Impact of FWM on Optical Scheme Performance under Different Limitations Factors and Modulation Formats

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Abstract: - Four-wave mixing (FWM) has been shown to be the leading nonlinear consequence in long transmission distance that can cruelly border the wavelength division multiplexing (WDM) and minor the scheme performance. In this work, the system analyze with performance under the effect of wavelength spacing in the case of normal RZ, NRZ intensity modulation - direct modulation (IM-DD) and in the existence of phase shift keying- modulation format, which comprised of (8-PSK and 16-PSK). In addition, the effect of wavelength spacing on FWM is evaluated through 4 kinds of optical fiber, SMF, DSF, NZDF and Large Effective Area Fiber (LEAF) for three channels. The outcomes show that the SMF presents minimum FWM power up to -40.88 dBm, while DSF offers maximum FWM power of -30.99 dBm. It is observed that for NZDF and LEAF, the FWM powers are -31.99dBm and -35 dBm, respectively. In the case of system quality with the channel spacing tuning after 150 Km, BER is 3.3×10⁻¹¹ on received power of -12 dBm using 16-PSK modulation. Nevertheless, in the existence of NRZ arrangement the BER was originated to be worse and equal to 8×10⁻³ at same received power.

Keywords: BER, FWM, Modulation format, WDM, PSK.

1. Introduction

The requirement of high information percentage, extended transmission distance and high spectral effectiveness is the utmost tests in optical communication schemes. The goal of completely scientists and engineers is how proposal ideal transmission scheme chance wholly these tests. So, it can present effectual scheme parameter. In optical communication, the FWM is single of the substantial difficulties that may reduce the effectiveness of the optical transmission scheme [1].

The FWM seems as a misrepresentation of a signal in which unique representation delays with succeeding codes. The pulse will spread outside its selected period interval get it to affect with original channel[1-3]. FWM is the robust disadvantageous outcome, which originates after the n inside the fiber variations with the power [4].

WDM is much appropriate method for an improved communication system providing high transmission dimensions [5]. By WDM, it can communicate multiple signals having changed wavelengths done the identical fiber. Then to diffuse huge information also it must rise the number of networks or the information rates. Sophisticated statistics charges are not possible to instrument practically [6]. To increase number of users, it needs low channel spacing. For this resolution, the choose DWDM or UDWDM with condensed channel design of (100 – 25) GHz [7,8].

In the last years, the performances have been planned to decrease the harmful properties of FWM in WDM schemes. In ordinary transmission distances, the RZ and NRZ modulation procedures are in record suitcases working. The experimentations and reviews have presented that RZ considers to be upper significance proportionate to the regular NRZ schemes, if characteristic single-mode fibers are applied for example communication media [9,10]. While, by reason of the slighter optical range of the NRZ setup, NRZ can reach difficult spectral effectiveness in WDM schemes in evaluation to RZ in the linear outline. Lately, approaches of optical multiplexing and demultiplexing with the mixture of time positions are unique of the substantial several FWM procedures [11], Also, the apply of an advance modulation performance and the system of space between the networks donated to decrease nosiness with the signals communicated to around level [12-20]. In this work, we investigate the outcome of
channel spacing on FWM power with different types of fibers. The system performance is determined based on channel spacing in available of normal NRZ and M-PSK advance modulation formats.

2. Mathematical model and system simulation

Figure (1) refers to assumption of optical communication system which includes: transmitted part, linked part and received part as in [12]. The Proposed optical communication scheme with transmitted modulation signals (NRZ, RZ & RC) for distance more than 100 k signal of a fiber optic to be established in a receiving portion of the simulated scheme. The power relocated as a result of FWM of original frequencies subsequently light has been spread in a distance in the fiber can be summarized in the equation [9]. The all parameters in Eq (1) is defined in Table 1

\[
P_{\text{FWM}} = \frac{1024\pi^6}{n^8 \lambda^2 C^2} \left[ \frac{Dx_{111} L_{\text{eff}}}{\lambda_{\text{eff}}} \right]^2 \left( \frac{p_i p_j p_k}{c a^2 + 2\pi \nu D_0 (\Delta f/j)} \right)
\]

(1)

Table-1 shows the scheme simulation constraints that are used in this work. The FWM noise power NFWM is [9]:

\[
N_{\text{FWM}} = 2b^2 P_s \left( \frac{P_{\text{FWM}}}{8} \right)
\]

(2)

Where \(b\) is the responsively of the detector, \(b= (e/\hbar)^{1/2} \left(1/e\hbar \right)\), \(h\) is the Planck's constant, \(\nu\) is the quantum effectiveness of the detector and \(e\) is the basic electric charge. The system performance can be assessed with Q factor as [9]

\[
Q = \frac{bP_s}{\sqrt{N_{\text{th}} + N_{\text{sh}} + N_{\text{FWM}}} + \sqrt{N_{\text{th}}}}
\]

(3)

The FWM noise is the control in this scheme,

\[
Q^2 = \frac{b^2 P_s^2}{2b^2 P_s \frac{P_{\text{FWM}}}{8}}
\]

(4)

And the BER has been designed from the Q factor:

\[
BER = 0.5 \times \text{erfc} \left( \frac{Q}{\sqrt{2}} \right)
\]

(5)

To calculate the BER under the effect of M-PSK modulation formats [10], we utilize

\[
BER = \text{erfc} \left( \frac{SNR \times \sin(2\mu M)}{2} \right)
\]

(6)

\[
SNR = \frac{E_b}{N_0} \times \frac{\mu}{B}
\]

(7)

Where: \(fb\) is the channel data rate (net bit rate), \(B\) is the channel bandwidth , \(Eb\) = Energy-per-bit, \(N0\) = Noise power spectral density, \(M\) : number of phases and SNR: Signal to noise ratio

The parameter of BER under M-PSK modulation format is given in Table 2.
Figure 1. Suggested optical communication system network.

Table 1
Proposed scheme parameter

| Restriction                      | Unit   | Values                        |
|----------------------------------|--------|-------------------------------|
| Fiber length, L                  | km     | 100-150                       |
| I/p power, Pi                    | mW     | 10-20                         |
| Wavelength spacing, Δλ            | nm     | 0.1 to 1                      |
| Dispersion, Dc                   | ps/nm.km | (0-18) based on fiber category |
| Cross active range, Aeff         | μm²    | (20-70) depend on fiber type  |
| Degeneracy factor, D             | --     | 6                             |
| 3 order Susceptibility, X₁₁₁     | m³/w.s | 6×10⁻¹⁵                      |
| Speed of light, c                | (m/s)  | 3×10⁸                         |
| Effective wavelength, λ          | (nm)   | 1550                          |
| Attenuation influence,           | (dB/km)| 0.2                           |
| Number of channels               | --     | 3                             |
| Data Rate                        | Gb/s   | 40                            |
Table 2
System parameters for M-PSK modulation

| Modulation type | Number of phases (M) | Channel Band width(B) Relation with channel data rate( fb) |
|-----------------|----------------------|----------------------------------------------------------|
| 8-PSK           | 8                    | fb = 3× B                                                |
| 16-PSK          | 16                   | fb = 4× B                                                |

3. Results and Discussion

This section discusses the result of channel design and chromatic dispersion on FWM power with four categories of optical fiber. The scheme performance is compared in terms of BER between the normal NRZ and M-PSK modulation set-up. The all findings recorded, and Eye diagram performed were gotten by using MATLAB software (2018A) and Opti system 16.

3.1 Effect of wavelength spacing on FWM power

Figure 2 demonstrates the association between the FWM power and wavelength spacing as a purpose of various categories of optical fibers; which are SMF, DSF, NZDF, and NZDSF. It can be observed that increasing wavelength spacing can reduce the FWM properties for completely kinds of fiber. Furthermore, the FWM control is having a determined through the DSF fiber which has a dispersion rate of 0 ps/nm.km, the FWM power is -30.99 dBm at wavelength spacing 1nm. The differing was gotten in the SMF fiber which has a dispersion rate of 17ps/nm.km, wherever the FWM power released to -40.88 dBm for the same spacing. Also, in the NZDF and the LEAF the FWM power was -31.99 dBm and -35 dBm respectively at the same wavelength spacing.

![Figure 2. FWM power VS channel spacing for various types of optical fiber.](image)

3.2 Effect of dispersion on FWM power

Figure 3 illustrations the connection between the FWM power as a purpose of dispersion below various standards fiber types, i.e., SMF, DSF, NZDF, and LEAF and using 0.9 nm wavelength spacing. The FWM effectiveness has been designed with eq (1). Its illustrations that the rising of the dispersion
constraint may reduce the FWM effectiveness. This behaviour might be described that with chromatic spreading existing, the various signals portable with various assembly speeds.

It is experimental that the FWM effectiveness is higher with DSF and influences approximately -19 dBm. Moreover, the FWM efficiency is low with SMF and reaches to -34 dBm. Also, for the NZDF and LEAF, the FWM efficiency was around (-27 to -24 dBm).

![Figure 3](image)

**Figure 3.** FWM power VS channel spacing for various types of optical fiber.

### 3.3 System performance analysis under the effect of wavelength spacing for different modulation formats types

Fig. 4 shows the connection the received power, BER below the result of channel spacing 1st 100km distance, with two types of PSK modulation format, i.e. 8-PSK and 16-PSK. The results are obtained after applied equ 6. Opinion of the outcomes illustration that raised received power will decrease the BER for both categories of modulation techniques applied. The performance of BER changed from one modulation technique to additional leads to the tolerance of each of the modulation format to the FWM noise. At this step 16-PSK, the scheme parameter gives the least for BER and it is $1.57 \times 10^{-10}$ by received control of -29 dBm.

Contrariwise, 8-PSK, it gets the determined rate of BER the assortment of $(2.47 \times 10^{-8})$ at the identical received power. More significantly, that increasing the number of phases (M) in PSK modulation can enhance the signal to noise ratio which reduces the BER. An increased in the number of phases in the modulation may translate as an off-setting element to nonlinear effect and increase the capacity of wavelength division multiplexing.

![Figure 4](image)

**Figure 4.** Received power and BER under PSK-modulation format result.
For further investigation the FWM power versus channel spacing has been tested under four modulation types with 150 km distance Fig.5 illustrates the comparison between the scheme parameter in term of BER as the effect of channel spacing in normal RZ, NRZ and M-PSK modulation format. From this figure, in the case of channel spacing with NRZ modulation, the system parameter gives the higher value for BER reaches to $8 \times 10^{-3}$ at -12 dBm. However, in 16-PSK, it gives the lower value of BER reaches $3.3 \times 10^{-11}$ at identical received power. Overall; it can be determined from the BER behavior that increasing the channel spacing leads to enhance system performance and differed from modulation to other.

![Figure 5. Received power and BER for all modulation format types used.](image)

Figure.6 explains that the illustration for the different modulation after 150 km and using wavelength spacing. The eye diagram seems clearer with the 16-PSK modulation i.e. the optimized pulse and better than NRZ pulse. (a) Inversely with Sine wave and NRZ pulse, (b) the eye diagram here seems less efficiency.

The development in the eyes diagram gives an indication that high-level phase modulation has more resistance to nonlinear effect even at a high bit rate and correct receiving of detection bits.
Figure 6: Performance of eye diagram for 240 km distance modulation set-up of (a) NRZ, (b) NRZ RZ, (c) 8-PSK and (d) 16-PSK

4. Conclusion
In this work, the WDM optical scheme performance has been studied by comparing the properties of wavelength spacing and advance modulation format. Furthermore, the study is observed for FWM on WDM system for different optical fiber types; SMF, DSF, NZDF and LEAF. The outcomes verified that the SMF experiences the smallest amount FWM power, i.e. -40.88 dBm, despite the fact DSF
suffers FWM power of -30.99 dBm. In the system parameter after 150 Km, the channel spacing tuning introduces the lowest BER at $3.3 \times 10^{-11}$ at a received power of -12 dBm for 16-PSK. However, for NRZ format it offers the higher BER around $8 \times 10^{-3}$ at same received power. Finally, it can be resolved that the channel spacing technique with 16-PSK is a promising candidate to overpower the FWM in WDM schemes.

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