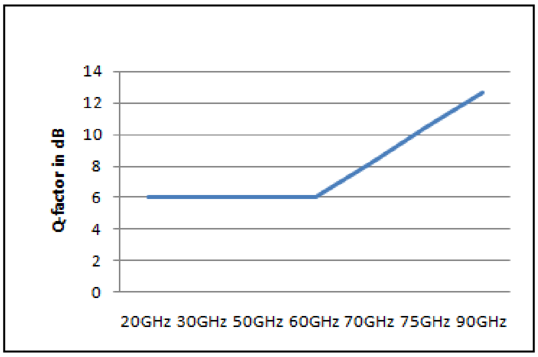


Figure 15: BER vs. channel spacing.

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 of 95 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 Figure12 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 20GHz 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 thespacing is 20GHz and are minimum when the spacing is 95GHz. This shows that lesser thespacing between different input users/channels, more is the interference between the inputfrequencies i.e. more is the four wave mixing effect. On increasing the spacing between the inputchannels, the four wave mixing decreases.

Figure 13 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 interferencebetween the input frequencies and hence the four wave mixing effect decreases with the increasing channelspacing.

Figure 14 shows the variation of BER on the basis of spacing between the input channels. Thefigure shows that BER goes on decreasing with the increasing spacing.

Figure 15 shows the variation of Q-factor with the spacing between the input channels.The graph shows that the Q-factor increasesas thechannel spacing increases. It is maximum when the channel spacing is 95 GHz and is minimum when the channel spacing is 20 GHz.

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							
	20GHz	30GHz	50GHz	60GHz	70GHz	75GHz	90GHz	95GHz
Q-factor (linear)	2.00000	2.00000	2.00000	2.00000	2.58070	3.34055	4.30506	4.34502
Q-factor (dB)	6.02060	6.02060	6.02060	6.02060	8.23474	10.47636	12.67959	12.75983
BER	0.22750E-01	0.22750E-01	0.22750E-01	0.22750E-01	0.52921E-02	0.37681E-03	0.83581E-05	0.86281E-05
Eye opening	0.22340E+03	0.22340E+03	0.22340E+03	0.46430E+03	0.16669E+04	0.59204E+04	0.71059E+04	0.75052E+04

6. CONCLUSION

In this paper, the design, implementation and performance analysis of four wave 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 95 GHz spacing has the edge over 20 GHz spacing in optical communication system. It is found that spacing of 95GHz has the lowest BER and better system performance.

Hence, the higher spacing values between the input channels are recommended for long distance transmission without four wave mixing. It can be seen from the graphs of BER, Q-factor and eye opening that higher channel spacing gives the best performance as compared to lower channelspacing. 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. The results are in accordance with the study reported in [3, 8].

In the transmission of dense wavelength-division multiplexed (DWDM) signals, FWM is to be avoided, but for certainapplications, it provides an effective technological basis for fiber-optic devices. FWM alsoprovides the basic technology for measuring the nonlinearity and chromatic dispersion of opticalfibers.

7. REFERENCES

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