REDUCTION OF FOURWAVE MIXING USING ODD EVEN CHANNEL SPACING

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Abstract-In a Wavelength Division Multiplexing (WDM) system with multiple channels, one important nonlinear effect is Four Wave Mixing (FWM). Four waves mixing significantly degrades system performance and is one of the major drawbacks for optical communication systems. The performance comparisons of two different FWM reduction methods are done. The methods are Four Wave Mixing suppression method based on Odd-Even Channels (OEC) arrangement strategy and Four-Wave Mixing suppression on unequally spaced channel. The performance of these two methods are compared based different parameters such as input power, channel spacing, Bit Error Rate (BER) etc. and the best method is understood. The design and analysis of optical communication system can be performed efficiently and effectively with the help of software tool Optisystem.

***Keywords*—Optical, Four Wave Mixing (FWM), Odd-Even Channel (OEC), Wave Division Multiplexing (WDM), Bit Error Rate (BER), Channel Spacing, Optisystem**

I. INTRODUCTION

Recently, optical communication has tremendous growth in the communication field. We are witnessing a new world with the ever-expanding growth of internet traffic. The applications in optical communication have increased numerously. To cover all the application with necessary transmission data rate, the Wavelength Division Multiplexing (WDM) system must be expanded.

WDM system allows transmission of data at a high rate of bits per second. The huge demand for the communication services and data increased and it forced to increase the capacity of optical communication system by the means of data rate.

When capacity of optical channels increased, there is a great chance of nonlinear effects such as Four Wave Mixing (FWM), Self-Phase Modulation (SPM) and Cross Phase Modulation (XPM). These nonlinear effects produce degradation effects, which affects the system performance.

FWM generates severe crosstalks due to interference between channels. Advanced modulation technique,
unequal channel spacing, dispersion management are some of the methods for suppression of FWM and thereby improving system performance.

Singh et al. made numerical analysis for both single and combined effects of dispersion parameters, i.e., second-, third-, fourth-, and fifth-order on FWM power at varied input power values and cross effective areas. FWM power has been suppressed by mixing the second- to fifth-order dispersion terms effects, but the weakness of this analysis is the absence consideration of dispersion compensation. Kaler et al. performed a comparison for FWM using low unequal channel spacing. Increasing the channels spacing can prevent the interference between spaced channels and mitigate the FWM effect. However, decreasing the FWM crosstalk levels by using unequal channel frequency spacing will not be practical because it disallows the implementation of DWDM. According to the nonlinear effect, fiber FWM efficiency is strongly based on the polarization states of mixing channels. A previous study attempted to reduce FWM crosstalk by setting the polarization state of the channels randomly. Random change in the state of polarization (SOP) is not guaranteed to minimize all interferences in the active channel. However, all these given techniques either are inefficient or require a complex system design. Moreover, some of these techniques can minimize the crosstalk defect but at the expense of DWDM capacity. A new suppressing approach with increased transmission capacity and simple system design has not been reported.

In this paper, we had done Odd-Even Channel Arrangement (OEC) scheme is implemented in design of the WDM system to reduce the FWM effect. By this simulation method, the outputs obtained were compared with the different parameters. The FWM power, OSNR values under equal channel spacing and unequal channel spacing are compared.

II. THEORY

Four-Wave-Mixing (FWM), or Four Photon Mixing (FPM), is a nonlinear effect in optical fibers at which four waves or photons interact with each other due to the third order nonlinearity of the optical fiber. As a result, new waves with sum and difference frequencies are generate during the propagation in the waveguide. FWM is comparable to the so-called intermodulation in electrical communication systems. The intermodulation, as well as the FWM, leads to noise in the neighboring channels which degrades the system performance. For WDM systems in Dispersion-Shifted Fibers (DSF), FWM is the most important nonlinear effect. When three frequencies (f1, f2, and f3) interact in a nonlinear medium, they give rise to a fourth wavelength (f4) which is formed by the scattering of the incident photons, producing the fourth photon, they can interact nonlinearly and give rise to nine new waves at frequencies:

$$f4 = f1 \pm f2 \pm f3$$

In general, the number of new waves generated by the FWM is given by:

$$\mathbf{M = N^2(N-1)/2}$$

Where N corresponds to the number of multiplexed channels

The optical power of the new wave at the frequency $f4$ can be written as:

$$P_4 = \eta \frac{1024\pi^6}{n^2\lambda^2c^2}\left(\frac{D\chi_{1111}L_{eff}}{Ae_{ff}}\right)^2 P_1P_2P_3e^{-\alpha L}$$

P_1 P_2 P_3 : input power

α: fiber loss coefficient

n: Core refractive index

Ae_{eff}: Core effective area

D: Degeneracy factor

C: velocity of light in vacuum

λ: Central wavelength

L_{eff}: Fiber effective length

χ_{1111}: 3rd order nonlinear susceptibility

III. SIMULATION SETUP

Odd-Even Channels Arrangement (OEC) scheme is implemented in designing the WDM system to reduce FWM nonlinear action and also to improve the performance of the WDM system. Basically, the function of OEC scheme is to partition the whole channels (N) into two sets. The first one is an odd channel, and the other is an even channel. So the two sets are multiplexed individually. Both sets undergo various polarization states. Eight channels (N = 8) were utilized in the design of the system. The channels, planned as n1, n2, n3, n4, n5, n6, n7, and n8, were categorized into odd channels set (n1, n3, n5, and n7) and even channels set (n2, n4, n6, and n8). One set was supplied into a multiplexer while the other set was supplied to another multiplexer. The output of the two multiplexers was supplied into a polarization controller (PC). (PC) is an appliance in which the signal feed of State of Polarization SOP is changed through adjusting the azimuth and ellipticity variables. SOP of odd channels set is 0◦, while that of even channels set is 90◦, rendering any channel adjacently vertical. In a conventional system, the SOP of the all signals is sorted on 0◦. The signals which are polarized by both multiplexers are pushed all together over the ultimate multiplexer. The optical link involves seven spans, and every span comprises post dispersal compensation accompanied by two erbium-doped fiber amplifiers (EDFAs) in the middle of them, which have a noise figure amount of 4 dB and gains of 14dB. When the signal is propagated through the channel of the optical fiber, the signal will be detected and collected at the receiver. The collecting received signal is divided by a Polarization Splitter (PS) into even- as well as odd-channel sets which are passed to the de-multiplexers. As soon as the de-multiplexers divide the channels, a photodiode (PIN) is utilized to detect them. Then, they are passed into the low-pass Bessel filter. Eventually, the signal is linked immediately to the eye illustration analyzer, so the graph is collected. The simulation parameters of the system are listed in Table 1.

A. *Transmitter*

The transmitter portion consist of CW laser array, external modulator, WDM multiplexer, polarization controller. Single Mode Fiber (SMF) is used to transmit the signals. Erbium Doped Fiber Amplifiers (EDFA) is used for the amplification of the signals. The CW laser array produces eight signals. The signal is split into two halves and fed to two external modulators. The Four odd channel signals are fed to one WDM multiplexer and even channel signal is fed to another WDM multiplexer. Both multiplexer produces one output each. The signals from both multiplexers are fed into two separate polarization controllers. The polarization controller has different azimuth. The outputs of both polarization controllers are fed into the ultimate WDM multiplexer. The output of WDM multiplexer is connected to the optical link. Standard single mode fiber is used to obtain long distance transmission. The optical link involves seven spans, and every span comprises post dispersal compensation accompanied by two Erbium-Doped fiber amplifiers (EDFAs) in the middle of them. When the signal is propagated through the channel of the optical fiber, the signal will be detected and collected at the receiver. The system transmitter model is shown in figure 1.

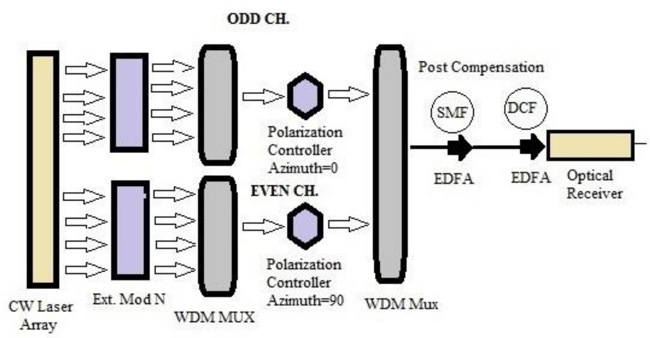

Figure 1. System Transmitter Model

B. *Receiver*

The signal is propagated through the channel of the optical fiber, the signal will be detected and collected at the receiver The receiver portion consist of Polarization splitter (PS), WDM demultiplexer, Photodiode, Low Pass Filter (LPF), BER analyzer. Figure 2 shows the receiver model. The polarization splitter splits the odd and even channels and are fed to two different WDM demultiplexer. The odd channel signal is fed into first demultiplexer and the even channel signal is fed into second demultiplexer. Each demultiplexer has four outputs. The demultiplexed outputs are connected to photodiodes individually. PIN diode is used as the photodetector. Eight photodiodes are used in the circuit for eight inputs. They are connected parallel to each other. The photodiode is followed by the low pass filter and BER analyzer. Eight low pass filter and BER analyzer is use to connect with photo diodes. Each photodiode is connected in series with low pass filter and BER analyzer. From the BER analyzer, we can observe the values of Q factor, BER, Minimum threshold. From the WDM analyzer we can observe the values of receive FWM power and OSNR values.

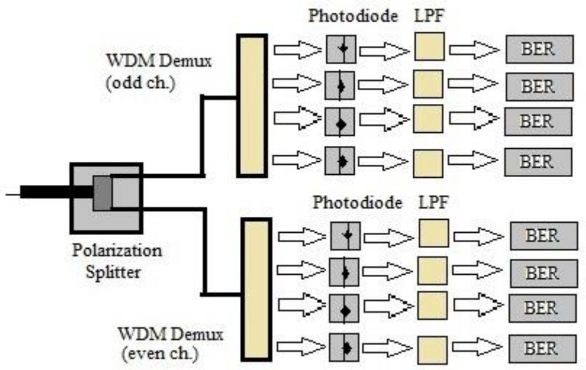

Figure 2. System Receiver Model

Parameter	Values	Unit
Fiber length, l	100	km
Input power, Pi	-12 to 0	dBm
Input frequency	191.5 to 192.2	THz
Dispersion, Dc	16	Ps/nm.km
Cross effective area, A_{eff}	72	μm^2
Attenuation factor	0.2	dB/km
Detector responsivity	8	A/W

Table 1. System design parameters.

Using the simulation parameter presented in Table 1, the system was designed and simulate under Optisystem software.

IV. RESULT AND DISCUSSION

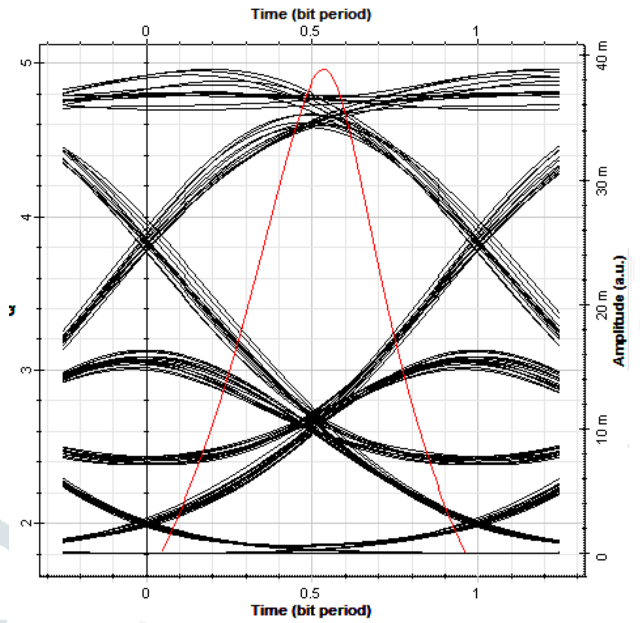

Figure 3. Performance of eye diagram at Pin= 0 dBm

The figure 3 shows the eye diagram at Pin=0 dB, the eye diagram has a more BER. The eye diagram shows the effectiveness of the proposed technique. It is clear from the eye diagram the system performance has improved. The figure 4 shows the graph of minimum BER obtained.

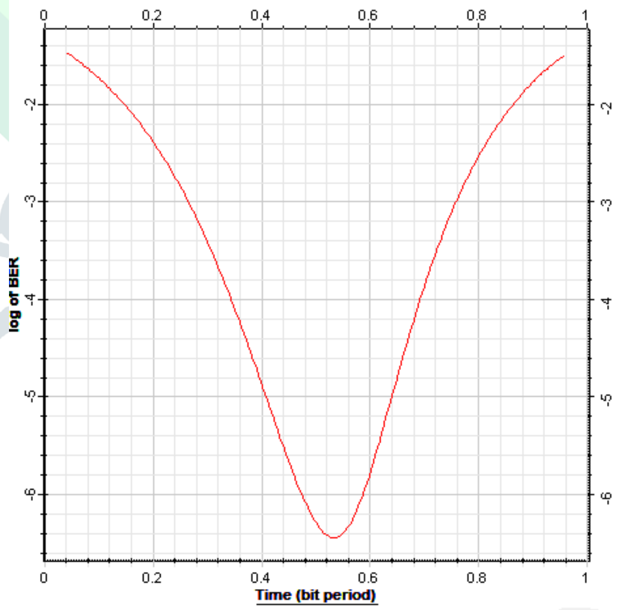

Figure 4. Min BER obtained

The frequency against FWM power is shown in the figure 5. The frequency ranging from 191.5 to 192.2 THz is applied to the CW laser array and input power from -12 dB to 0 dB is applied. The signal power obtained from -16.498 dBm to -4.498 dBm.

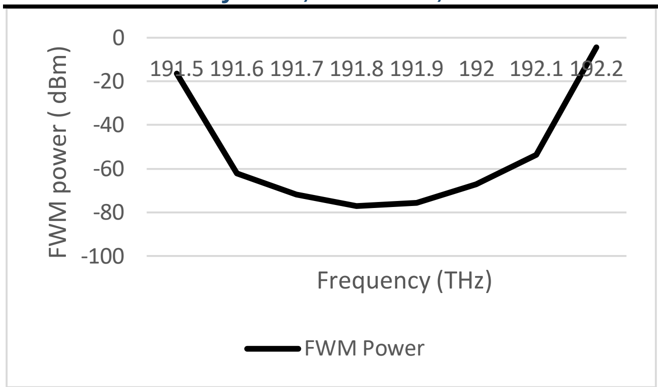

Figure 5. Frequency against FWM power

The figure 6 shows frequency versus FWM OSNR at the receiver for various input. The frequency ranging from 191.5 to 192.2 THz is applied to the CW laser array and input power from -12 dB to 0 dB is applied. The OSNR values obtained are 83.501 dB,37.877 dB, 28.342 dB, 22.799 dB, 24.300 dB, 32.843 dB, 46.378 dB and 95.501 dB for corresponding frequency.

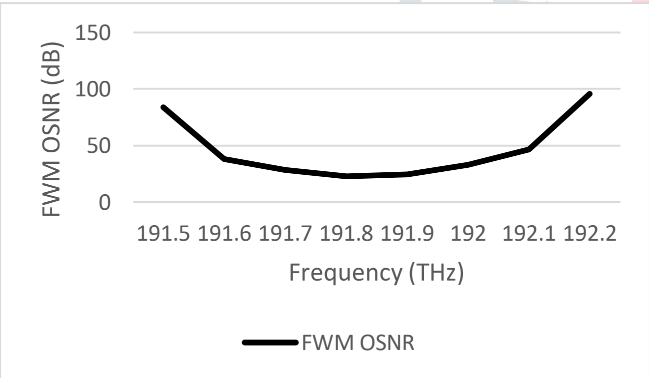

Figure 6. Frequency against FWM OSNR

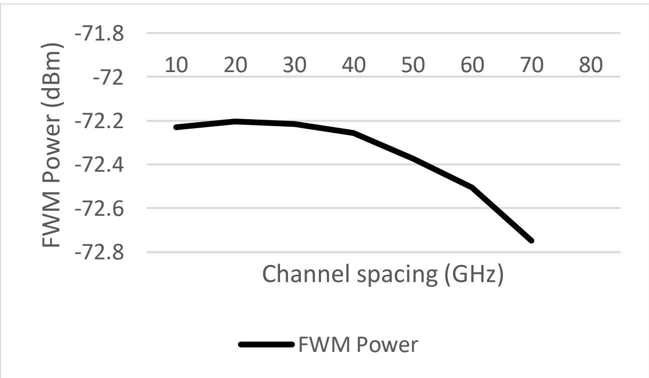

Figure 7. Channel spacing versus FWM power for equal channel spacing

The figure 7 shows the Channel spacing versus FWM power for equal channel spacing is shown. Channel spacing of 10 GHz is given. The FWM power varied from -72.23 dBm to -73.04 dBm for corresponding frequency. As shown in the figure the FWM power decreases with increase in the channel spacing

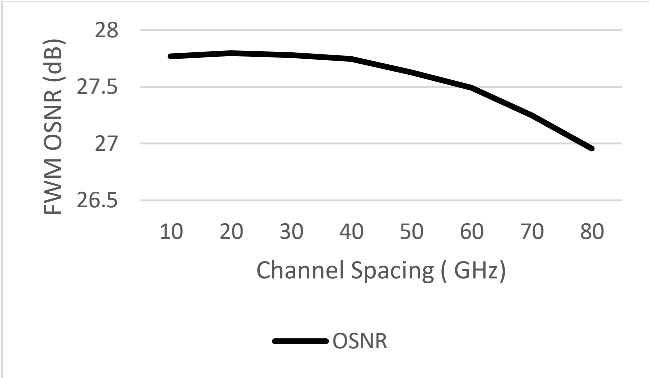

Figure 8. Channel spacing versus FWM OSNR for equal channel spacing

Channel spacing versus FWM OSNR is shown in the figure 8, with increase in the channel spacing the OSNR value decreases. Each channel has 10 GHz equal spacing. The values of OSNR obtained ranges from 27.76 dB to 26.95 dB. The values of OSNR decrease with increase in power.

The figure 9 shows the input power versus the received FWM power.

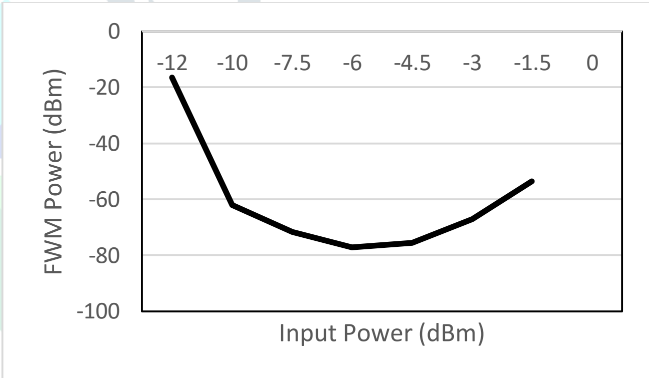

Figure 9. Input power against FWM power for various channel spacing.

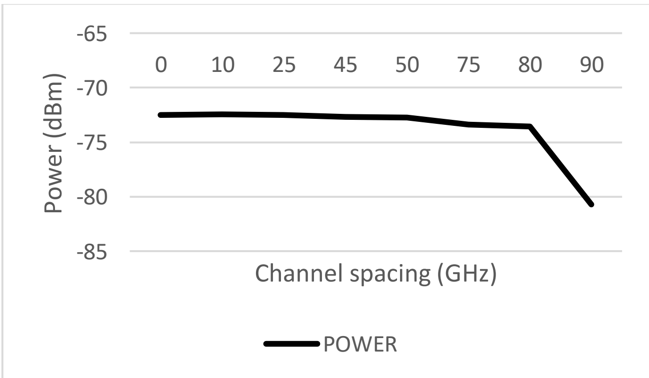

Figure 10. Channel spacing versus FWM power for unequal channel spacing

The figure 10 shows the channel spacing versus FWM power at the receiver for unequal channel spacing is shown. Unequal channel spacing 10 GHz ,25 GHz, 45

GHz, 50 GHz, 75 GHz, 80 Hz, 90 Hz is applied. The values of FWM power obtained are -72.484 dBm, -72.456 dBm, -72.470 dBm, -72.666 dBm, -72.714 dBm, -73.368 dBm, -73.524 dBm, -80.670 dBm. As shown in the figure when channel spacing increases the FWM power decreases more than that of the equal channel spacing.

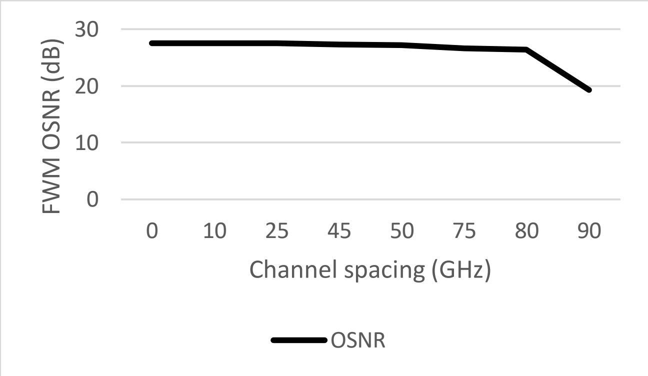

Figure 11. Channel spacing versus FWM OSNR for unequal channel spacing

The figure 11 shows the channel spacing versus FWM OSNR. With the OEC approach the OSNR value decreases with the increase in the channel spacing of unequal channel spacing. It decreases more obvious than the OSNR of equal channel spacing. The OSNR value obtained are 27.515 dB, 27.543 dB, 27.529 dB, 27.331 dB, 27.285 dB, 26.631 dB, 26.475 dB, 19.329 dB.

V. CONCLUSION

Odd-Even Channels arrangement (OEC) scheme is implemented in designing the WDM system to minimize FWM nonlinear action and also to upgrade the capacity utilization of the WDM system. This technique provides experimental verification that the use of OEC scheme can reduce significantly the level of FWM products. The OEC technique has displayed progress in improving system performance from the simulation analysis. The channel with unequal spacing shows the more obvious reduction than the channels with equal spacing. The FWM power, OSNR reduces with increase in the channel spacing.

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