Survey of Four Wave Mixing with Different Number of Channels under the Impact of Different Channel Spacing

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Abstract—In this paper, literature survey of four wave mixing (FWM) effect in optical communication system for different number of inputs channels at various channel spacing. It reveals that FWM is minimum when minimum number of input channels with maximum channel spacing. It is also studied that on increasing the channel spacing, the interference between the propagating waves decreases and hence FWM effect also decreases. Also, on increasing the number of users or reducing the channel spacing, the interference between the input frequencies increases and thus the FWM effect also increases.

Keywords— FWM, Number of users, channel spacing, BER, Q-factor, Eye Pattern.

1. Introduction

To increase the information carry capacity, optical core network is one of the most efficient techniques. As the broadband techniques is speedily growing everywhere in the world, internet traffic is enhancing day by day [1]. Optical network have been consider the only medium to deliver the bulky traffic in a flexible, genuine and reliable way [2]. Dense wave division multiplexing (DWDM) is a transparent technique that employs light wavelength to transmit the data in a flexible and dynamic way to achieve high network capacity [3]. To improve the network performance, studies of various nonlinear optical effects are very important. Optical fiber nonlinear effect may result into interference, attenuation and distortion of optical signal which result into poor performance of the system [4].The most common nonlinear effects in optical fiber communication due to fiber nonlinear refractive index. The non linearity in the refractive index is known as Kerr non linearity. The nonlinearity produces a carrier induced phase modulation of the propagating signal, which is called as the Kerr effect [4, 5]. The Kerr nonlinearity gives rise to various effects such as Self phase modulation (SPM), Cross phase modulation (XPM) and four wave mixing (FWM) [4]. In single-wavelength links, this gives rise to self phase modulation, which converts optical power fluctuations in a propagating light wave to spurious phase fluctuations in the same wave [5]. Modulation is the frequency change caused by a phase shift induced by the pulse itself. Thus, SPM causes pulse spreading through chromatic dispersion, so it can distort the performance of a communication system [8]. Cross-phase modulation which converts power fluctuations in a particular wavelength channel to phase fluctuations in other co-propagating channels [5]. XPM hinders system performance through the same mechanism as SPM such as chirping frequency and chromatic dispersion [8]. This can be greatly mitigated in DWDM systems operating over standard non-dispersion-shifted single-mode fiber, but can be a significant problem in DWDM links operating at 10Gb/s and higher over dispersion-shifted fiber. When combined with fiber dispersion, the spectral broadening from SPM and XPM can be significant limitation in a very long transmission links, such as cross-country or undersea systems [5].

FWM is one of the dominating degradation effects in 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 that is 100% dispersion compensation per span, the FWM crosstalk occurs at its maximum [4].DWDM transmission in which individual wavelength

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channels are modulated at rates of 10 Gb/s offers capacities of N x 10 Gb/s, where N is the number of wavelength. To transmit such high capacities over long distances requires operation in the 1550-nm window of dispersion-shifted fiber. In addition, to preserve an adequate signal to noise ratio, a 10 Gbps system operating over long distances and having nominal optical repeater spacing of 100 km needs optical launch powers of around 1 mW per channel. For such DWDM systems, the simulations requirements of high launch power and low dispersion give rise to the generation of new frequencies due to four-wave mixing. FWM is a third order nonlinearity in silica fibers that is analogous to intermodulation distortion in electrical systems. When wavelength channels are located near the zero-dispersion point, three optical frequencies (V_i,Vj,V_k) will mix to produce a fourth intermodulation product V_{ijk} given by

$$V_{ijk} = Vi + Vj - Vk$$

When this new frequency falls in the transmission window of the original frequencies, it can causes severe crosstalk [5]. Multiwave mixing, especially FWM, is a fundamental process in nonlinear optics. Nonlinearity couples the underlying modes, generating new sum and differences frequencies from the original waves [6]. The occurrence of FWM depends on several factors, such as the frequency spacing between channels, the input power per channel, the dispersion characteristics of the optical fiber, and the distance along which the channels interact. The FWM is one of the major and significant degrading factors in WDM and DWDM optical communication systems [7].

2. Basic Principle

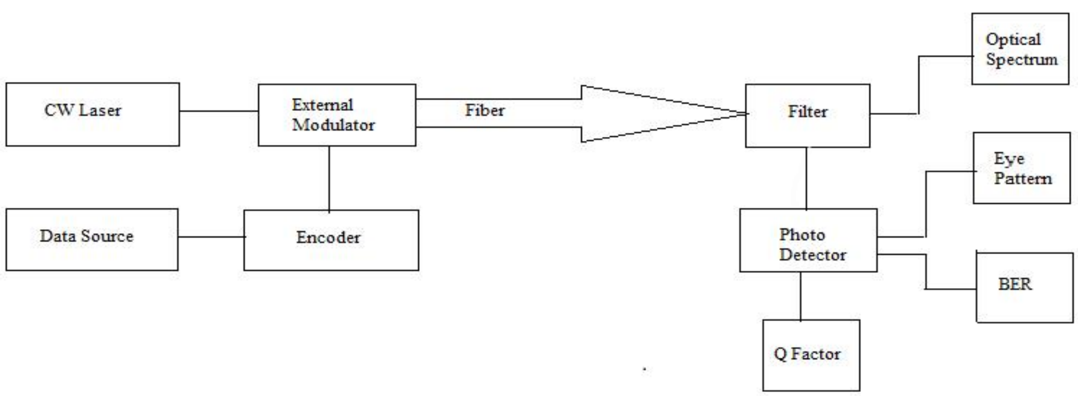

Fig. 1. Different number of channel with different channel spacing in the presence of FWM.

The basic fig.1 shows that different numbers of input channels are combined at the input with the help of optical coupler. The numbers of channels are driven by with the help of CW laser. The external modulator is driven by an Electrical signal with corresponding data rate e.g. RZ, NRZ. Depending on the electrical driving signal, different transmission speeds can be realized. All the modulated signals are multiplexed by an ideal optical multiplexer whose ports are varied as according to the number of input channels. The output of the multiplexer forms a single fiber output sent over the fiber of a specified distance. The post-amplifier, in-line amplifier and pre-amplifier are used in case of long transmission distance. It is optically filtered such that the optical power within a definite wavelength window is only transmitted and the rest is either reflected or absorbed. At the receiver end, the various channels are splitter with the help of optical splitter. The various channels are received at their desire destinations. An optical compound sensitivity receiver follows the link which converts the filtered optical signal to

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electrical signal. The BER estimator, an eye diagram, optical spectrum and Q-factor are used to measure and evaluate the system performance.

3. Techniques Used For Analysing Fwm Effect

3.1 EYE PATTERN

The eye-pattern is a simple but powerful measurement method for assessing the data-handling ability of a digital transmission system. This method has been used extensively for evaluating the performance of wire systems and can also be applied to optical fiber data links. The eye-pattern measurements are made in the time domain and allow the effects of waveform distortion to be shown immediately on an oscilloscope [5].

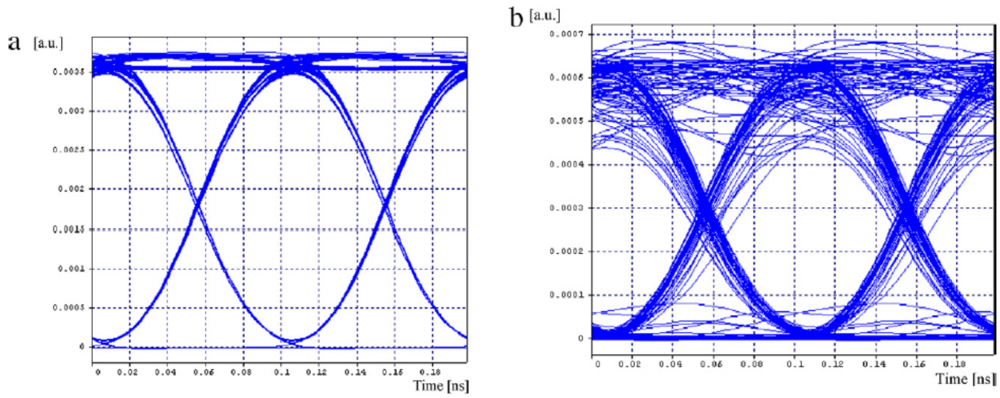

Fig. 2. Eye diagram with different number of input channel with different channel spacing.

Comparing the eye diagrams in Fig. 2, it is observed that on increasing the number of input channels/users, the interference increases and thus, the four wave mixing effect also increases. Analyzing the effect of increasing the channel spacing can be seen. The interference between input frequencies decreases on increasing channel spacing and hence, the four wave mixing effect also decreases [4].

3.2 OPTICAL SPECTRUM ANALYZER

The widespread implementation of WDM systems calls for making optical spectrum analyses to characterize the spectral behavior of various telecommunication network elements. A variety of optical spectrum analyzers (OSAs) with different degrees of capabilities, such as wavelength resolution, are available to measure the optical output or transfer characteristics of a device as functions of wavelength. The wavelength resolution is determined describes the width of this optical filter in th OSA. The term resolution bandwidth describes the width of this optical filter. Typical OSA normally sweeps across a spectral band making measurements at discretely spaced wavelength points. This spacing depends on the bandwidth-resolution capabilities of the instruments, and is known as trace-point spacing [5].

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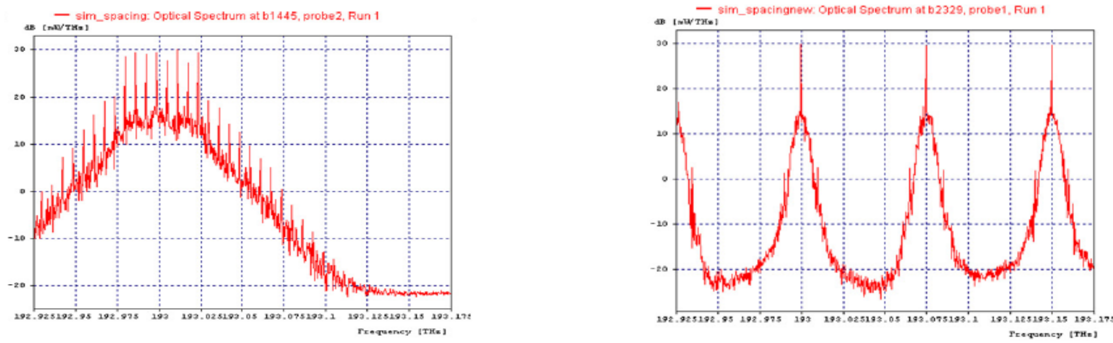

Fig. 3. Optical Spectrum Analyzer with different number of input channel with different channel spacing.

Fig. 3 represents the 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 low spacing as unnecessary peaks at variousfrequencies are occurring at thesides of the input spectrum. Moreover,the peaks at the input frequencies have also diminisheddue to four wave mixing occurred after crossing the nonlinearfiber. The above spectrums show 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 low and are minimum when the spacing is high. 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 [6].

3.3 BIT ERROR RATE

In practices, there are several standard ways of measuring the rate of error occurrence in a digital data stream. One common approach is to divide the number N_e of errors occurring over a certain time interval t by the number $N_t$of pulses (ones and zeros) transmitted during this interval. This is called either the error rate or the bit error rate, which is commonly abbreviated BER. Thus, we have

$$BER = N_e/N_t= N_e/B_t$$

Where $B=1/T_b$ is the bit rate. The error rate is expressed by a number, such as 10^{-9}, for instance, which states that, on the average, one error occurs for every billion pulses sent. Typical error rates for optical fiber telecommunications systems range from 10^{-9} to 10^{-12}. This error rate depends on the signal-to-noise ratio at the receiver.

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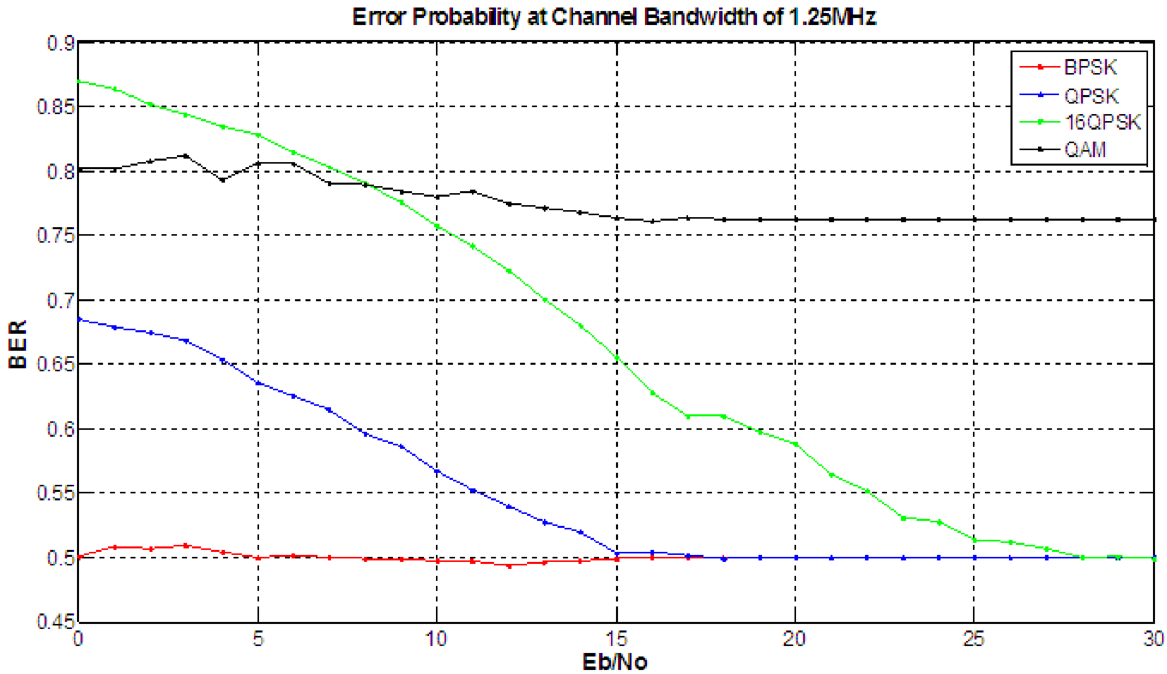

Fig. 4. Variation of BER with different number of input channel with different channel spacing.

Fig. 4 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 [6].

3.4 Q-FACTOR

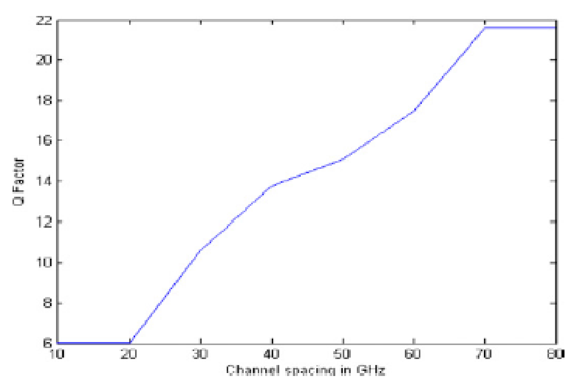

Fig. 5. Variation of Q Factor with different number of input channel with different channel spacing

We derive an analytical expression that explicitly relates the Q-factor to the optical signal-to-noise ratio in optical fiber transmission systems with any given pulse shape and receiver characteristics using an accurate receiver model. Fig. 5 shows the variation of Q-factor with the spacing between the input channels. The graph shows that the Q-factor increases on increasing the channel spacing. It is maximum when the channel spacing is high and is minimum when the channel spacing is low [6].

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4. Conclusion

It reveals that on increasing the number of input users, the interference increases and thus FWM effect also increases. The eye opening decreases as the number of channel increases. Increase in number of channel which results into decrease in Q factor. Moreover, as user increases, BER increases. It can be seen from the graphs of BER. Q factor, optical spectrum and eye opening that higher channel spacing gives the best performances as compare to lower channel spacing. Thus it is revealed that FWM is minimum when number of channel is minimum and channel spacing is maximum.

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