Optics & Laser Technology 76 (2016) 64–69

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Investigation on four wave mixing effect in various optical Fibers for different spectral efficient orthogonal modulation Formats

Surinder Singh*, Sukhbir Singh

Department of Electronics and Communication Engineering, Sant Longowal Institute of Engineering & Technology, Sangrur, Longowal, Punjab 148106, India

ARTICLE INFO

Article history:
Received 17 February 2015
Received in revised form
11 July 2015
Accepted 21 July 2015
Available online 7 August 2015

Keywords:
FWM
Orthogonal modulation formats
Channel spacing
BER

ABSTRACT

The paper analyzes the four wave mixing (FWM) effect in different spectral efficient orthognal modulation formats at equal channel spacing of 100 GHz and 50 GHz to design long haul wavelength division multiplexing (WDM) optical system. Further, the comparison of reduction of FWM for existing and proposed modulation format have been analyzed by varying the laser input power from −10 dBm to 10 dBm.

1. Introduction

In rapid growth of optical communication systems, the demand for higher information capacity is more because of growth in multimedia traffic such as internet usage, VoD (video on demand), cloud computing, and streaming videos and voice. In addition to pack more channels into limited bandwidth, orthogonal modulation formats and WDM multiplexing techniques are emerging and promising alternative [1,2]. Orthogonal modulation formats has high compact spectrum and more tolerance to phase noise. Therefore, it can go through less channel spacing to put more channels close to each other to improve spectral efficiency optical communication system and WDM technique for the long haul of high capacity optical transmission system in present time to fulfill demand of data rate above 40 Gb/s. These technologies are suggested to increase total information capacity of single fiber with less channel spacing of <100 GHz [3,4]. Orthogonal modulation techniques have better exploitation of the existing optical transmission network as emerging and promising technologies due to their large information carrying capacity, flexible scalability and enhanced security.

Fiber nonlinearities such as self phase modulation (SPM), cross phase modulation (XPM) and four wave mixing (FWM) restrict the transmission distance and bandwidth efficiency of optical communication systems. These nonlinearities effects become major issue when optical power is very high and important to mitigate for better performance of long houl WDM systems. The FWM is one of the major and significant degrading factors in WDM optical communication systems [5,6]. Four wave mixing effect represents the inelastic scattering that occurs when two or more frequency signal are mixed while propagating through the same fiber in the same direction and produce new frequency signals which leads to degradation of the performance of WDM systems [7].

In the case of FWM effect, three copropagating optical signals through the optical fiber in the same direction of frequencies say f_p, f_q and f_r interact with each other and generate a fourth signal at frequency f_{pqr}, where $f_{pqr}=f_p+f_q-f_r$. These interactions become more severe in WDM system because a number of high optical power signals copropagate at different wavelengths. These newly generated frequency signals interact with the original frequency signals and there happens to be some frequency match between them, which leads to interchannel noise and degradation of the WDM system performance. When channels are equally spaced then probability of this frequency match increases [8].

The FWM effect can be more severe when in-line amplification used in optical link because by use of in-line amplification the effective area of fiber increases over which nonlinear interaction take place. FWM power generated at the frequency f_{pqr} when in-line amplifiers are used, is (assuming equal signal power P launched in all the wavelength channels) [9,10].

$$P(f_{pqr}) = k^2P^3e^{-a.La}((M+1)L_e/A_e)^2\eta_{pqr}d^2{}_{pqr} \quad (1)$$

Where $k=(32\pi^3X)/(n^2c\lambda)$.

$$\eta_{pqr} = [\alpha^2/(\alpha^2+\Delta\beta^2{}_{pqr})][1+(4e^{-\alpha L}/(1-e^{-\alpha L})^2)\sin^2(\Delta\beta_{pqr}L/2)] \quad (2)$$

* Corresponding author.
E-mail address: surinder_sodhi@rediffmail.com (S. Singh).

http://dx.doi.org/10.1016/j.optlastec.2015.07.013
0030-3992/

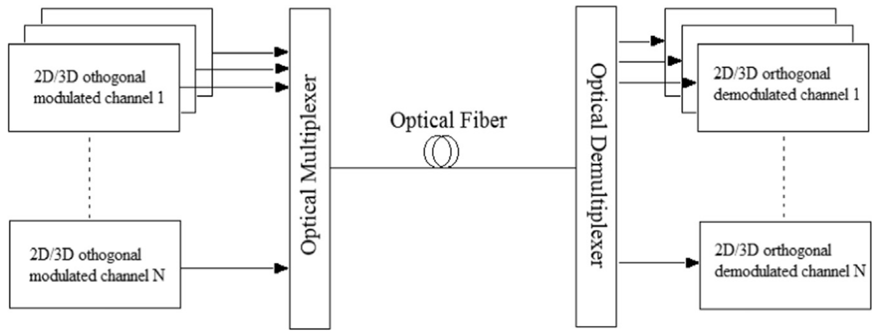

Fig. 1. Architecture for WDM system employing orthogonal modulation.

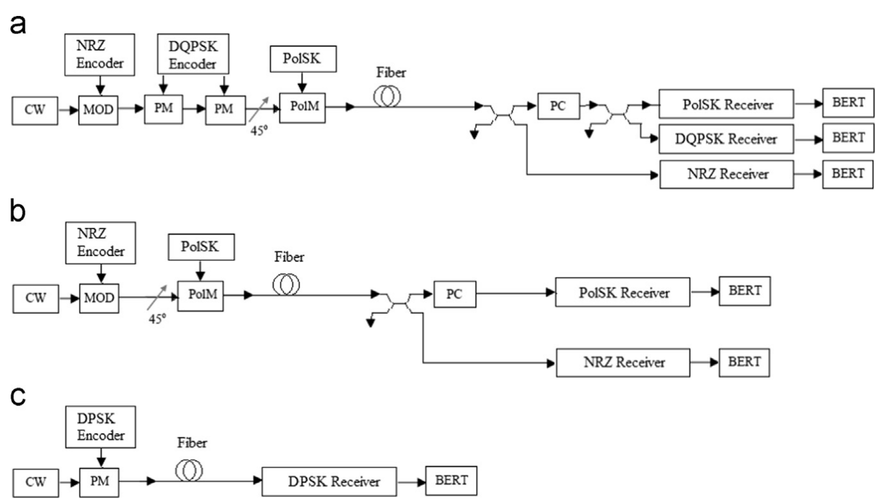

Fig. 2. Simulation setup for single channel (a) NRZ/DQPSK/PolSK orthogonal modulated transmitted and receiver, (b) NRZ/PolSK orthogonal modulated transmitted and receiver (c) DPSK modulated transmitted and receiver.

Table 1
Different parameters of SMF and DCF considered for demonstration of FWM in different orthogonal modulation format.

Fiber type	Fiber length	Attenuation (dB/km)	Dispersion (ps/nm/km)	Dispersion slope (ps/nm^2/km)	Effective area (μm^2)	Differentia group delay (ps/km)
SMF	40	0.2	17	0.075	70	0.2
DCF	8	0.5	−85	−0.3	22	0.2

Table 2
Parameter of EDFA gain amplifier considered for demonstration of FWM in different orthogonal modulation format.

Amplifier type	Gain (dB)	Noise figure (dB)	Noise center frequency (THz)	Noise bandwidth (THz)
EDFA (Gain control)	20	4	193.4	13

$$\Delta\beta_{pqr} = [(2\pi\lambda^2)(\left|f_p - f_r\right|\left|f_p - f_r\right|)] \times \{D + dD/d\lambda(\lambda^2/2c)(\left|f_p - f_q\right|\left|f_q - f_r\right|)\} \quad (3)$$

Where P is input laser power, a is fiber attenuation coefficient and M is number of amplifiers. L_e is effective length of system, A_e is effective area of fiber, α is total fiber attenuation, L is system length n is refractive index of the fiber, λ is center wavelength, X is third-order nonlinear electric susceptibility, d_{pqr} is degeneracy factor, D is dispersion coefficient, and η_{pqr} is FWM efficiency. FWM efficiency depends on phase mismatch between channels, also depends on channel separation and fiber dispersion coefficient.

In literature, various techniques has been reported for suppressing the FWM effect, such as the use of nonzero dispersion fibers, dispersion management and unequal-channel spacing techniques [11–13]. In this paper, we investigate the effect of FWM in spectral effeicient orthognal modulation formats with variable laser input power to design the WDM optical communication system. This paper organized as follows: Section 1 introduced the WDM techniques, optical nonlinearities and orthogonal modulation techniques and Section 2 describes the general discussion of WDM system description, followed by discussion of generation and detection of two-dimension orthogonal signal and three-dimension orthogonal signal. In Section 3, the results of effect FWM in WDM system is presented and in Section 4 the conclusions have been made.

2. System setup

Fig. 1 shows the architecture of WDM system employing orthogonal modulation formats. As shown in Fig. 1, the optical signals are generated from CW laser sources that are modulated as 2D/3D orthogonal modulation as shown in Fig. 2(a) and (b) and transmitted over 40 km fiber link. The driving input power of all