SELF PHASE MODULATION EFFECTS ON DISPERSION COMPENSATED TRIBUTARY MAPPING MULTIPLEXING TRANSMISSION

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ABSTRACT : *In Fiber Optical Transmission System, non-linear effects have generally conveyed as destructive and gain significant consideration in Self Phase Modulation and Cross Phase Modulation. In this paper, we investigated Self phase modulation (SPM) effect on 40 GB/s novel mapping multiplexing technique also called tributary mapping multiplexing (TMM). These investigations are made through launched power and dispersion compensation methods. In order to manage optical fiber transmission links, combination of pre and post compensation dispersion is used to compensate the dispersion effects by Single Phase Compensation. Evaluation results show that SPM effect is stronger in 100% dispersion post-compensated links in comparison to the combination of pre and post-compensated transmission links. Moreover, 18-20% dispersion pre-compensation is investigated and verified as optimum range of pre-compensation ratio for TMM system, that improve the system performance for high launched power.*

Keywords: Self Phase Modulation, Tributary Mapping Multiplexing, Dispersion, Compensation

1. INTRODUCTION

Non-linear effects have been considered as being generally destructive for long haul fiber optic transmission system [1].Fiber nonlinearities such as self phase modulation (SPM) and cross phase modulation (XPM) have drawn significant consideration [2].Dispersion effects can be minimized by utilizing periodic dispersion compensation (DCF) along with standard single mode fiber(SSMF) [3].By doing this, bandwidth-length product of optical transmission system link is no more limited by chromatic dispersion(CD),leaving nonlinear effects as main concern. Pulse broadening and recompression become significant factors with the continuous increase in transmission rate are needed to be addressed [4].the most dominant nonlinear effect in high speed optical transmission systems such s time division multiplexing (TDM) [5] and novel mapping multiplexing [6] is self phase modulation, that occurs due to the fiber refractive index dependence on pulse intensity. Induced phase shift due to nonlinear refractive index is proportional to the pulse intensity [6-7]. Pulses chirping are due to the different phase shifts of the different parts of the pulse. Pulses chirping increase the pulse broadening effects due to the chromatic dispersion (CD).This effect is proportional to the input launched power that makes SPM effect more prominent in an optical transmission systems using large input launched power. Long haul and high speed optical transmission systems need large power for error free transmission and detection, their performance are affected by this nonlinear SPM effect [8].Modulation format like Return-to-zero (RZ) has clear advantages over the most commonly used modulation format,non-return-to-zero (NRZ) only because of its better tolerance to fiber nonlinear effects [9-10].

TMM was first introduced in [13] as an efficient multiplexing technique that has better spectral efficiency, dispersion tolerance to improve the optical long haul transmission systems performance. In Comparisonto 4× 10 GB/s NRZ-OOK, 40GB/s TMM has ~50% narrow spectral width that leads to better tolerance to chromatic dispersion (CD) [12].

In this paper, we report an investigative mathematical study of SPM effect on TMM optical transmission system. Nonlinear Schrodinger (NLS) equation is refer to the dispersion model and SPM effect in our optical transmission links. Simulation was performed in both scenario, 100% dispersion post compensation and combination of pre and post compensated optical transmission links. Dispersion pre-compensation optimum value is reported in [13].

The rest of this paper is organized as followed. Section 2 describes in detail the Tributary Mapping Multiplexing technique. While in Section 3 we have described the comparative implementation and in Section 4 results are discussed followed by conclusion in the Section 5.

2. Tributary Mapping Multiplexing Technique

Tributary Mapping Multiplexing (TMM) is a multiplexing technique, whichuses RZ with 50% duty cycle and unipolar signaling to distinguish the number of channels. For ‘N’ number of TMM users, symbol duration T_s(1/bitrate), is divided into two slots.TMM user to transmit bit, Tiis [13]

$$T_i = \frac{T_s}{2} \qquad (1)$$

Thus each TMM user has the fixed pulse width (50% duty cycle).Different TMM users transmit their data on the single communication channel in the same time period, wavelength and duty cycle but with different amplitude levels and slots as shown in Figure 1.

Table 1

U1	U2	U3	U4	TMM Symbol
0	0	0	0	D0
0	0	0	1	D1
0	0	1	0	D2
0	0	1	1	D3
0	1	0	0	D4
0	1	0	1	D5
0	1	1	0	D6
0	1	1	1	D7
1	0	0	0	D8
1	0	0	1	D9
1	0	1	0	D10
1	0	1	1	D11
1	1	0	0	D12
1	1	0	1	D13
1	1	1	0	D14
1	1	1	1	D15

(a)

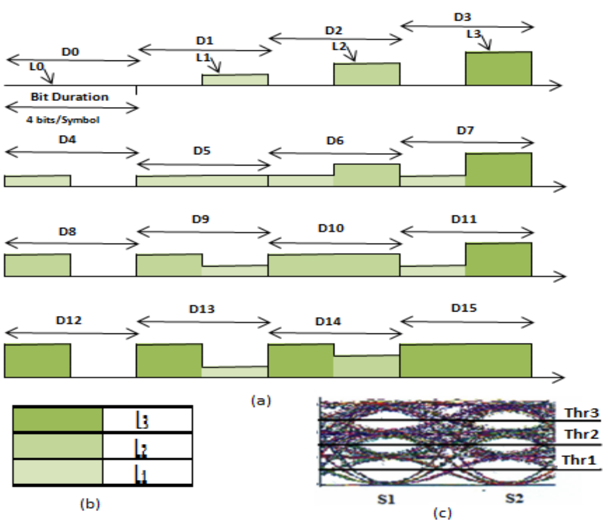


Figure 1: (a) TMM signal multiplexing process for 4 users**(b).** TMM 16 possible combination of bits for 4 users **(c).**Example of 4 TMM users data stream

This technique is in contrast to other modulation technique like pulse width modulation (PWM), that is the modulation technique where width of the every pulse is proportionally varied by the instantaneous variation of the modulating signal at the instant of the pulse while signal amplitude is kept fixed. This technique is also in contrast to optical code division multiplexing (OCDM), where different users use different code to share the spread spectrum[14].TMM uses compact spectrum that provides better tolerance to chromatic dispersion[15] and can be transmitted over the wavelength division multiplexing (WDM) system. In general, multiple channel interference (MCI) can be reduces by orthogonality between adjacent pulses. In TMM, orthogonality is not an issue of concern. The pulses that are representing different users are intentionally overlapped in manner to produce unique multilevel patterns.Clock data recovery (CDR) unit on the receiver side can easily recover the actual data even channels are overlapped in time domain, without an issue to resolve the orthogonality [16].

3. Implementation

In this study, system performance is accessed by commercial software's OptiSystem and MATLAB.Bit Error Rate (BER) is used to evaluate the performance of optical system that is described in section 4 and [13].

At low input power level, SSMF acts as a dispersive medium. During propagation process, transmitted spectrum does not change but the pulses become weaker due to the attenuation and broadening in time domain by the dispersion. In 100% dispersion post compensation link, launched pulses are first spread significantly as they propagate over the optical fiber span. At the receiving side, pulses are recompressed to their original shapes by dispersion slope compensation. As the power at the input is increased, nonlinear effects, especially SPM, must be counted to describe the pulse dynamics in the optical transmission link [13].

The NLS equation is considered to include higher order dispersion scenario that is quite helpful in accurate modeling of pulse propagation in SSMF [13,17,18].The modified NLS equation integrating the effect of fiber loss, SPM and chromatic dispersion (CD) is given by

$$i\frac{\partial A}{\partial z} = -N^2\,|A|^2 e^{-\alpha z l d} + \frac{1}{2}\beta_2\frac{\partial^2}{\partial \tau^2} + \frac{1}{6}\beta_3\,\frac{i}{|\beta_2\ |To} \times \frac{\partial^3}{\partial \tau^3} \qquad (2)$$

Where Z=z/L_d and $\tau = t - z/vg$ represent the normalized distance and retarded time variables, respectively. 'A' is the normalized amplitude such that the amplitude of pulse envelope equals to $\sqrt{P0}\,\exp\left(-\frac{\alpha z}{2}\right)A(z,\tau)$. P_0 represents the peak power of the input pulse and T_0 is the pulse width.β_2 and β_3 are the dispersion and dispersion slope parameter of the fiber,respectively,where α is fiber loss coefficient.L_d=To^2/|β2| represents dispersion length and L_{NL} =1/γp_0 represents nonlinear length, provide the length scales over which the dispersion and nonlinear effect becomes important,respectively.γ represents nonlinear coefficient and it is related to n_2 and A_{eff} represents the effective core area by γ=$n_2\omega_0/cA_{eff.}$Non linearity factor obtains by the ratio of L_d and $L_{NL.}$

In our model, we consider 2nd and 3rd order dispersion effects and consider SPM as the source of nonlinear effect. Other higher order nonlinear effect such as the Raman scattering contribution to the nonlinear refractive index is neglected because of its large stokes a shift (up to 13 THz) that islarger than the whole bandwidth of our simulated TMM.Table 2given below presents the regeneration rules for the TMM system of each user.

Table 2.TMM symbol Detection Rules

No	Rules		Decision
1	If $S_1 < \delta_1$ Then	$S_2 < \delta_1$	0000
		$\delta_1 < S_2 < \delta_2$	0001
		$\delta_2 < S_2 < \delta_3$	0010
		$S_2 > \delta_3$	0011
2	If $\delta_1 < S_1 < \delta_2$ Then	$S_2 < \delta_1$	0100
		$\delta_1 < S_2 < \delta_2$	0101
		$\delta_2 < S_2 < \delta_3$	0110
		$S_2 > \delta_3$	0111
3	If $\delta_2 < S_1 < \delta_3$ Then	$S_2 < \delta_1$	1000
		$\delta_1 < S_2 < \delta_2$	1001
		$\delta_2 < S_2 < \delta_3$	1010
		$S_2 > \delta_3$	1011
4	If $S_1 > \delta_3$ Then	$S_2 < \delta_1$	1100
		$\delta_1 < S_2 < \delta_2$	1101
		$\delta_2 < S_2 < \delta_3$	1110
		$S_2 > \delta_3$	1111

Where δ represent the threshold levels of the TMM symbol.
Two simulation setups were proposed for 4-channel TMM system, post dispersion compensation and asymmetric pre-post compensation. Figure.4 shows the post compensation scenario of the 4-channel TMM system. Four electrical RZ pulses with 50% duty cycle each with data rate of 10 GBPs that can produce an aggregate data rate of 40 GBPs.TMM mapping unit produces the unique symbols and these symbols are used to modulate a laser diode (LD) that is having operating wavelength of 1550 nm using the mach-zehnder modulator (MZM) .Bias voltages of the optical modulator are the major factor in the usefulness for the TMM receiver ability to generate an optimal eye opening for the system.
First simulation setup Figure 4 was sorted for the post compensation scenario where the SSMF and DCF lengths were proposed to be 80 km and 13.4 km respectively presented in the Table 3.An erbium Doped Fiber Amplifier (EDFA) and Optical Attenuator were employed to inspect the SPM effect on the SSMF fiber. In order to ignore the SPM effect in DCF,launched power to the DCF was fixed to minimal value of 13 dBm.TMM receiver have PIN photodiode and low pass filter (LPF) where the decoded TMM symbol is received.

Figure 4. Dispersion post compensation setup

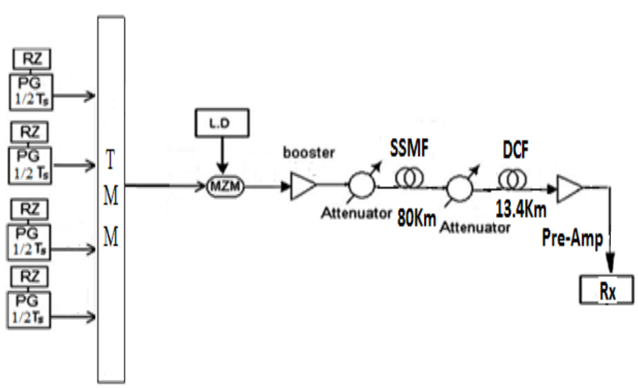


Table 3.100% Post Compensation Scenario Table

Fiber	SSMF	DCF
Length(Km)	80	13.4
Loss(Db/Km)	0.2	0.5
Dispersion(D)[ps/nm/km]	16.75	-100
Affective Area(A_{eff})[μm^2]	80	12
Non-linear index of refraction (n_2) m^2/W	2.7×10^{-20}	2.7×10^{-20}

In Figure 5, another optimized system setup known as pre-post compensation was introduced with a combination of SSMF and DCFs.

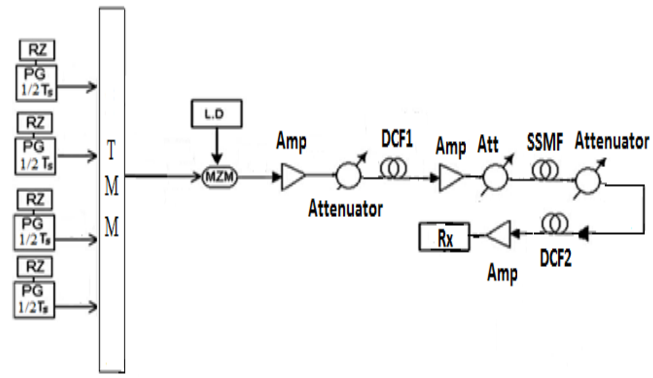


Figure 5. Dispersion pre compensation Setup

4. RESULTS AND DISCUSSION

The Figure 6(a) shows the input data stream in the 100% post compensation scenario. WhileFigure 6(b) shows the received data after passing through the SSMF and finally Figure6(c) represents the data received after post compensation.
It can be clearly observed from the Figure 6(b), several data bits are overlap on each other to build a non-uniform intensity distribution that is mainly depend on the input data stream. It is clearly observed that non-linear effect is non-uniformly distributed over different bits. While applying post compensation, different data bits experience different degree of degradation. It is clear from the Figure6(c), energy is transferred from high to lower level that degrade the system performance.

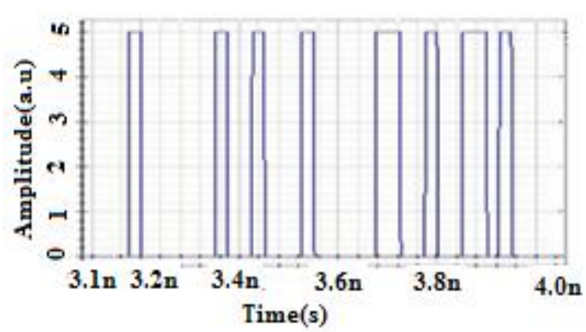


Figure 6(a).Portion of transmitted TMM sequence

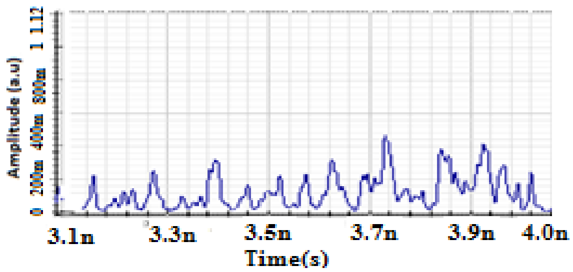


Figure 6(b). TMM received sequence after SSMF, before post compensation

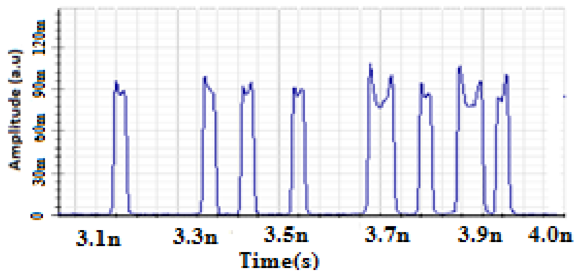


Figure 6(c). After 100% post compensation

The Figure 7 given below shows the BER dependence on the input power for dispersion post compensation in TMM,4-Ary (2 × 20 Gbps) and OOK (40Gbps) systems. At high power where SPM effect is consider, signal degraded seriously and results in higher BER.From the result, it is obvious that maximum threshold (SPM Threshold) at BER of 1×10^{-9}in TMM,4-Ary and OOK systems are +12.44 ,+7 and +12dBm respectively. TMM has 4.3improvements compared to 4-Ary and less than 1dBm improvement compared to OOK system.

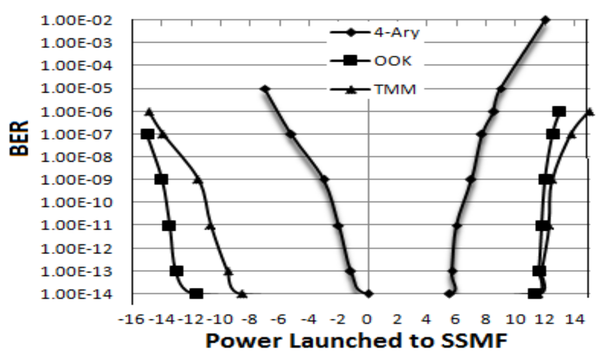


Figure7. BER as function of input power in 100% dispersion post compensation scenario

Important characteristic of SPM effects is noticing is that its behavior changes tremendously by Changing the position of dispersion compensated fiber (DCF).This phenomena is done by non-uniform distribution of anomalous chromatic dispersion (CD) and normal chromatic dispersion (CD) in the compensated link [10 spm impact]. In 100% dispersion SPM introduces a positive chirp in the pulse, so as a result pulse expansion slow down. Since magnitude of SPM is intensity dependant, therefore total effect is noted increased in 100% post compensation link, when pre-compensation is applied a large amount of power can be allowed. Figure.8 shows the BER that is the function of dispersion pre-compensation value for +15 dBm input power, where BER is improved from 10^{-6} to 10^{-12} in pre-compensation so that small amount of pre-compensation value improves the overall system performance and as a result overall SPM effect reduced.

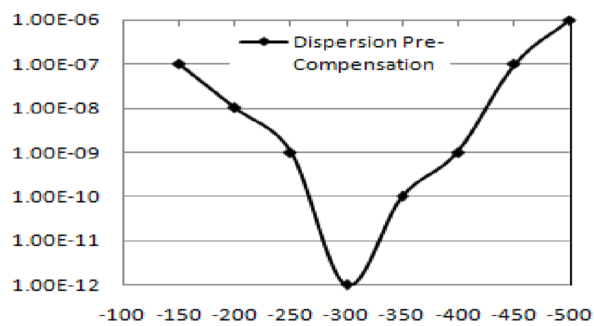
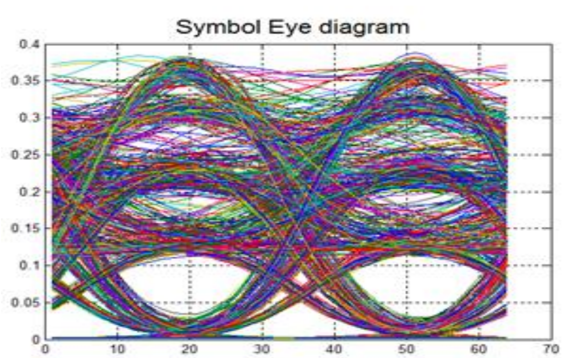
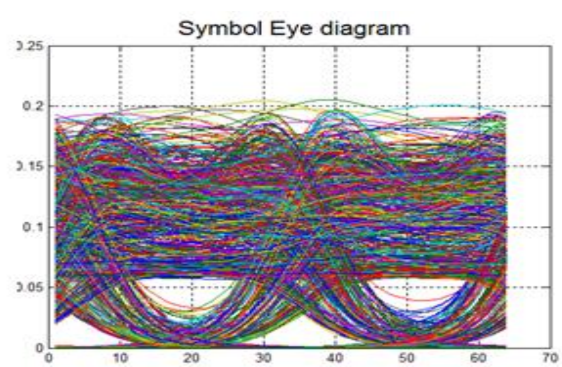


Figure 8. BER as function of dispersion pre-compensation value for fixed power of +15dBm

Below in the Figure 9, simulated eye diagram for the launched power of 15dBm in post compensation and 18-22%pre-compensation are shown. The signal of post compensation setup degrades due to strong SPM effect; this is because of overlapping of neighboring pulses, so as a result time jitter and eye closer.In this pre-compensation set up, average pulse distortion is reduced.



(a)



(b)

Figure9. Eyes diagram for the launched power of + 15 dBm (**a).**100% post compensation (**b).** 18-20% pre compensation

5. CONCLUSION

In this paper we investigated the effect of Self Phase Modulation on Tributary Mapping Multiplexing by applying launched power and dispersion compensation methods in order to compare it with 4-Ary and OOK systems. We have applied Pre and Post Compensation techniques to improve the performance of TMM system. It is observed that self phase modulation degrades the pulse shape and reduces pulse energy on high power rate. Furthermore, 40 GB/s TMM system shows a 4.3dB and less than 1dB improvement in comparison to 40 GB/s 4-Ary and On-Off keying (OOK) transmission systems, respectively. We came to conclusion that as TMM system has a low BER at high power, which makes this technique efficient to work with high data rate in the long haul optical transmission.

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