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Reduction of Four-Wave Mixing in Wavelength Division Multiplexing Using Polarization Controller

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ABSTRACT:-

Optical fiber networks are fast, robust and error-free, but there are some nonlinearity hindrances which prevent them from being a perfect medium. Four-wave mixing (FWM) is a type of nonlinear effect which occurs in WDM systems when light of two or more different wavelengths are launched into a fiber. FWM causes inter-channel crosstalk, inter-symbolic interference, generates additional noise and degrades system performance in WDM systems. The objective of this paper is to simulate the FWM effect in WDM with optical components using optical simulation software called Optisystem in order to minimize this nonlinear effect called FWM. Previously, duobinary modulation technique was used. This paper uses polarization controller technique to minimize the FWM effect. From obtained results, the proposed polarization controller scheme lead to the FWM effect being minimized to – 80dBm with respect to the FWM sideband and the threshold value of input power obtained was 22dBm. The FWM minimization method employed eliminated noise in the WDM systems.

Keywords: FWM, Polarization Controller, Threshold value of input power.

I. INTRODUCTION

The interactions between three wavelengths produce a fourth wavelength. This phenomenon is called four-wave mixing (FWM). Four-Wave Mixing is a non-linear effect in Wavelength Division Multiplexing (WDM) systems. Four-wave mixing (FWM) is a third-order non-linear effect. It is caused by the dependence of refractive index on the intensity of the optical power. The concept of three electromagnetic fields interacting to produce a fourth field is central to the description of all FWM processes. Physically, we may understand this process by considering the individual interactions of the fields within a dielectric medium. The first input field causes an oscillating polarization in the dielectric which re-radiates with some phase shift determined by the damping of the individual dipoles. The application of a second field will also drive the polarization of the dielectric, and the interference of the two waves will cause harmonics in the polarization at the sum and difference frequencies. Now, application of a third field will also drive the polarization, and this will beat with both the other input fields as well as the sum and difference frequencies. This beating with the sum and difference frequencies is what gives rise to the fourth field in FWM. Since each of the beat frequencies produced can also act as new source fields, a bewildering number of interactions and fields may be produced from this basic process (Schneider T, 2013). The phenomenon of interaction between two or more wavelengths to produce more wavelengths due to scattering of photons incident on the fiber is known as FWM also named as four photon mixing. It is one of the most crucial parameter which determines the performance of an optical transmission system. It is observed that two or more information carrying optical signals travelling in the same fiber interact with each other very weakly. However, over long-haul transmission, these weak interactions become very significant. The main reason of FWM in optical fiber is the change of refractive index with optical power. Four wave mixing can also be considered as kerr effect in optical domain. Chromatic dispersion and fiber non-linear effects pose a major restriction on maximum repeater distance and bandwidth of fiber optic communication system. The interactions between information carrying optical signal and optical fiber can lead to signal interference, signal distortion, scintillations and distortion of information carrying signal which degrades system's performance. Four wave mixing is a third order distortion of signal in which two or more nearby frequency travelling in the same fiber interact with each other and as a result produce new frequencies also known as beat frequencies which travel along the original signal travelling in the fiber. As a result of FWM in a multichannel system, several impairments occur in the transmission process such as crosstalk and inter symbolic interference (ISI) which degrades the overall performance of the system (Singh, M 2015).

II. RELATED WORK

Habib U. M. et. al. (2019) proposed a FWM reduction using different modulation techniques and optical filters in DWDM optical communication systems using a comparative study. Different modulation techniques and optical filters were considered and investigated to reduce the FWM effect in DWDM optical communication systems. System performance is evaluated through its quality factor (Q-factor), optical signal-to-noise ratio, optical received power and FWM efficiency. All used techniques have shown a reduction in FWM efficiency. The highest reduction in FWM efficiency is 25 dB and is reported while using modified Duobinary modulation with an increase of 2 in the Q-factor. A comparative study is carried out for the different techniques at 10–20 Gbps bit rate. All simulations are performed through Optisystem.

Abin K. M. et. al. (2019) work was based on Reduction of four wave mixing(FWM) using odd even channel spacing. In a Wavelength Division Multiplexing (WDM) system with multiple channels, one important nonlinear effect is Four Wave Mixing (FWM). They observed that 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 were carried out. 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 on different parameters such as input power, channel spacing, Bit Error Rate (BER) etc. and the best method was determined as the Odd-Even Channels (OEC) arrangement strategy. The design and analysis of optical communication system can be performed efficiently and effectively with the help of software tool Optisystem.

Habib U. M. et. al, (2015) introduced a method in which alternative circular polarizers are used to change the polarization of input pulses into right and left handed polarized pulses before multiplexer which results in reduction of FWM. With the help of this technique we can completely eliminate FWM by optimizing optical network's parameters. Exhaustive set of simulations were performed in Optisys and system's performance calculated. In their work, a new technique to suppress FWM was been described by employing circular polarizers in the optical network. Circular polarizers of alternating left and right hand polarizations placed before the multiplexer at transmitter change the polarization of input pulses. Circular polarizer reduces FWM products without any degradation to original pulses. It is determined by performing exhaustive set of simulations in OptiSys that employing circular polarizers does not affect much received power, OSNR, Q factor and BER. Furthermore, they found that using circular polarizers, FWM can completely be eliminated by optimizing the system parameters such as increasing channel spacing, reducing data rate and increasing the length of fiber. This technique is quite generic and can easily be implemented in practical systems.

Osamu A. et. al. (2000) examined Four-Wave Mixing in Optical Fibers and Its Applications. They described Four-wave mixing (FWM) is a phenomenon that must be avoided in DWDM transmission, but depending on the application it is the basis of important second- generation optical devices and optical device measurement technology. Their work discusses the theory of FWM, and then introduces one of its applications --a broadband all-optical simultaneous wavelength converter developed using a high nonlinearity dispersion fiber (HNL-DSF) that efficiently produces FWM. The conversion bandwidth extends to 23.3 nm HWHM (half width at half maximum), the widest yet reported for wavelength conversion using non polarization maintaining fiber. The authors have examined techniques for achieving broadband all-optical simultaneous wavelength conversion by taking advantage of four-wave mixing (FWM) occurring in the fiber, together with techniques for the simultaneous measurement of the nonlinear coefficient and chromatic dispersion. They were able to demonstrate that the use of short-length HNL-DSF simultaneously solves the problems of chromatic dispersion variance along the longitudinal direction and polarization mismatch of probe and pump. It has been experimentally demonstrated that simultaneous wavelength conversion is possible over a bandwidth of 23.3 nm, the widest for non-polarization-maintaining fibers.

III. METHODOLOGY

The simulation set-up consists of a sine wave generator, duobinary pulse generator, pseudo-random bit sequence generator, continuous wave laser, mach-zehnder modulator, WDM multiplexer, optical fiber CWDM, Polarization Controller (PC), Bessel Optical Filter (BOF), Dispersion Compensation Fiber (DCF), Fiber Bragg Grating (FBG), Optical Infinite Impulse Response (Optical IIR) filter, optical spectrum analyzer, WDM analyzer, and optical power meter. The setup consists of signals with sine wave generator in analog form and the random bit sequence in digital form. The sine wave generator generates an electrical sine waveform signal. It excellently generates the waves. It allows both frequency and amplitude of the sine wave output to be varied. Both fine and coarse frequency control are included. The pseudorandom bit sequence generator generates a stream of O's and 1's at a rate of 2.5Gbps. The duobinary pulse generator functions to combine both sine wave and bit sequence. The duobinary pulse generator convert the sine analog waveform into binary pulse and also converts these O's and I's in form of electric pulses having duobinary format. These electrical pulses from output of duobinary pulse generator are directed to input of mach-zehnder modulator which modulates information with a continuous wave (CW) laser. The CW laser produces the light. Laser is a device that emits light through a process of optical amplification. The mach-zehnder modulator also function for the balancing of optical paths (optical power output) of light produced by CW laser. The setup consists of two such channels separated at some frequency interval. These two WDM channels are multiplexed and directed into an optical fiber of length 25km. The optical signal from the output of the optical fiber is directed to filter which eliminates all the high frequency noise present in the received electrical signal. At the last stage, the received signal is analyzed using optical spectrum analyzer and WDM analyzer. The block diagram of this setup is shown in Figure 3.1, where the filters (BOF, Optical IIR), PC, DCF + FBG and UCS are the correction of FWM compensators. The optisystem simulation setup is shown in Figure 3.2, were each WDM channel comprises of a sine-wave generator, pseudorandom bit sequence generator, CW laser, duobinary pulse generator and a mach-zehnder modulator.

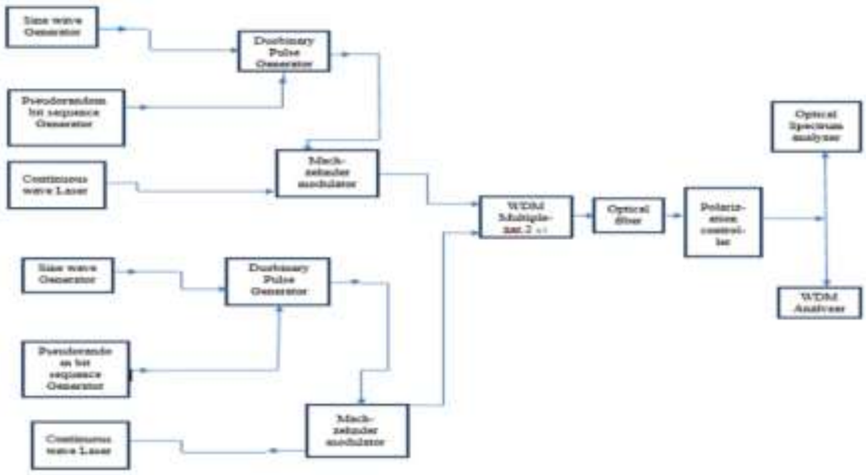


Fig.3.1 Block diagram of setup

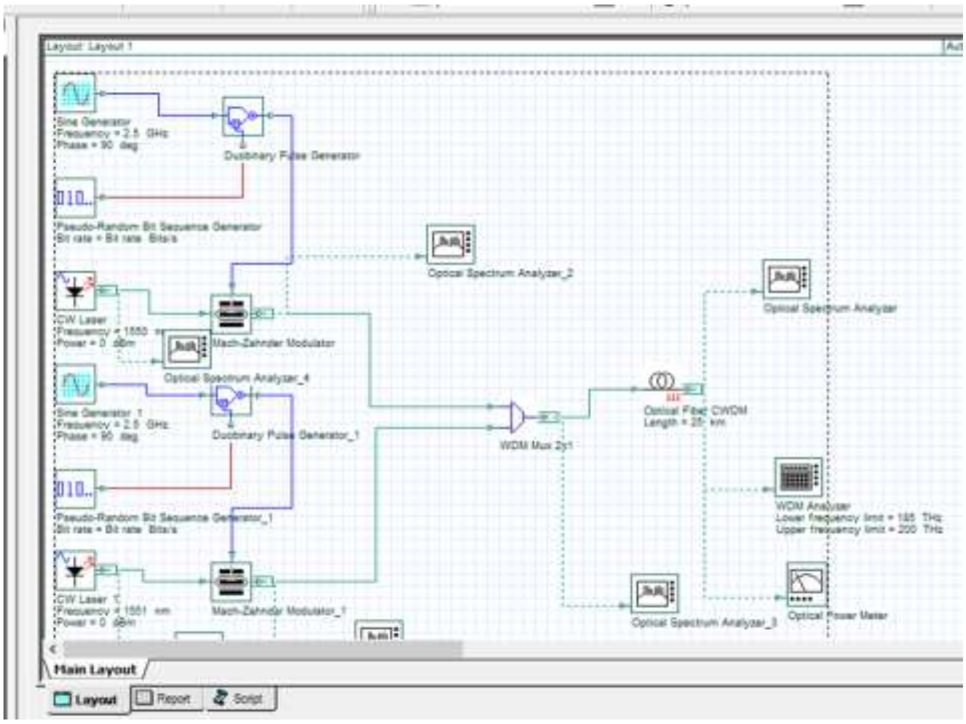


Fig. 3.2 FWM simulation set up in Optisystem

IV. RESULTS AND DISCUSSION

The spectrums in Figures 4.1, 4.2, 4.3, and 4.4 shows the four wave mixing sidebands. The channel spacing was set at 1nm (1550nm to 1551nm) so as to differentiate the allocated frequencies and also because an increase in channel spacing from 1550nm to 1551nm reduces the FWM effect, with input powers of 0dBm, -4dBm, -8dBm and -10dBm respectively. The performance at 0dBm shows maximum FWM sideband of -80dBm.This shows improvement over (Jain and Therese, 2015) because at 0dBm the maximum FWM sideband obtained was -69.6dBm which is higher as compared to -80dBm FWM sideband realized in this work. The reason for this performance is because of the incorporation of polarization controller in this work. This is due to the fact that the polarization controller (PC)) controls the state of polarization of light within the fiber core and then sets the input signal in an arbitrary polarization state. The polarization controller adjusts the first two incident waves to linear polarization. The PC controls the polarization angle between the pump light and the signal light. With the PC most of the FWM frequencies were cancelled because the interaction between multiple optical channels that pass through the same fiber reduced, which suppressed the FWM. The interfering wavelengths generated around the original two wavelength system are 1549nm and 1552nm. Further when we decreased the power level from 24dBm to -10dBm, the input power level was compared with the noise power and signal to noise ratio to find the threshold power level. Table 1 below shows the output of the WDM analyzer giving the value of the noise power and the OSNR with respect to the input signal power, as the input power level increases, the signal power also increases. Figure 4.5 below shows the graph of the input power and noise power, as the input power level decreases, the noise power also decreases. Figure 4.6 below shows the graph of the input power level and OSNR, the threshold value of input power is found to be 22dBm below which the OSNR is constant.

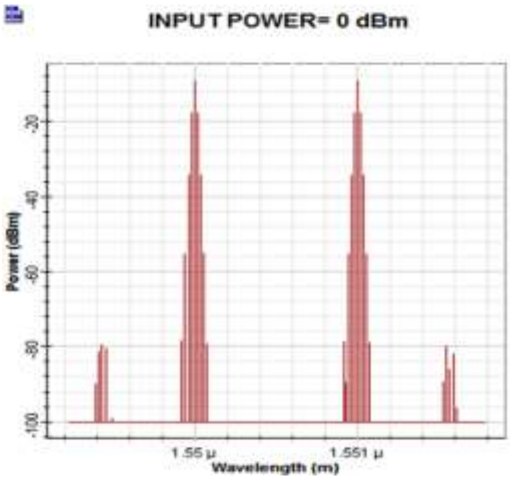


Fig 4.1 The optical spectrums at the output when the two wavelengths are transmitted at 0dBm.

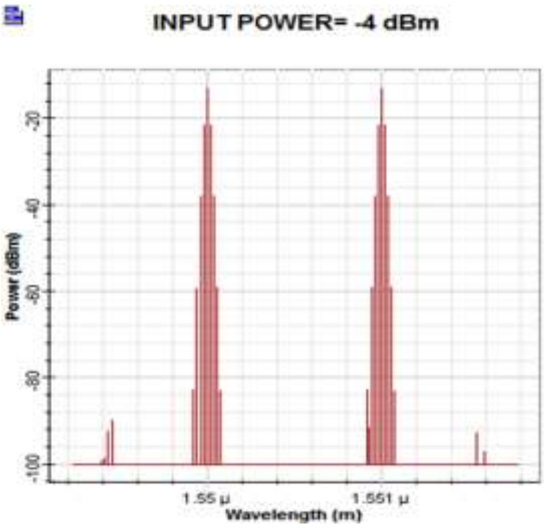


Fig 4.2 The optical spectrums at the output when the two wavelengths are transmitted at -4dBm.

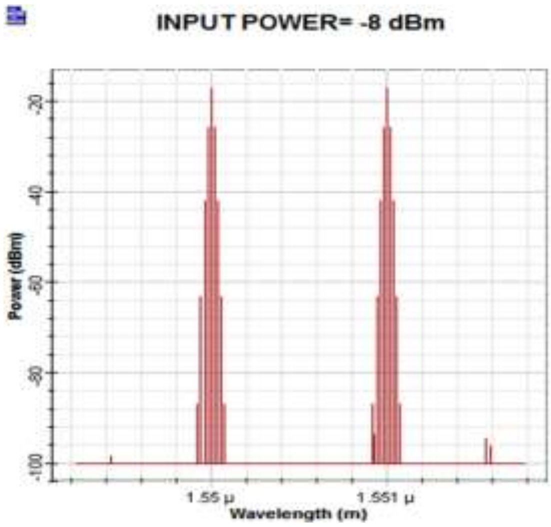


Fig 4.3 The optical spectrums at the output when the two wavelengths are transmitted at -8dBm.

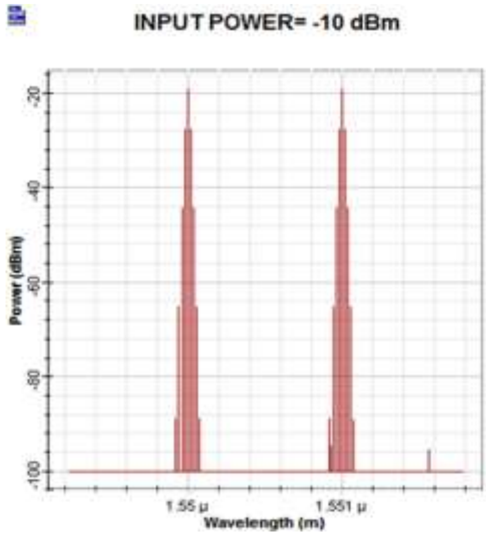


Fig 4.4 The optical spectrums at the output when the two wavelengths are transmitted at -10dBm

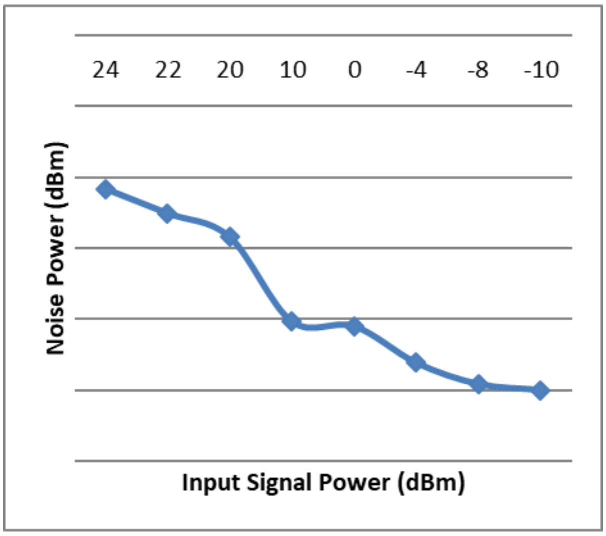
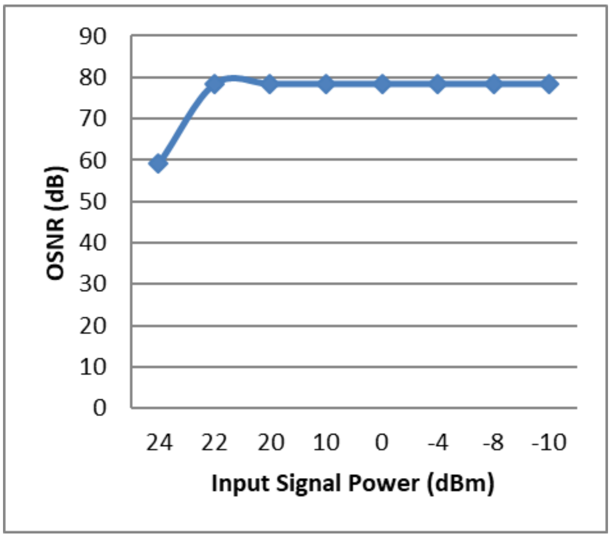


Fig 4.5 Graph of Input Signal power and Noise Power

Table 1: Comparison of Parameters for Different Input Power

Input Power (In dBm)	Signal Power (In dBm)	Noise Power (In dBm)	OSNR (dB)
24	15.80	-43.30	59.10
22	13.80	-50.22	78.30
20	11.80	-56.89	78.30
10	1.80	-80.71	78.30
0	-8.20	-82.03	78.30
-4	-12.20	-92.37	78.29
-8	-16.20	-98.32	78.29
-10	-18.20	-100	78.29



4.6 Graph of Input Signal Power and OSNR

Further decrease in power level from 24dBm to 10dBm, the sideband of FWM increases due to the pronounced effect of the signal degradation of FWM as a result of low noise in the channel. This is clearly shown in Figure 4.6. The effect of the input power on OSNR, signal power and noise power is compared and comprehensively shown in Table 1, as the input power level increases, the signal power also increases. Figure 4.6, as the input power decreases, the noise power also decreases and Figure 4.7 where the threshold value of the input power is found to be 22dBm below which the optical signal to noise ratio (OSNR) is constant.

Polarization Controller (PC)

In the case of PC, fig. 4.7, the graphs of input signal power and noise power shows how large amount of noise was minimized from the system in this work, -42dBm to -100 dBm compared to previously, -17dBm to -85dBm, since FWM generates additional noise and degrades system performance and also, fig. 4.8, the graphs of input signal power and OSNR, the optical signal to noise ratio of proposed work (78.3dB) is higher than previously (72dBm).

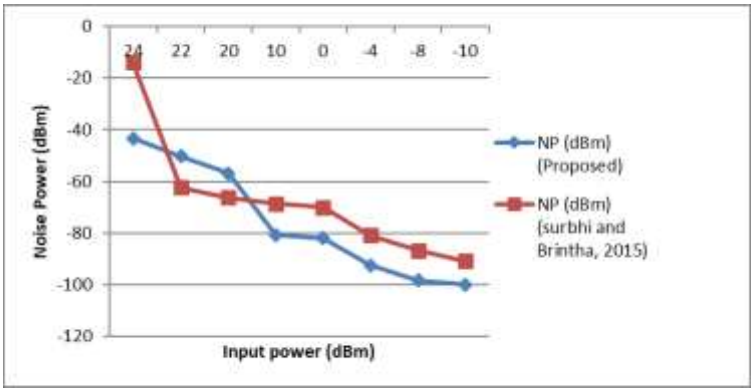


Fig. 4.7: Graph of Input Signal Power and Noise power

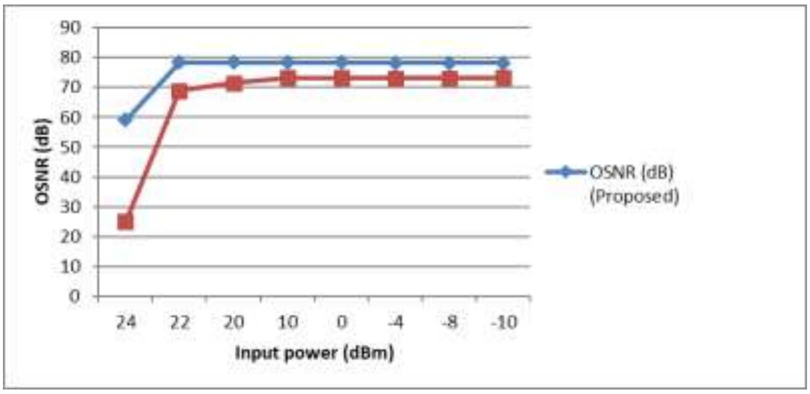


Fig. 4.8: Graph of Input Signal Power and OSNR

V. CONCLUSION

In conclusion, not like the linear effects which can be replaced, the nonlinear effects become more and degrade the system performance. The capacity of information of a light wave is majorly limited by the nonlinear interactions between the information signals and the fiber medium. Four-Wave Mixing (FWM) is a type of nonlinear effect which occurs in wavelength division multiplexing (WDM) when light of two or more different wavelengths are launched into a fiber. FWM is a main source of nonlinear crosstalk since they interfere with the desired signals. The effect of four wave mixing (FWM) as one of the key factors in the WDM has been studied here using optisystem. The investigation of FWM effect for various parameters has been done. The four wave mixing effect has been minimized.

VI. REFERENCES

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