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FWM Investigation in 3-D, 2-D Orthogonal Modulations and 1-D Modulation in WDM System

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Abstract: Four wave mixing is a prominent and major performance deteriorating factor in WDM systems. To suppress the FWM effects and increase data rate supportability of WDM systems, optimal modulation formats are required. In this research, a WDM system supporting 8 channels and each at 10 Gbps is proposed by incorporating 2 and 3D orthogonal modulation formats. Polarization shift keying is an essential modulation and studied at different distances in terms of Q-factor. Moreover, FWM power is analyzed and comparison has been established for 1-3D modulations at different frequency spacings such as 25, 50 and 100 GHz. The 2-D orthogonal modulation exhibits minimum FWM and thus, recommended to use in WDM systems at ultra dense spacings.

Key words: Polarisation Shift Keying (PolSK), Differential Phase Shift Keying (DPSK), Differential Quadrature Phase Shift Keying (DQPSK), Four Wave Mixing (FWM), Wavelength Division Multiplexing (WDM), exhibits

INTRODUCTION

In expeditious development of optical fiber communication, the need for information capacity carrying systems is more because of augmentation in services reliant on internet, video on demand and cloud computing (Shao and Chi, 2012). Wavelength division multiplexing is a promising technology to cater the demands of multi users by packing more dense channels. A potential and well competent alternative to fullfil the demands of user is the joint technique of WDM and orthogonal modulation formats (Boffi *et al*., 2004). Orthogonal modulation formats are bandwidth efficient and also less vulnerable to noise induces due to phase. Consequently, it allows the accommodation of more channels and accumulation at dense spacing's in WDM system. These technologies are capable to support high data rate such as 40 Gbps and also can be spaced at the frequency difference of <100 GHz (Sheetal *et al*., 2010). Orthogonal modulation formats have numerous advantages such as high security, information carrying capacity and flexibility. Optical fiber nonlinearities are limiting factor in signal transmission and also restrict the data carrying capacity of the system. Major deteriorating Kerr's effect reliant nonlinearities are Four Wave Mixing (FWM), Self Phase Modulation (SPM), cross Phase Modulation (XPM) (Shao *et al*., 2008). Main cause of the emergence of non-linear effects is the power dependence of refractive index of optical fiber. In order to accomplish long haul transmission, these factors need to be addressed. In multi-channel systems, FWM is a major performance deteriorating nonlinearity that arises due to power accumulation of WDM channels inside single optical fiber (Inoue and Toba, 1995). FWM effect represents the fluctuation of refractive index when more than one frequency is simultaneously travelling through fiber optic and generates the new frequency signals that limit the overall performance of wavelength division multiplexing systems. Numerous researches has been reported till now to suppress the FWM effects in WDM systems such as unequal spacing (Forghieri *et al*., 1995), Non Zero Dispersion Fiber (NZ DCF) (Nikodem *et al*., 2008), hybrid modulators (Sugumaran *et al*., 2013), dispersion management (Matsuda *et al*., 1998) techniques. Singh and Singh (2016), four wave mixing is suppressed by using orthogonal formats at low launched power levels and 2-channel WDM system was proposed. However, due to ever increasing demands of high data rates motivate us to enhance the capacity of the system and investigate the emergence of FWM in more channel WDM system.

In this research study, we investigate the 8×10 Gbps WDM system incorporating orthogonal modulation formats at different channel spacing's (25, 50 and 100 GHz) and different distances in terms of Q factor and FWM power.

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MATERIALS AND METHODS

Four Wave Mixing in WDM systems: FWM is a kind of optical parametric oscillations and based on principle of Kerr's effect. This is a major performance deteriorating issue in wavelength division multiplex systems. Four wave mixing introduce crosstalk and performance degradation and is comprehended by noting the side frequency peak that is emerged due phase mismatch of travelling optical pulses as shown in Eq. 1. This condition arises when the three frequencies simultaneously propagate in the optical fiber as expressed as:

$$\omega_{ijk} = \omega_i + \omega_j - \omega_k \quad (1)$$

$$\omega_i, \omega_j, \omega_k \quad (2)$$

When, the case of equal channel spacing of WDM is considered, a coherent in-band crosstalk occurs. Major reason of in-phase crosstalk is that the new generated frequency coincides with the already present frequencies. On contrary in the case of unequal channels spacing, a non-coherent out of phase crosstalk induces due to the placement of FWM frequency in between the channels. Power loss and performance degradation of WDM system occurs in both cases. If total FWM products are denoted by M and N is the total number of channels, then equation is written as:

$$M = \frac{1}{2}(N^3 - N^2) \quad (3)$$

If, we further consider that three channels travelling inside optical fiber and contributing FWM, remains un-depleted and the attenuation, dispersion effects are incorporated, then the amplitude is expressed as:

$$\frac{dA_F}{dz} = -\frac{\alpha}{2}A_F + d_F \gamma A_i A_j A_k \exp(-i\Delta kz) \quad (4)$$

Where, $A_m(z) = A_m(0)\, e^{(-\alpha z/2)}$ for m = i, j, k and $d_F = 2-\delta_{ij}$ is the degeneracy factor stated as the value approaches to 1 when i = j, however becomes two times when $i \neq j$. This expression can be without difficulty incorporated to attain AF (z). FWM component power experienced by link length of optical fiber is given as:

$$P_F = [A_F(L)]^2 = \eta_F (d_{F\gamma} L)^2\, P_i P_j P_k \exp{-\alpha L} \quad (5)$$

Where, the input power in the mth channel and FWM is ηF are expressed in terms of power as:

$$P_m = |A_m(0)|^2 \quad (6)$$

The term η_F is represented as:

$$\eta_F = \left\{\frac{1-\exp(-(\alpha + i\Delta k)L}{(\alpha + i\Delta k)L}\right\}^2 \quad (7)$$

Channel spacing is a key factor determine the FWM efficiency and mismatch of phase is as shown as:

$$A_k = \beta_F + \beta_k - \beta_i - \beta_j \approx \beta_2(\omega_i - \omega_j)(\omega_j - \omega_k) \quad (8)$$

Consequently, with the augmentation of more number of WDM channels, four wave mixing will contribute its utmost indulgence. Therefore, it is essential to take care of four wave mixing designing the high capacity and ultra dense WDM systems. An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

System setup: In order to investigate the proposed wavelength division multiplexed system employing orthogonal modulation format, a simulation tool Optiwave's optisystem is used to realization and to comprehend the system. We accentuate on the major degrading factor FWM, that is analyzed at different channels spacings and for 1-3D modulations. A 8×10 Gbps WDM system is demonstrated over 40 km Single Mode Fiber (SMF) and FWM is observed for varied link lengths. Figure 1a-d depict the system architecture of proposed WDM incorporating 1-3D modulation formats, respectively.

A PRBS (Pseudo Random Bit Sequence generator) is a binary bits tributaries generator in the form of 1's and 0's and transmitting bits at the rate of 10 Gbps per channel. A continuous wave laser operating in C-band (1530-1570 nm) and at power level of 0 dBm. Laser linewidth is kept at 10 MHz to make system more practical. Further, the NRZ linecoding is used to provide pulse shape to the binary data. In case of 3-D orthogonal modulation, aforementioned signal is further encoded with DQPSK signal and fed to the linear polarizer to shift the polarization state to 45°. Polarization shifted signal is encoded with data such as to realize the polarization shift keying modulation. For 2-D orthogonal modulation, DQPSK encoding stage as shown in Fig. 1b is eliminated and signal direct fed to polsk encoding. A DPSK modulation is used for 1-D modulation without any polarization shift keying as depicted in Fig. 1d. Decoding is also illustrated in the Fig. 1b-d for 1-3D modulations. It is noteworthy that no amplifier such as Erbium Doped

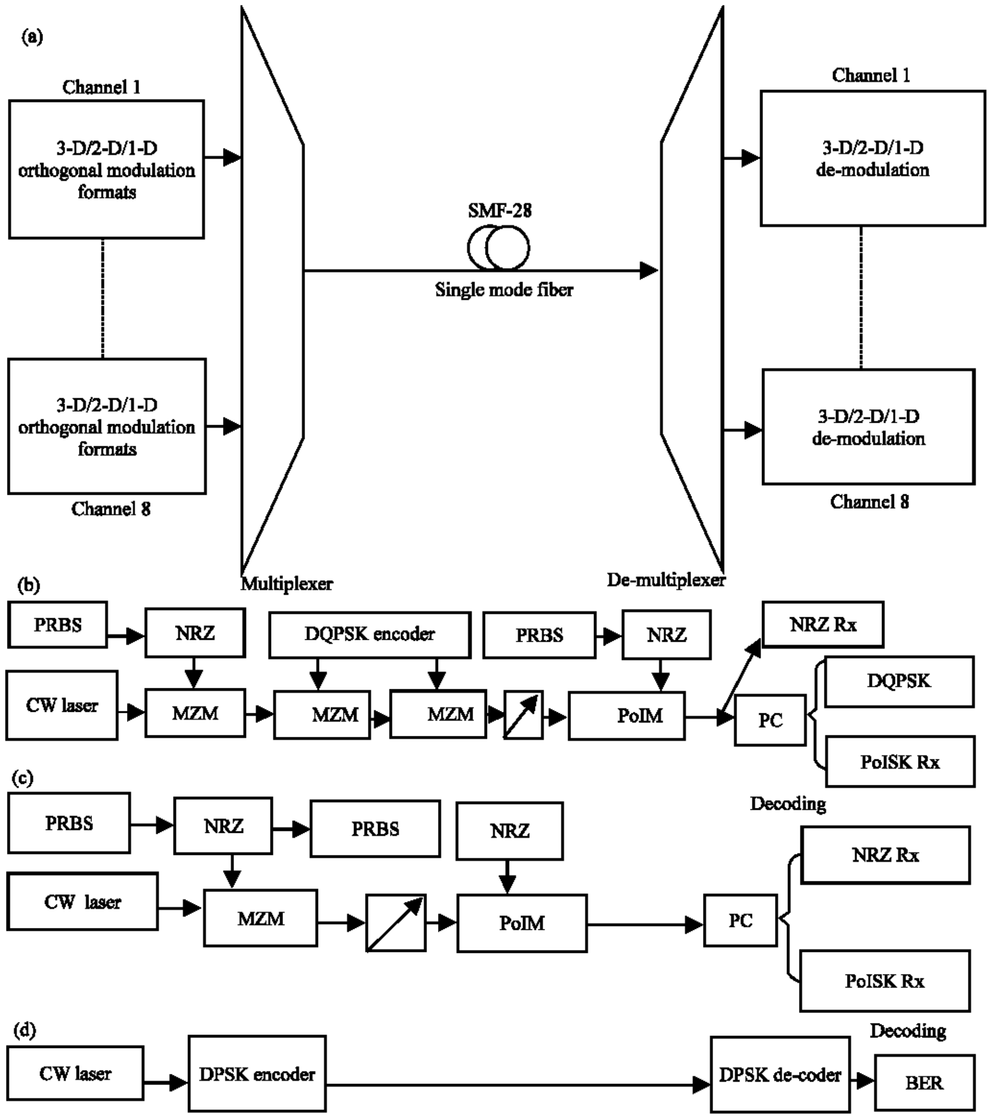

Fig. 1: a) Representation of 8×10 Gbps wavelength division multiplexed system incorporating 1-3D modulation formats; b) Internal structure of 3-D orthogonal modulation; c) Internal structure of 2-D orthogonal modulation and d) Differential phase shift keying 1-D modulation

Fiber Amplifier (EDFA), Semiconductor Optical Amplifier (SOA) and Raman amplifier is used in this work and FWM in optical amplifier is beyond the scope of this research.

RESULTS AND DISCUSSION

A PRBS (Pseudo Random Bit Sequence generator) is a binary bits tributaries generator in the form of 1's and 0's and transmitting bits at the rate of 10 Gbps per channel. A continuous wave laser operating in C-band (1530-1570 nm) and at power level of 0 dBm. Laser linewidth is kept at 10 MHz to make system more practical. Further, the NRZ linecoding is used to provide pulse shape to the binary data. In case of 3-D orthogonal modulation, aforementioned signal is further encoded with DQPSK signal and fed to the linear polarizer to shift the polarization state to 45°. Polarization shifted signal is encoded with data such as to realize the polarization shift keying modulation. For 2-D orthogonal modulation, DQPSK encoding stage as shown in Fig. 1b is eliminated and signal direct fed to polsk encoding. A DPSK modulation is used for 1-D modulation without any polarization shift keying as depicted in Fig. 1d. Decoding is also illustrated in Fig. 1b-d for 1-3D modulations. It is noteworthy that no amplifier such as Erbium Doped Fiber Amplifier (EDFA), Semiconductor Optical Amplifier (SOA)

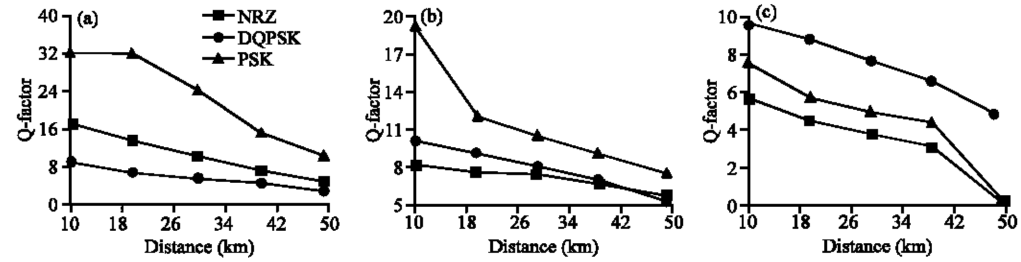

Fig. 2: Represents the Q-factor versus distance at; a) 100 GHz; b) 50 GHz and c) 25 GHz for 3-D orthogonal modulation

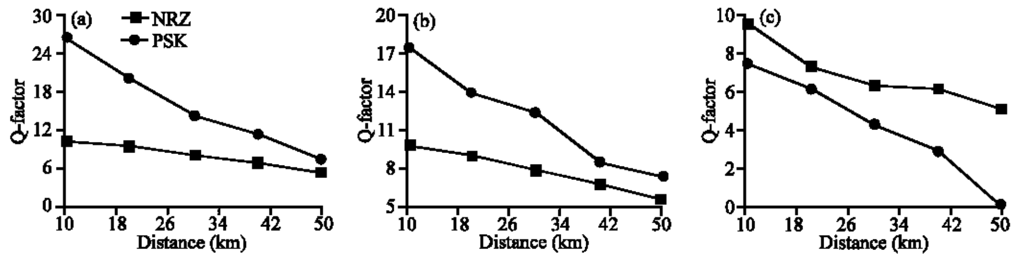

Fig. 3: Represents the Q-factor versus distance at: a) 100 GHz; b) 50 GHz and c) 25 GHz for 2-D orthogonal modulation

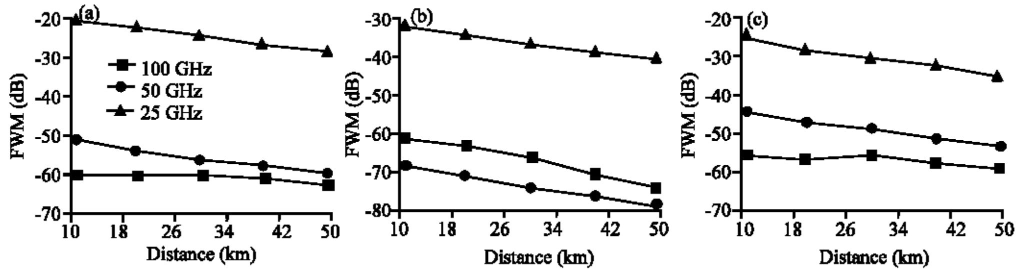

Fig. 4: Represents the Q-factor versus distance at: a) 100 GHz; b) 50 GHz and c) 25 GHz for 1-D modulation

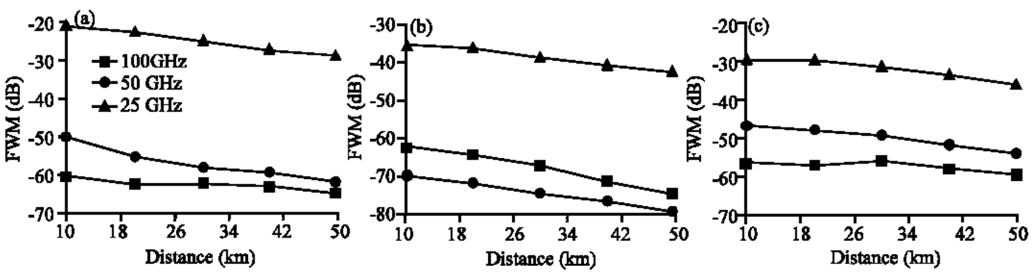

Fig. 5: Four wave mixing versus distance at different frequency spacings for: a) 1-D modulation; b) 2-D and c) 3-D orthogonal modulations

and Raman amplifier is used in this work and FWM in optical amplifier is beyond the scope of this research (Fig. 2).

Figure 3 represents the performance of 2-D orthogonal modulation for WDM system at different link lengths and frequency spacings. Results revealed that at 50-100 GHz channel spacings, PolSK performs best and at 25 GHz, NRZ crosses the PolSK performance and thus well suited for ultra dense WDM. Figure 4 depicts the 1-D DPSK modulation performance at different frequency spacings and varied link lengths. It is seen that Q decreases with the increase of distance and at lower spacings. Further, four wave mixing is investigated for all modulation proposed in this work at different frequency spacings and distances as shown in Fig. 5a-c for 1-3D, respectively. It is seen that maximum FWM emerges at

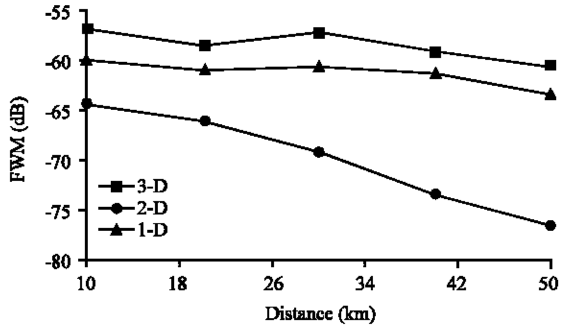

Fig. 6: Comparison of all proposed modulations

25 GHz and minimum for 100 GHz for all modulations. So, with the decrease in frequency spacings, FWM increases. Figure 6 illustrates the comparison of three modulations at different distances in terms of FWM generated. The 3-D orthogonal modulation is generating the maximum power FWM followed by 1-D modulation. For WDM systems at ultra dense frequency spacings, 2-D orthogonal modulation is suggested as it produces minimum power FWM components.

CONCLUSION

In this research study, a capacity enhanced 8×10 Gbps WDM system is proposed and investigation of four wave mixing has been done at different frequency spacings. Orthogonal modulation formats 3-D (NRZ-DQPSK-PolSK) and 2-D (NRZ-PolSK) are analyzed along with 1-D modulation at 25, 50 and 100 GHz to evaluate the FWM. Results revealed that for all modulations with the increase of distance, value of Q factor decreases and also there is significant degradation as channel spacing reduces. The 3-D orthogonal performs best in terms of Q factor and 1-D performs least. Also comparison has been done amid different proposed modulations and it is observed that FWM emerges minimum in case of 2-D orthogonal modulation and maximum for 3-D orthogonal modulation. However, for 1-D modulation, four wave mixing components exceed the power than 2-D but lower to 3-D orthogonal modulation formats. So, 2-D orthogonal modulation is suggested for ultra dense WDM systems under the effects of four wave mixing.

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