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Effects of Four Wave Mixing on an Optical WDM System by using Dispersion Shifted Fibre

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ABSTRACT

The trend toward higher bit rates in lightwave communication has interest in dispersion-shifted fibre to minimize dispersion penalties. At the same time optical amplifiers have increased interest in wavelength multiplexing. These two methods of increasing system capacity if used together can result in severe degradation due to fibre nonlinearity. So the effect of dispersion, input power, fibre length and channel spacing on the bit error rate and received or resultant power are investigated in our study. The performances are analyzed in terms of transmitted channel power, channel spacing and bit error rate (BER) of the system.

Keywords: *Dispersion shifted fibre (DSF), four-wave mixing (FWM), signal to noise ratio (SNR), bit error rate (BER), wavelength division multiplexing (WDM).*

1. INTRODUCTION

Optical fibre communication provides a very large bandwidth (50 THz) and it becomes the most modern means of communication. To utilize the available bandwidth, we can multiplex numerous channels on the same fibre and to increase system margins, higher transmitter power or lower fibre losses are required [1].

Optical wavelength division multiplexing (WDM) systems using low dispersion fibres and erbium-doped fibre amplifier (EDFA) are very attractive to meet up the growing demand for broadband information distribution networks. WDM systems having high bit rate with a span of thousands of kilometer have become a reality [2-4]. However, these networks suffer performance degradation because of fibre nonlinear effects, such as stimulated Raman scattering, stimulated Brillouin scattering, self and cross phase modulation and, more importantly, Four wave mixing(FWM) [5-6]. FWM effect generates new frequency components some of which may interfere with the transmitted signals [6]. Unequal channel spacing can be employed so that no FWM component has the same frequency as that of any channel [7]. So interference will be greatly reduced. Even when unequal channel spacing is used, the system may suffer from power depletion because of new FWM components. Uniform chromatic dispersion effect favors the generation of FWM components [8]. In this paper we try to analyze the performance of an optical WDM communication system under the effect of FWM. The ratio of generated mixing-product power to transmitted channel power versus channel spacing and bit error rate (BER) of an optical WDM system by using dispersion shifted fibre are evaluated.

2. METHODS

The four-wave mixing phenomenon is one of the dominating nonlinearities in optical fibres. The other nonlinear effects by which the degradation of the transmission characteristics in Wavelength Division Multiplexing (WDM) using dispersion shifted fibre occurs are Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), chromatic dispersion, self and cross-phase modulation. The FWM characteristics are related to frequency allocation of channels.

In FWM interactions, a forth wavelength light is generated from three lights of different wavelengths. With the increase in number of channel the number of FWM light is drastically increased. When three light passes through an optical transmission system a fourth light frequency is produced by the interactions among those three intelligence lights. This newly produced light is known as FWM light and the phenomenon is known as Four wave mixing. It originates from the weak dependence of the fibre refractive index on the intensity of the optical wave propagating along the fibre through the third order non linear susceptibility.It 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. The simplest embodiment is shown in figure 1.

Two co-propagating waves at frequencies f_1 and f_2 mix and generate sidebands at $2f_1$-f_2 and $2f_2$-f_1.These sidebands copropagate with the initial waves and grow at their expense. Similarly, three copropagating waves will generate nine new optical waves at frequencies $f_{ijk}=f_i+f_j-f_k$ where i,j,k can be 1,2 or 3.If the channels are equally spaced, some of the generated waves will have the same frequencies as the injected waves. Clearly the appearance of the additional waves as well as the depletion of the initial waves will degrade multichannel systems by crosstalk or excess attenuation.

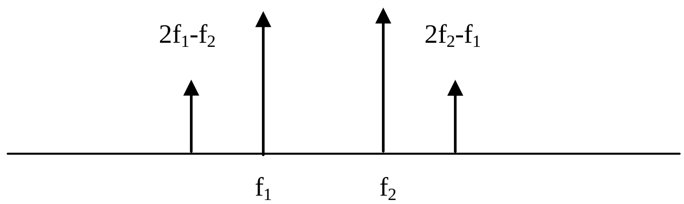

Figure 1: Four wave mixing with injected wave at frequency f_1 and f_2

3. EFFECT OF FWM

By FWM the following effect occurs in the optical fibre

i. To produce the new optical waves the signal power is reduced. This is known as power depletion.

ii. In multichannel system several channels are transmitted with several equally spaced frequencies. So some of these mixing products will occur at or near some of the operating wavelengths. These new optical waves interfere destructively with the signal and degrade the system performance.

4. THEORETICAL ANALYSIS

Four-photon mixing is a third-order nonlinearity in silica fibres, which is analogous to intermodulation distortion in electrical systems, so that in multichannel systems three optical frequencies mix to generate a fourth

$$f_g = f_i + f_j + f_k \quad (1)$$

If we assume that the input signals are not depleted by the generation of mixing products, the magnitude of this new optical signal is given by (in esu)

$$P_g = \frac{1024\Pi^6}{n^4\lambda^2c^2}\left(\frac{3d\chi_{1111}L_{eff}}{A_{eff}}\right)^2 P_iP_jP_k e^{-\alpha L}\eta \quad (2)$$

Where η is the refractive index, λ is the wavelength of the light , c is the speed of light, P_i, P_j, P_k are the input powers of the channels, L_{eff} is the effective length of the fibre, given by

$$L_{eff} = \frac{1}{\alpha}\left(1-e^{-\alpha L}\right) \quad (3)$$

with α the fibre loss , here taken to be 0.2 dB/km. A_{eff} is the effective area of the fibre, d is the degeneracy factor, which takes value 1 and 2 for degenerate and nondegenerate terms, respectively, and $\chi_{1111}=4\times10^{-15}$ esu is the nonlinear susceptibility. The nonlinear susceptibility can be expressed in terms of the nonlinear index of refraction n_2, in the case of a single polarization, as

$$\chi_{1111}[esu]= \frac{cn^2}{480\pi^2} n_2[m^2/W] \quad (4)$$

The efficiency η is given by

$$\eta = \frac{\alpha^2}{\alpha^2+\Delta\beta^2}\left(1+\frac{4e^{-\alpha L}\sin^2(\Delta\beta L/2)}{\left(1-e^{-\alpha L}\right)^2}\right) \quad (5)$$

The quantity $\Delta\beta$ is the difference of the propagation constants of the various waves due to dispersion and for a two-tone product with channel spacing Δf, is given by

$$\Delta\beta=\beta_g+\beta_k-\beta_j-\beta_i=\frac{2\pi\lambda^2}{c}\Delta f^2\left(D + \Delta f\frac{\lambda^2}{c}\frac{dD}{d\lambda}\right) \quad (6)$$

Where the dispersion D and its slope are computed at λ_k. This analysis has been extended to multiple amplified spans. For sufficiently low fibre chromatic dispersion $\Delta\beta\approx0$ and $\eta\approx1$. If in addition all channels have the same power P_{in}, the ratio of the generated power P_g to the transmitted power of the channel P_{out} can be written as

$$\frac{P_g}{P_{out}} = \frac{1024\pi^6}{n^4\lambda^2c^2}\left(\frac{d\chi^{(3)}L_{eff}}{A_{eff}}\right)^2 P_{in}^2 \quad (7)$$

For theoretical analysis here we use the following equation

$$P_g = \kappa L_{eff}^2 P_i P_j P_k e^{-\alpha L} \eta \qquad (8)$$

Where,

$$\kappa = \frac{1024\pi^6}{n^4 \lambda^2 c^2} (3\chi)^2 \frac{1}{A_{eff}^2} \qquad (9)$$

The probability of error can be expressed as

$$P_e = \frac{1}{\sqrt{2\pi}} \int_Q^{\infty} \exp[-\frac{t^2}{2}] dt \qquad (10)$$

5. RESULTS AND DISCUSSION

Following the analytical approach presented in section 4, we evaluated the performance in terms of transmitted channel power, channel spacing, bit error rate (BER) and the power penalty of the system. For the convenience of the readers the parameters used for computation in this paper are shown in table 1.

Table 1: System Parameters used for computation

Parameter	Properties
Length	50km
Loss	.25dB/km
Dispersion	dD/dλ=.07ps/nm^2-km (Dispersion-shifted) D=17ps/nm-km (Nondispersion-shifted)
Nonlinearity κ	5.84×10^{-6} m^{-2}W^{-2} (Dispersion-shifted) 2.44×10^{-6} m^{-2}W^{-2} (nondispersion-shifted)

In figure 2 we represent the plots of bit-error-ratio curves for the D=-0.2ps/nm-km case at three different launched powers. Values quoted are for the total launched power of the three channels. The plots show that, with the increase in received power the bit error rate decreases. Again for the same received power as input power increases bit error rate increases.

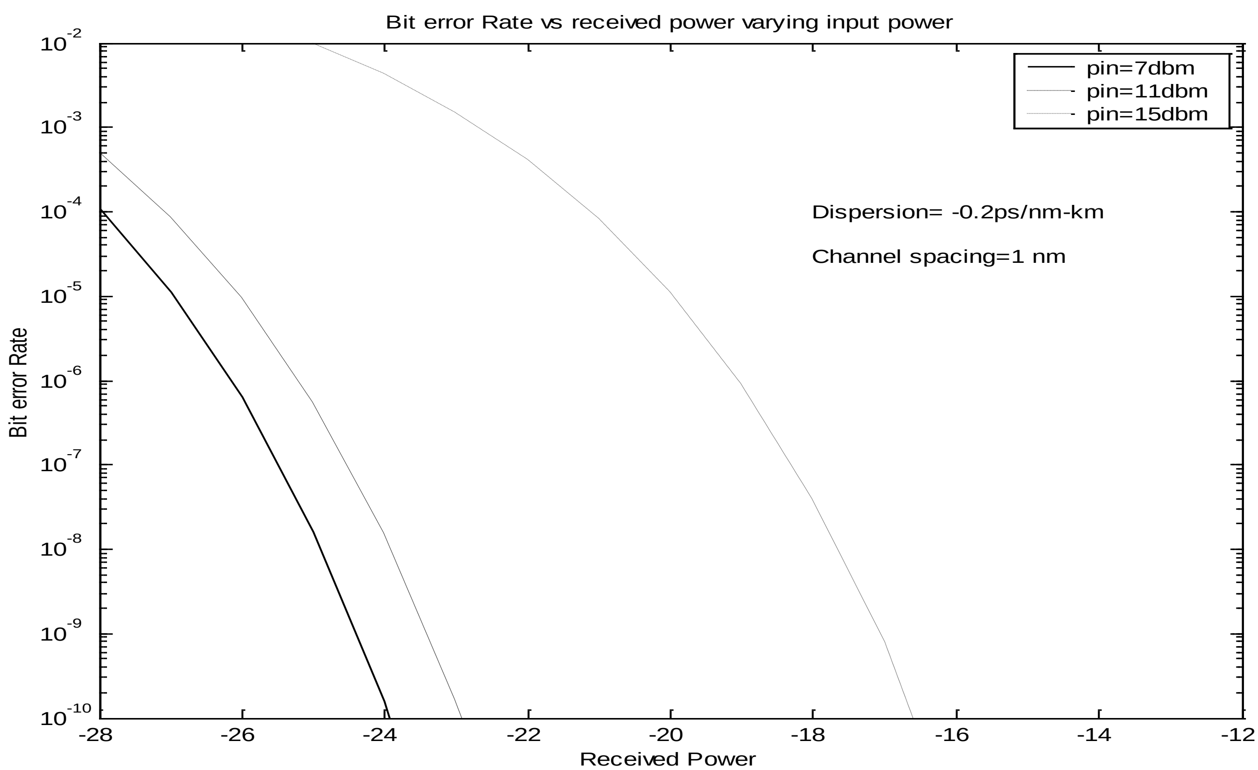

Figure 2: Plots of bit-error-rate vs. received power varying input power

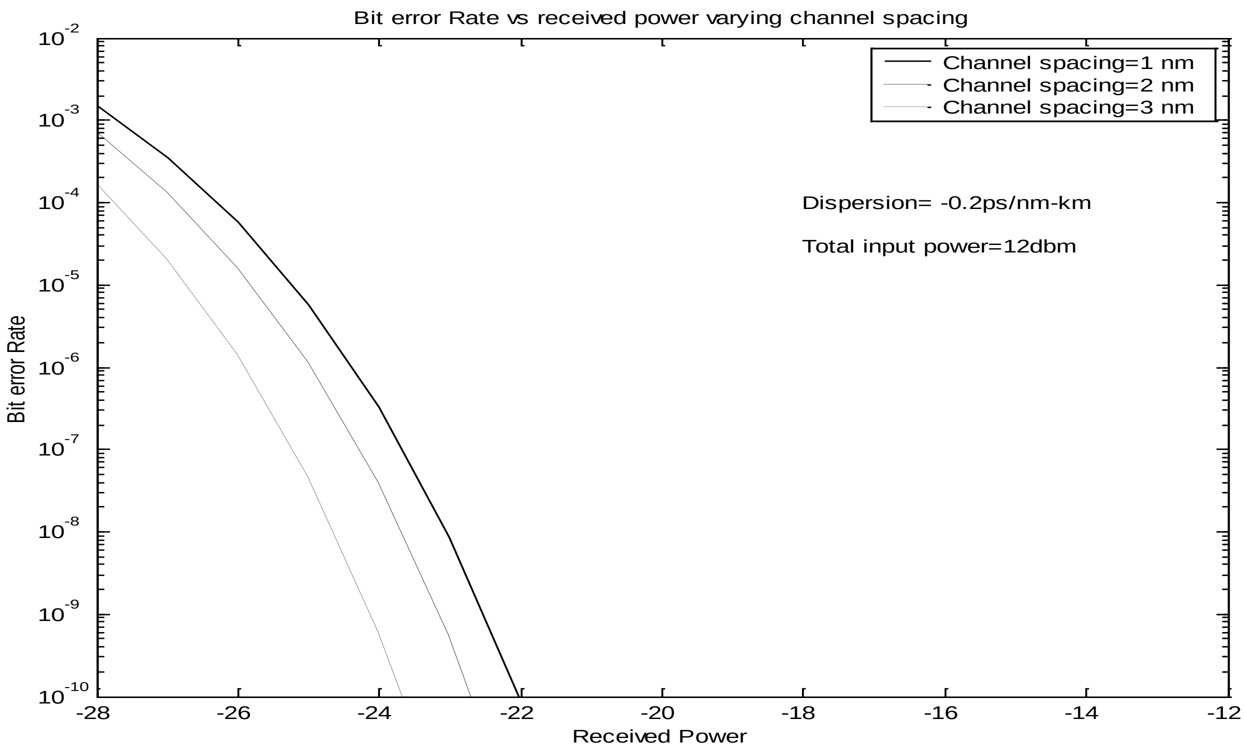

Figure 3: Plots of bit error rate vs. received power varying channel spacing

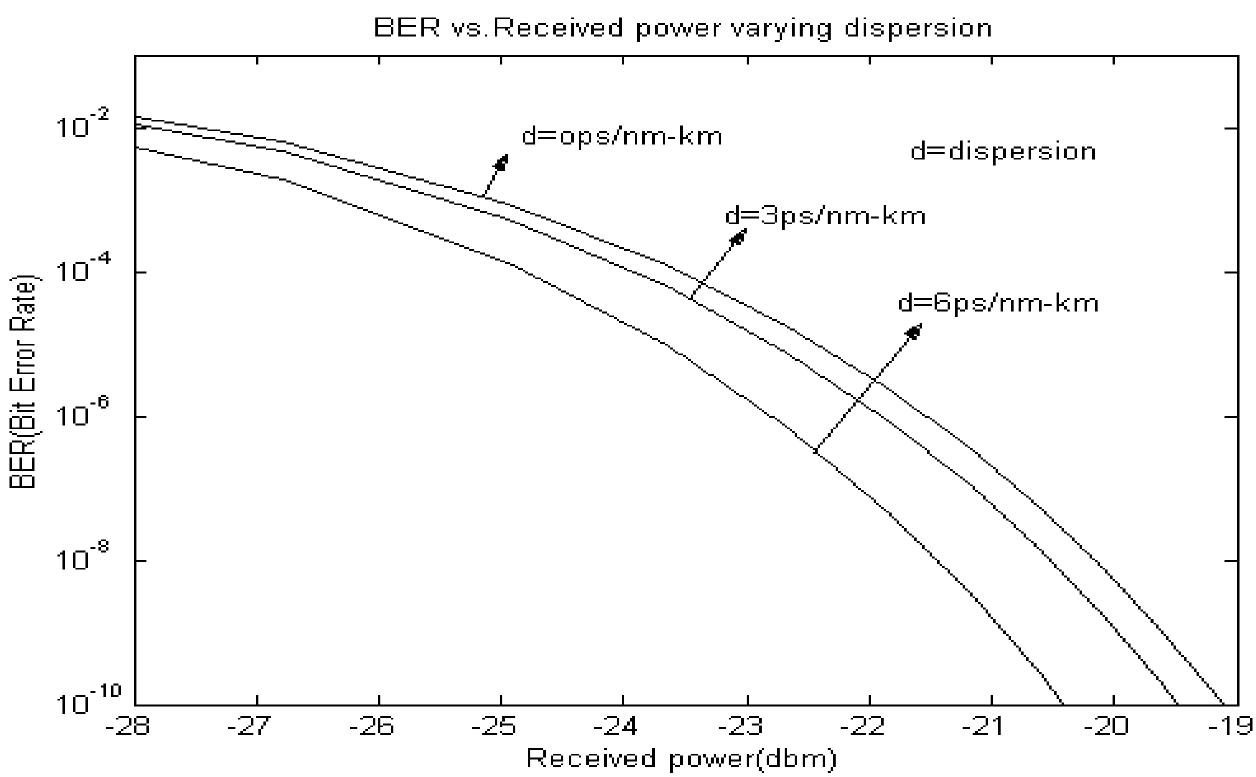

Figure 4: Plots of bit error rate vs. received power varying dispersion

figure 3 shows the plots of bit error rate vs. received power with varying channel spacing. From the above figure we found that, for the same received power if channel spacing is increased then bit error rate will decrease.

Figure 4 represents the plots of bit error rate vs. received power with varying dispersion. From the plots it is clear that for the same received power if dispersion increases then bit error rate decreases.

6. CONCLUSION

We have investigated the effect of FWM in an optical wavelength division multiplexed (WDM) communication system. FWM lights degrade the performance of the system and as the number of channel increases, the no. of FWM lights increases almost exponentially. To reduce this nonlinear phenomenon we can use equal channel spacing scheme. But it produces large number of FWM light with the same frequency of the intelligence signals. Then we can use unequal channel spacing so that FWM lights produced do not coincide with the intelligence channel. This has the problem of requiring large bandwidth. The management of fibre dispersion can also reduce the effect of FWM in a WDM system. Low chromatic dispersion fibre causes high FWM efficiency, but if dispersion is increased with channel spacing then the FWM efficiency is reduced.

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