

## Investigation of Four wave mixing effects using different modulation formats in optical communication system

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### Abstract

In this paper, the four wave mixing effect on sixteen channel wavelength division multiplexing has been compared for different modulation formats at various values of dispersion, core effective area, channel spacing. The performance of system has been evaluated in terms of four wave mixing power, BER and Q-factor. This paper simulates that with increase in the channel spacing, core effective area of fiber, signal interference between input signals decreases hence four wave mixing effect also decreases. It has been observed that for duobinary FWM decreases 1dBm more than NRZ. So duobinary modulation format is best suitable technique to reduce four wave mixing power by varying dispersion from 0 to 4 ps/nm.km, core effective area and channel spacing.

**Keywords:** Non-return-to-zero (NRZ), return-to-zero (RZ), duobinary, wavelength-division-multiplexing (WDM).

### I. Introduction

Four-wave mixing is one of the major limiting factors in wavelength division multiplexing optical fiber communication systems that use the low dispersion fiber or narrow channel spacing. When multiple optical channels passing through the same fiber interact with each other very weakly and these weak interactions in glass can become significant over long fiber-transmission distances. The most important is four wave mixing in which three wavelengths interact to generate a fourth [1]. Four wave mixing is due to changes in the refractive index with optical power called optical Kerr effect. FWM is a third-order non-linearity in silica fibers that is analogous to inter-modulation distortion in electrical systems. When three electro-magnetic waves with optical frequencies co-propagate through one fiber, they mix to 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 [2]. The efficiency of four wave mixing can be reduced in a three channel wavelength division multiplexing span of 100 km by increasing the dispersion coefficient [2]. To suppress four wave mixing span of 200 km fiber for 8 channel WDM equal channel spacing with channel crosstalk in a delay, with optical coupler techniques were used [3]. In order to increase the capacity of the optical communication system, number of optical channels is being to be increased. Since the gain bandwidth of EDFAs is limited, to have more

number of channels spacing between them is 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 fibre come into play and output signal is degraded. Modulation schemes are now being developed which are robust to both the linear and non-linear behaviour of fibre. Duobinary modulation techniques are known to compress the optical spectrum and provide the tighter packing of channels into the EDFA gain window [4]. The term duo means doubling the bit capacity of a straight binary system. The main idea of duobinary modulation format was first described by Lender [7]. Amarpalet. al [4] discussed the effect of FWM on bit error rate for different NRZ, RZ modulation format by varying both dispersion and core effective area of fiber and observed that bit error rate got improved with NRZ raise cosine modulation format. Laxmanet.al. [4] investigated the effect of FWM on bit error rate for duobinary and binary modulation format like NRZ rectangular for two channel WDM optical communication system and for 100 Km fiber length. Laxmanet. al. [6] also investigated the impact of duobinary modulation format for two channel WDM to reduce FWM power more as compared to binary modulation format. We have extended this work for sixteen channels with 20Gb/s data rate at 300 km fiber length and also investigated the different binary modulation format like NRZ cosine, NRZ rectangular, RZ cosine, RZ rectangular along with duo-binary and effect of dispersion, core effective

area on the system performance. This paper is divided into five sections. In the first section, the introduction of four wave mixing effect is presented. The second section discusses the theoretical analysis of four wave mixing. The third section describes simulation setup for a sixteen channel optical communication system. In the fourth section, the comparison of performance of four wave mixing on the basis of different modulation format is done in terms of FWM power, BER, Q-factor. The fifth section gives the conclusion of this paper.

### I. Theoretical Analysis

$$\omega_4 = \omega_1 \pm \omega_2 \pm \omega_3$$

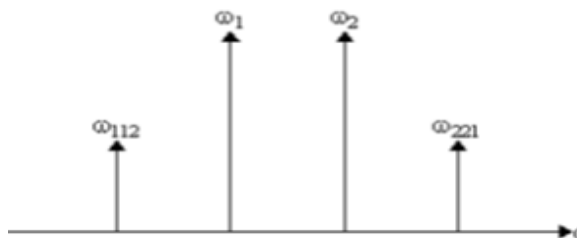


Fig. 1 (a)

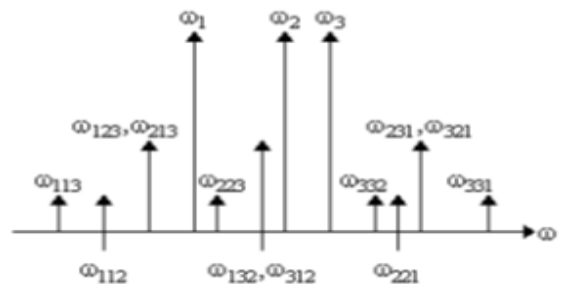


Fig. 1 (b)

The origin of FWM process lies in the nonlinear response of bound electrons of a material to an applied optical field. In fact, the polarization induced in the medium contains not only linear terms but also the nonlinear terms. The magnitude of these terms is governed by the nonlinear susceptibilities of different orders. The FWM process originates from third order nonlinear susceptibility  $\chi^{(3)}$ . If three optical fields with carrier frequencies  $\omega_1, \omega_2$  and  $\omega_3$ , co propagate inside the fiber simultaneously,  $\chi^{(3)}$  generates a fourth field with frequency  $\omega_4$ , which is related to other frequencies by a relation,

Let  $\lambda_i, \lambda_j, \lambda_k$  be the three wavelengths and these wavelengths are mixed together and give a fourth wavelength as follows:-

$$\lambda_{ijk} = \lambda_i \pm \lambda_j \pm \lambda_k \quad (1)$$

$\lambda_{ijk}$  may act as a interfering signal to the original signal.

The FWM power,  $P_{ijk}$  generated by three channels having input powers  $P_i, P_j, P_k$  at frequencies  $f_i, f_j, f_k$  at the output of a fiber with attenuation  $\alpha$  and length L is given by

$$P_{ijk} = d_{ijk}^2 \gamma^2 L^2 P_i P_j P_k \eta_{ijk} e^{-\alpha L} \quad (2)$$

where  $d_{ijk}$  is the degeneracy factor, taking a value of one or two for degenerate ( $i = j$ ) and non-degenerate ( $i \neq j$ );  $L_{eff}$  is the effective length;  $\gamma$  is the nonlinear coefficient; and  $\eta_{ijk}$  is the efficiency.

$$\gamma = \frac{2\pi n_2}{A_{eff} \lambda_0} \quad (3)$$

$$\eta_{ijk} = \frac{\alpha^2}{\alpha^2 + \Delta\beta_{ijk}^2} \left( 1 + \frac{4e^{-\alpha z} \sin^2(\Delta\beta_{ijk} z/2)}{(1 - e^{-\alpha z})(1 - e^{-\alpha z})} \right) \quad (4)$$

where  $n_2$  is the fiber nonlinear coefficient,  $\lambda_0$  is the central wavelength,  $A_{eff}$  the core effective area and  $\Delta\beta_{ijk}$  the phase-matching coefficient. The efficiency can be approximated, for long enough fiber spans as:

$$\eta_{ijk} = \frac{\alpha^2}{\alpha^2 + \Delta\beta_{ijk}^2} \quad (5)$$

The phase-matching coefficient  $\beta_{ijk}$  is

$$\beta_{ijk} = (f_i - f_k)(f_j - f_k) \frac{2\pi\lambda_0^2}{c^2} \left\{ -D_c + \lambda_0^2 \frac{\partial D_c}{2C\partial\lambda} [(f_i - f_d)(f_j - f_d)] \right\} \quad (6)$$

where  $D_c$  is the fiber chromatic dispersion,  $\frac{\partial D_c}{\partial\lambda}$  its slope and  $f_d$  the zero dispersion frequency.

Away from the zero dispersion region, (6) becomes

$$\Delta\beta_{ijk} = 2\pi D_c \Delta\lambda_{ik} \Delta\lambda_{jk} \quad (7)$$

where  $\Delta\lambda_{ik}$   $\Delta\lambda_{jk}$  are the wavelength spacing between channels i and k, j and k.

## II. SIMULATION SET UP-

The transmitter block consists of sixteen channels, each of them consist of data source and continuous wavelength laser source and external Mach-Zehnder modulator. The data source produces a 20 Gbit/s bit streams, which represents the information we want to transmit over fiber length. Then we need an electrical driver, which forms NRZ, RZ or duobinary pulses from incoming bits. The pulses are then modulated with continuous wave laser to obtain optical pulses. After transmission block the signal is sent directly to a single mode fiber (SMF) of 100 Km then to compensate dispersion signal is passed from fiber bragg grating and an EDFA with 35 dB gain is used for loss compensation and signal passes through three iteration loop of 100 Km SMF, fiber bragg grating and EDFA. The used fiber has a large core effective area  $80 \mu\text{m}^2$ , attenuation  $\alpha = 0.2$  dB/km, and nonlinear refractive coefficient  $n_k = 2.5 \times 10^{-20} \text{m}^2/\text{W}$  at the reference wavelength  $\lambda = 1550$  nm. At the receiver end an optical splitter is used to split the signal one splitter signal is sent to photodiode detector and other to optical scope. The photodiode detector is used for optical to electrical conversion. Then the signal is passed through the Bessel filter, which is made to work as low pass filters and the final output signal is received. An 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, BER, Q-factor.

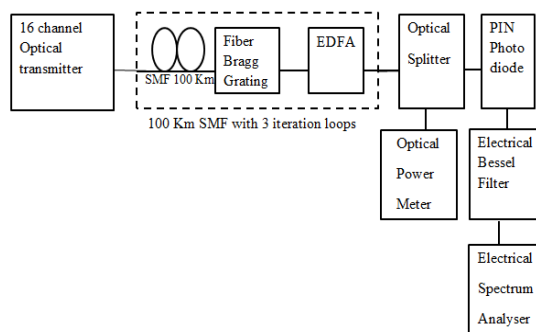


Fig. 2 Sixteen channel WDM optical communication system

Table no. 1

Parameter values of system set up in fig. 1

| Parameter                                 | Values(unit) |
|---|--------------|
| Channel Power                             | -10(dBm)     |
| Bit Rate                                  | 20(Gbps)     |
| Attenuation loss                          | 0.2(dBm/Km)  |
| Fiber Length                              | 300(Km)      |
| Output Power of EDFA                      | 6(dBm)       |
| Gain Shape of EDFA                        | Flat         |
| Maximum small signal gain of EDFA         | 35(dB)       |
| Dark current of pin Photodiode            | 0.1 Na       |
| Quantum efficiency of pin Photodiode      | 0.7          |
| Responsivity of pin Photodiode            | 0.8792 A/W   |
| -3 dB bandwidth of pin Photodiode         | 200 GHz      |
| No. of poles in low pass bessel filter    | 1            |
| -3 dB bandwidth of low pass bessel filter | 10 GHz       |

### III. Results and Discussion

The system set up as shown in fig. 2 is simulate for different modulation format by varying channel spacing between the channels at constant dispersion = 0 ps/nm/km and core effective area = 80  $\mu\text{m}$ . Figure 3 shows the variation in FWM power with channel spacing for binary and duobinary modulation. It is concluded that FWM power reduces for both binary and duobinary modulation format with increase in spacing between channels. When we increase the channel spacing between input channels from 25 GHz to 100 GHz, the FWM power is reduced from -80.25 dBm to -82.74 dBm because as discussed in the theoretical analysis more the channel spacing lesser the interference between signals so less the FWM power. The decrease in FWM power is more for duobinary modulation format with increase in channel spacing than binary modulation i.e. of 1dBm because bandwidth of duobinary is half than bandwidth of NRZ so duobinary has a spectrum bounded within the nyquistband, which makes it a minimum bandwidth coding-scheme and also a three level signal so there is less phase matching hence FWM power reduction is more.

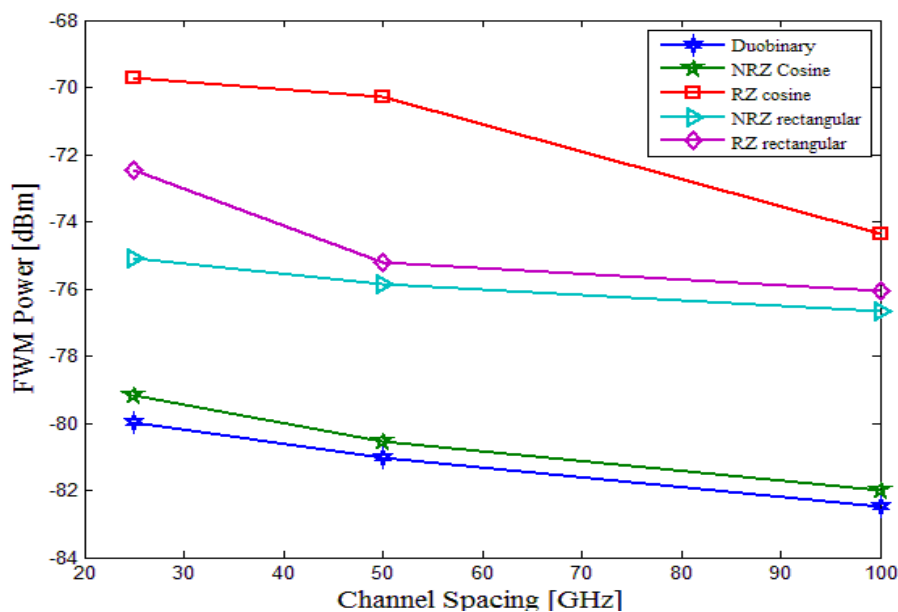


Fig. 3 Variation of FWM power with channel spacing

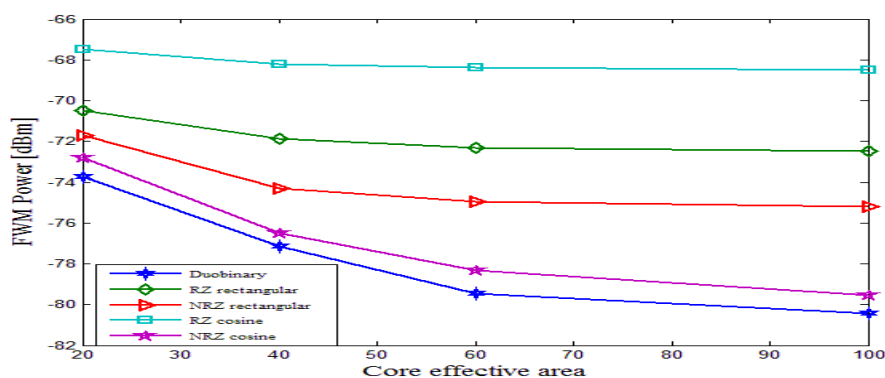


Fig. 4 Variation of FWM power with core effective area

Fig. 4 shows the variation of FWM power with core effective area at different modulation format like binary and duobinary. It has been observed that with increase in core effective area from 20  $\mu\text{m}$  to 100  $\mu\text{m}$  FWM power decreased in both modulation formats i.e. from -73.74 dBm to -81.24 dBm because it is concluded from equation (3) that FWM power is inversely proportional to the core effective area and lesser the interference between input frequencies hence with increase in the value of core effective area four wave mixing power goes on decreasing. It is observed that FWM effect decreases more in duobinary compared to binary at 100  $\mu\text{m}$  core effective area i.e. by 1dBm. Duobinary has narrow spectrum and three level signal so phase matching is less hence reduction of FWM power is more.

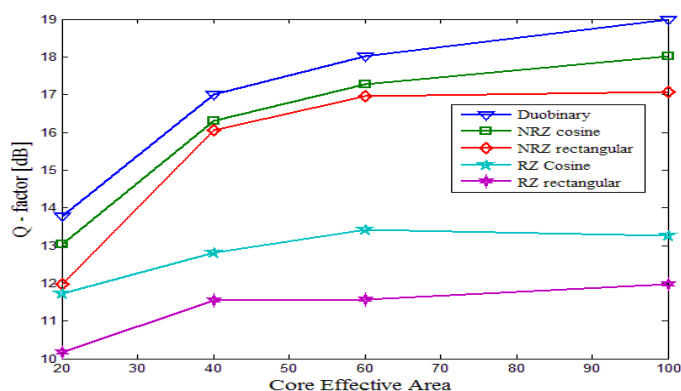


Fig. 5 Variation of Q- factor with core effective area

Fig. 5 shows the effect of core effective area on Q- factor at different modulation format like binary and duobinary. It has been analysed that as we increase the core effective area from 20 μm to 100 μm, Q- factor goes on increasing in both modulation formats i.e. from 13 dB to 17.8 dB in NRZ cosine and from 13.88 dB to 19 dB in duobinary. The reason behind this, with increase in core effective area, lesser the interference between input frequencies hence Q – factor increased. It is also observed that Q- factor increases more in duobinary compared to binary at 100 μm core effective area. Q- factor is 19 dB for duobinary and 17.8 dB for NRZ cosine at 100 μm because duobinary has narrow spectrum and three level signal so there is small phase matching hence increase in Q- factor is more.

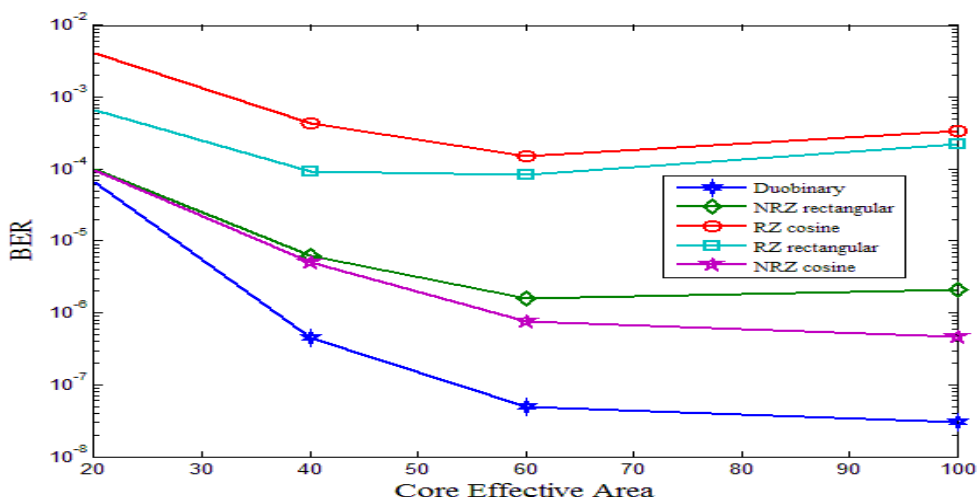


Fig. 5 Variation of BER with core effective area

Fig. 5 shows the effect of core effective area on BER at different modulation format like binary and duobinary. It has been observed that with increase in the core effective area from 20 μm to 100 μm, BER goes on decreasing in both modulation formats i.e. from  $2.43 \times 10^{-4}$  to  $10^{-6}$  in NRZ cosine and from  $8.796 \times 10^{-4}$  to  $10^{-7}$  because with increase in core effective area, lesser the interference between input frequencies hence lower the BER. It is also observed that decrease in BER is more in duobinary compared to binary at 100 μm core effective area. BER is  $10^{-7}$  for duobinary and  $10^{-6}$  for NRZ cosine at 100 μm because duobinary has narrow spectrum and three level signal hence small phase matching occurs with the transmitted signals.

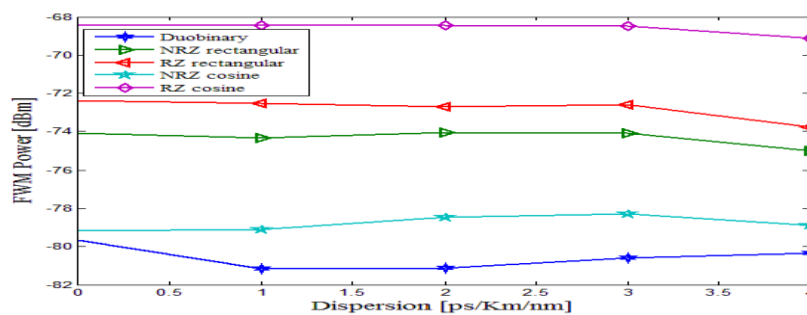


Fig. 6 Variation of FWM power with dispersion

The system set up shown in fig. 2 is run varying dispersion from zero to four. The FWM power is noted from optical power meter by increasing dispersion of fiber. Fig. 6 shows the variation of FWM power with dispersion at both binary and duobinary modulation format. From graph it is demonstrated that FWM power is reduced when we increase dispersion from 0 ps/km/nm to 4ps/Km/nm from -79 dBm to -80.4 dBm because effect of four-wave mixing depends on the phase relationship between the interacting signals. When the chromatic dispersion is zero then all the interfering signals travel with the same group velocity so the FWM effect is reinforced. On the other hand, when chromatic dispersion is present, the different signals travel with different group velocities, thus the different waves alternately overlap in and out of phase, and the net FWM effect is less that is why FWM power decreased by varying dispersion of fiber. But this reduction is more for duobinary as compared to binary modulation because of its narrow spectrum and due to three levels of duobinary, it has low phase matching with the transmitted signal.

#### IV. Conclusion

In this paper, the simulation of sixteen channel WDM optical communication system is presented in order to analyse the variation in FWM power with different core effective, dispersion, channel spacing using different modulation formats. Here we used both binary and duobinary formats. From the obtained results it is concluded that FWM power is reduced for both binary and duobinary modulation format in all cases as we increase channel spacing, core effective area and dispersion. The reduction in FWM power is 1 dBm more for duobinary modulation as compared to NRZ because duobinary has less bandwidth than binary. Duobinary is a three level signal while binary is a two level signal, So duobinary has less phase matching and FWM reduction is more. Moreover duobinary has narrower spectral width and greater tolerance to dispersion. The suppression is greater for narrower channel spacing which suggests that as WDM systems reach higher channel counts.

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