Simultaneous Reduction of Four Wave Mixing and Stimulated Raman Scattering using Duobinary Modulation format in DWDM Fiber Optic Communication System

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Abstract - Dense Wavelength Division Multiplexing (DWDM) enables the utilization of a significant portion of the available fiber bandwidth by allowing many independent signals to be transmitted simultaneously on one fiber, with each signal located at a different wavelength. In this paper, the two major non-linear effects such as FWM and SRS in transmission fiber must be simultaneously eliminated by Duobinary Modulation to achieve successful communication. The results taken for 4, 8, 16, 32 and 64 channels are carried out by using OPTSIM software.

Keywords: SRS, FWM, DWDM, Duobinary Modulation.

I. Introduction

Fiber optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The optical fiber is designed in such a way that all the nonlinearities inside the fiber have to be minimized and optimized to reproduce the original signal at the receiver.

The non-linearity in optical fiber falls into two categories: Inelastic Stimulated Scattering and Kerr Effect.

WDM is nothing but N independent optically formatted information streams each transmitted at a different wavelength are combined with optical multiplexer and send over the same fiber. The wavelength in WDM must be properly spaced to avoid inter-channel interference. Dense Wavelength Division Multiplexing (DWDM) is a technology that puts data from different sources together on an optical fiber, with each signal carried at the same time on its own separate light wavelength [i]. Using DWDM, upto 64 (and theoretically more) separate wavelengths or channels of data can be multiplexed into a light stream transmitted on a single optical fiber.

II. Fiber Nonlinearities

Nonlinearities in optical fibers originate due to the third order susceptibility. Fiber nonlinearities become a problem when several channels coexist in the same fiber. In an optical fiber, non-linear effects arose due to increased data rates, transmission length, number of wavelengths and optical power levels. The longer the optical fiber, the more the light interacts with the fiber material and the greater the nonlinear effects. On the other hand, if the power decreases while the light travels along the optical fiber, the effects of nonlinearity diminish [i].

1. Stimulated Raman Scattering

Stimulated Raman Scattering is a combination of Raman process with stimulated emission. If three (or) different wavelengths are transferred in the optical fiber, Stimulated Raman Scattering produces the output optical power is transferred from lower signal wavelength to the higher signal wavelength.

Threshold power of SRS can be estimated by,

$$P_{th} \approx 16\, A_{eff} / g_R\, L_{eff} \qquad (1)$$

Where,

g_R = Raman gain

L_{eff} = Effective length of the fiber

$$(NP)\ [\ (N\text{-}1)\ \Delta f\ ] < 6.623 * 10^{11}\ \text{Hz. W} \qquad (2)$$

Where,

NP-Product of Total optical power

Modified power due to SRS is given by [i],

$$p_m[k] = p_t[k] - p_t[k]\sum_{i=k+1}^{N} D[k,i] + \sum_{j=1}^{k-1}(p_t[j]D[j,k]) \qquad (3)$$

for k=1,2,3….N

D[k,i]=0 for i>N

D[j,k]=0 for k=1

$P_t[k]$= Transmitted power in the k^{th} channel

D[j,k]= Power transfer coefficient for power transmitted from λ_j to λ_k

SRS effects depend on the optical power level, channel spacing, number of channels, etc. The SRS spectrum is shown in Fig.1.

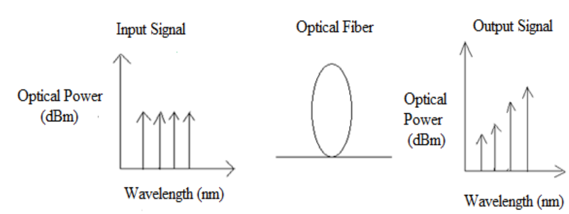

Fig.1 SRS spectrum

SRS effect can be mitigated by decreasing channel spacing and in presence of dispersion reduces the SRS penalty.

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2. Four Wave Mixing

When three wavelengths (λ_1, λ_2 & λ_3) interact in a non-linear medium they give rise to a fourth wavelength (λ_4) which is formed by scattering of incident photons, producing the fourth photon that is the FWM or interfering signal is shown in Fig. 2 [ii] in terms of frequency w. The interference FWM in DWDM systems causes an interchannel crosstalk.

$$\lambda_{123} = \lambda_1 + \lambda_2 + \lambda_3, \text{ Where } 1,2 \neq 3 \qquad (4)$$

$\boldsymbol{\lambda_{123}}$ is called as interfering signal or FWM signal.

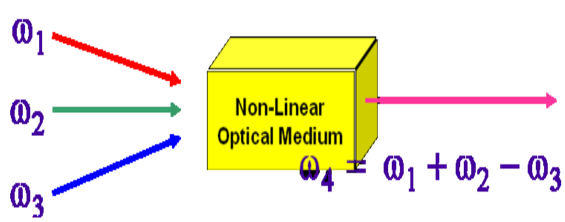

Fig.2 Formation of Fourth Spurious Component

The total number of mixing components increases dramatically with the number of channels. The total number of mixing components, M is calculated from the equation

$$M = ½ [(N^3)-(N^2)] \qquad (5)$$

Where, M= mixing component and N= number of component. As N increases, M increases rapidly [ii].

Therefore FWM effect, three co-propagating waves produce nine new optical sideband waves at different frequencies [iii]. When this new frequency falls in the transmission window of the original frequencies, it causes severe crosstalk between the channels propagating through an optical fiber. Moreover, the degradation becomes very severe for large number of WDM channels with small channel spacing.

III. Proposed Method

In this paper, Duobinary Modulation method is used to analyze the effect of SRS and FWM in DWDM system and how it reduces these effects after the fiber. Duobinary Modulation is resilient to dispersion and simple to implement.

Duobinary coding is an effective method in high speed optical transmission systems to increase dispersion tolerance, to improve spectral efficiency and to reduce the sensitivity to non linear effects. The term 'duo' means doubling the bit capacity of a straight binary system. The main advantages attributed to this modulation format are increased tolerance to the effects of chromatic dispersion [iv].

The fundamental idea of Duobinary Modulation that was first described by Lender in 1964 is to deliberately introduce Inter Symbol Interference (ISI) by overlapping data from adjacent bits. This correlation between successive bits in a binary signal leads the signal spectrum to be more concentrated around the optical carrier. This is accomplished by adding a data sequence to a 1-bit delayed version of itself, which can be obtained by passing the binary signal through the delay-and-add filter. It is given by,

$$Y_K = X_K + X_{K-1} \qquad (6)$$

Binary signal is a two level signal but Duobinary is a three level signal. Binary has information capacity 1, but Duobinary is twice than that of Binary [iv]. For Duobinary system, degree of complexity and amount of circuitry required are low. Precoder is added to eliminate error propagation in receiver.

Proposed system is shown in Fig 3. Here the transmission fiber has length L km with attenuation of α dB/ km. The fiber dispersion is set to non-zero values to observe the FWM in the DWDM system. The fiber birefringence value is set for the correlation length of the fiber. The optical signal source is passed through the fiber to analyze the fiber non-linearities such as FWM and SRS.

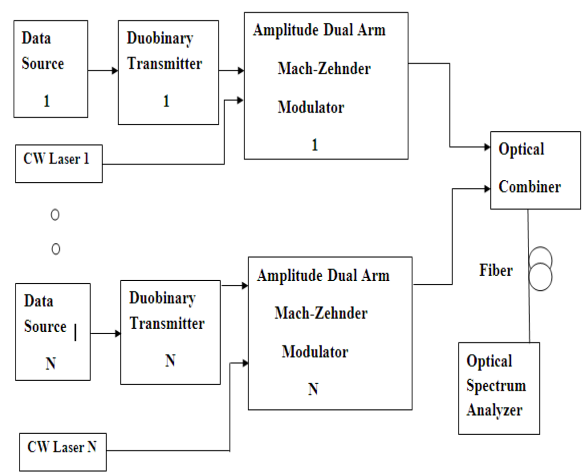

Fig.3 Block diagram for proposed system

Duobinary Modulation format is obtained by driving an external dual arm Mach-Zehnder modulator with opposite phase signal. A Dual arm Mach-Zehnder modulator is based on Mach-Zehnder Interferometer (MZI) and is fabricated from LiNbO3. 10 Gbps data sources and CW Lasers are used. Modulated signals are combined by optical combiner. Then the combined signal is transmitted through a 100 km standard single mode fiber. While traveling through the fiber, the signal may be distorted due to FWM and SRS. Optical spectrum analyzer is connected before and after the fiber inorder to see these effects. Before fiber, the clear spectrum is obtained and after the fiber the original spectrum is affected by FWM and SRS.

A Duobinary transmitter mainly consists of two NRZ rectangular drivers, Bessel electrical filters and a NOT gate. Here the NOT gate is used to invert the signal. NRZ rectangular driver is the modulator drive. Bessel electrical filter is a type of

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linear filer which preserves the wave shape. Bessel filter is also called Bessel-Thompson filter and it has maximally flat group delay.

IV. Experimental setup

For 16-channel WDM system, the outputs of each compound component are combined and it is passed through the fiber. The transmission fiber has a length of 100 km with attenuation of 0.1dB/km. The fiber has Polarization Mode Dispersion (PMD) of 0.1 ps/nm-km with the core effective area of [80x (10^-12) m^2]. The correlation length of fiber birefringence is 0.2 km.

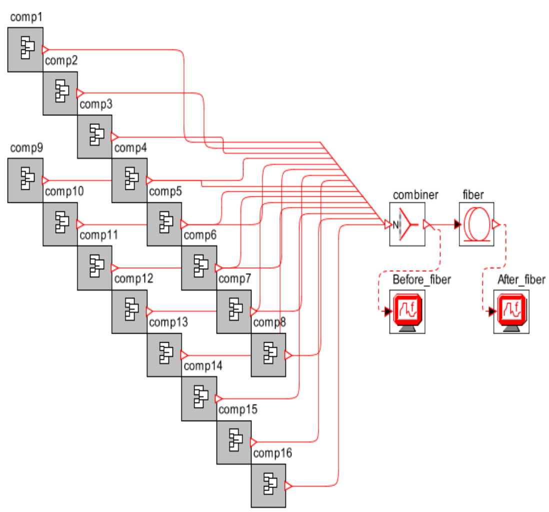

Fig.4 Optsim layout for 16-channel WDM system with Duobinary Modulation

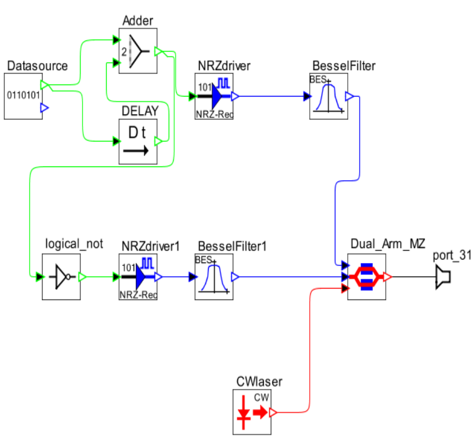

Fig.5 Look inside view of transmitter

V. Results & Discussions

For 16-channel WDM system has equal channel spacing of wavelength is 1 nm is simulated in OPTSIM. The output of the combiner is passed through the 100 km fiber with attenuation of 0.1db/km. The output spectrum is obtained before and after the fiber. The spectrum obtained before fiber has equal optical power level (i.e. power tilt=0) and no FWM terms are present are shown in below.

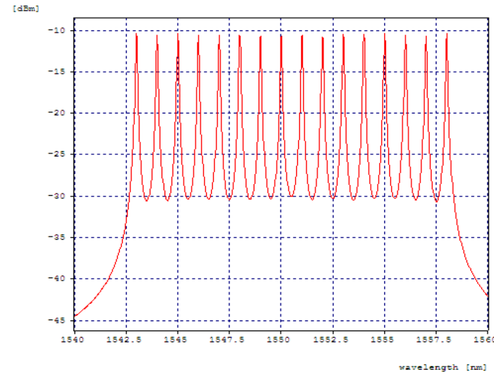

Fig.6 Spectrum of Combiner output for 16- Channel WDM Layout

The spectrum obtained after fiber contains the extra optical signal (FWM) and also power tilt≠0 (SRS) other than the original signal is present. The output of fiber clearly shows the FWM and SRS effect in 16-channel WDM system is shown below.

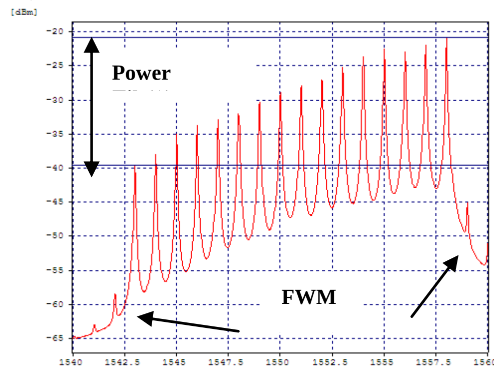

Fig.7 Fiber output spectrum for 16-channel WDM layout without Duobinary system

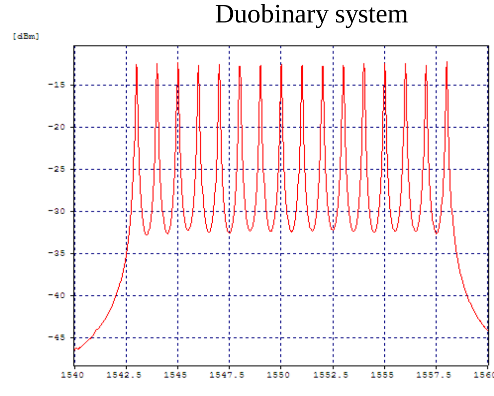

Fig.8 Fiber output spectrum for 16-Channel WDM layout with Duobinary system

Hence, the effect of fiber non-linearities such as FWM and SRS is analyzed using Duobinary Modulation with equal channel spacing. The spectrum obtain after the fiber with Duobinary Modulation suppress the FWM and SRS effects simultaneously is shown in Fig 8. In most of the spectrum of fiber, out-bound FWM is clearly identified. By adding proper amount of dispersion, non-linear effects are reduced. In this paper, Duobinary Modulation with equal channel spacing is shown for 16-channel WDM system. It can be scaled to more number of channels by using Duobinary method.

VI. Conclusion

OPTSIM layouts for 4, 8, 16, 32 and 64 channels have been simulating with Duobinary Modulation format. The spectrum of fiber output obtained from DWDM and WDM system shows the FWM and SRS effects clearly and it can be mitigated by Duobinary modulation.

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