International Journal of Combined Research & Development (IJCRD)
eISSN:2321-225X;pISSN:2321-2241 Volume: 4; Issue: 5; May -2015

DESIGNING A CHROMATIC DISPERSION COMPENSATOR, PERFORMANCE COMPARISON BETWEEN NRZ AND RZ

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Abstract: The Optical communication network offers very high potential bandwidth and flexibility In terms of high bit-rate transmission. However, their performance slows down due to some parameter like dispersion, attenuation, scattering and unsynchronized bit pattern. A chromatic dispersion compensator plays an essential role in the optical fiber communications system in order to recover the degraded transmission performance. Nowadays, On-Off shift keying (OOK) modulation format is being widely used in the optical communications because of its simplicity over other modulation formats. This paper demonstrates compensation of chromatic dispersion by using optical phase conjugation (OPC) or mid-span spectral inversion (MSSI) technique for two types of OOK modulation format: non-return-to-zero (NRZ) and return-to-zero (RZ). MSSI is implemented by degenerate four wave mixing (FWM) inside the 500m-long highly nonlinear fibre (HNLF). For the proposed dispersion compensator, performance comparison between NRZ and RZ formats is carried out over different lengths of transmission fiber.

Keywords: **Single mode Fiber, Erbium Doped Fiber Amplifier black box [EDFA], power penalties, Q-factor, BER, MSSI, FWM, HNLF.**

I. INTRODUCTION

Optical transmission systems have been managed to our demands to be able to transfer the required data volumes. Unfortunately, these requirements are increasing, forcing us to deal with problems, which we saw only in theory so far. Specifically, one of these is the chromatic dispersion influence. Optical transmission system transmits information encoded in optical signal over long distances. The electrical signal in the transmitter at the fiber input is converted into light impulses that are transferred through the fiber to the receiver at the end of the fiber. In the receiver the light impulses are converted back to the original electrical signal [1]. Chromatic dispersion which is the variation of the phase velocity of light according to wavelength dependence of refractive index leads to pulse spreading or waveform distortion in the optical fiber. Unless compensated, chromatic dispersion increases bit error rate (BER) due to intersymbol interference (ISI). There are many ways to compensate chromatic dispersion. But Mid-span spectral inversion (MSSI) method is a more efficient way instead of using DCF for long distance optical signal transmission. In this paper, MSSI is used as dispersion compensator based on optical phase conjugation (OPC) property from four-wave mixing nonlinear effect in a highly nonlinear fiber (HNLF). Moreover, since OOK modulation format is commonly employed in optical transmission system, it is worth making a performance comparison between non return-to -zero NRZ-OOK and return-to-zero RZ-OOK formats for the MSSI-based dispersion compensation. With the help of Optisystem software, simulation results are analyzed in terms of signal waveform, spectrum, Q factor and bit error rate (BER) measurements [3].

MSSI-mid span spectral inversion

The concept here is to use a device in the middle of the link to invert the spectrum. This process changes the short wavelengths to long ones and the long wavelengths to short ones. If you invert the spectrum in the middle of a link (using standard fibre) the second half of the link acts in the opposite direction (really the same direction but the input has been exactly pre-emphasised). When the pulse arrives it has been re-built exactly compensated by the second half of the fibre [3]. As depicted in Fig-1

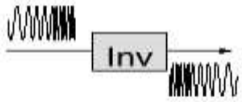


Fig-1 MSSI

OPC-optical phase conjugation

Using nonlinear optical processes, to exactly reverse the propagation direction and phase variation of a beam of light. The reversed beam is called a *conjugate* beam, and thus the technique is known as **optical phase conjugation [4].**

MECHANISM OF FWM

When three frequencies (f_1, f_2, and f_3) interact in a nonlinear medium, they give rise to a fourth wavelength (f_4) which is formed by the scattering of the incident photons, producing the fourth photon.

Given inputs f_1, f_2, and f_3, the nonlinear system will produce:

$$\pm f_1 \pm f_2 \pm f_3$$

With the most damaging signals to system performance calculated as

$$f_{ijk} = f_i + f_j - f_k, \text{ where } i, j \neq k$$

Since these frequencies will lie close to one of the incoming frequencies. As shown in Fig.2

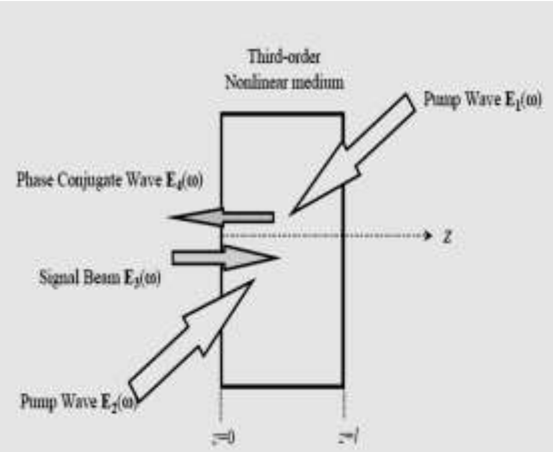


Fig-2 FWM

DEGENERATE FOUR WAVE MIXING

Four-wave mixing is also present if only two components interact. In this case the term

$$f_0 = f_1 + f_1 - f_2$$

couples three components, thus generating so-called **degenerate four-wave mixing**, showing identical properties as in case of three interacting waves .FWM is a fiber-optic characteristic that affects wavelength division multiplexing (WDM) systems, where multiple optical wavelengths are spaced at equal intervals or channel spacing. The effect of fwm are pronounced with decreased channel spacing of wavelength and at high signal power levels .high chromatic dispersion decreases FWM effects, as the signals lose coherence. Degenerate FWM is depicted in Fig.3 in which the converted signal at 2ωp-ωs possesses phase-conjugation property [4].

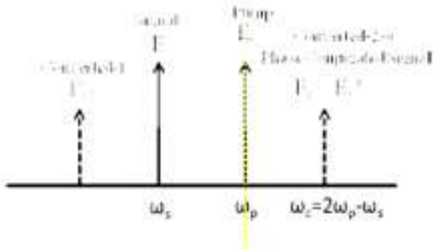


Fig-3 Degenerate FWM

The induced third-order nonlinear polarization PNL due to the nonlinear characteristics of the medium is generated as anew light or phase- conjugated signal

$$P_{NL} \propto E_p(z)^2 E_s^*(z)^2 \exp\left[j(2\beta(\omega_p) - \beta(\omega_s))z\right]$$

Where,
Ep(z) = the pump electric field at distance z
Es(z) = the phase-conjugated electric field at distance z
β (ωs) = the propagation constant at signal light
β (ωp) = the propagation constant at pump light

This phase-conjugated signal is used for MSSI because it inverts the spectrum or conjugates the phase of the signal which is required for dispersion compensation.

II. SIMULATION SETUP

- Refer Fig-7 .For RZ format, Gaussian pulse with 33% duty cycle is used. For both formats, the average input optical power to the first transmission span is set to 0 dBm by EDFA-1(a) and EDFA-1(b) (black box).

- For both formats, the average input optical power to the first transmission span is set to 0 dBm by EDFA-1(a) and EDFA-1(b). Besides, 5 nm optical band pass filters OBPF-2(a) and OBPF-2(b) are used to suppress amplified spontaneous emission (ASE) noise from EDFA-1s and EDFA-2s.

- In this scheme, standard single mode fibers (SSMF) are used as transmission fiber and highly nonlinear fiber (HNLF) as the nonlinear medium. The 0.5km-long HNLF is used as a nonlinear medium for the FWM process.

- The dispersive signal waves are then inputted to an optical coupler with the pump wave at λp=1551.1nm to achieve degenerate FWM. Fig.3 shows the spectrum of output signals from HNLF.

- OBPF (a) and OBPF (b) with 0.6nm bandwidth (FWHM) filter out the phase-conjugated waves at 1552.7nm.

- Then, EDFA-2 amplifies the phase conjugated signal to restore the power attenuation of SSMF-2 (0.2dB/km and 16.94ps/nm.km at λc) and then OBPF-2s are used to suppress the ASE noise from EDFA-2s.

III. COMPONENTS

SINGLE MODE FIBER (SMF):
In the single mode fibers, the transmission loss and dispersion or degradation of the signal are very small. it is very useful in long distance communication.

HIGHLY NON LINEAR FIBER (HNLF):
Main advantage of nonlinear fiber is that nonlinear response is ultrafast.Instaneous nature of nonlinear fiber can be used for fast switching action and ultrafast signal processing [5].

ERIBIUM DOPED FIBER AMPLIFIER (EDFA)blackbox:
The erbium-doped fiber amplifier (EDFA) black box is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber. Two bands have developed in the third transmission window – the *Conventional*, or C-band, from approximately 1525 nm – 1565 nm, and the *Long*, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands. The principal difference between C- and L-band amplifiers is that a longer length of doped fiber is used in L-band amplifiers. The longer length of fiber allows a lower inversion level to be used, thereby giving at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful amount of gain [4].

CW laser:
It is used as optical source.

Pseudo random sequence generator:
It provides binary input sequence.

Gaussian pulse generator:
With 33% duty cycle it is used for generating bit sequence in RZ format as shown in Fig-4

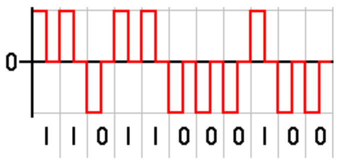


Fig.4 Bipolar RZ format

NRZ Pulse Generator:
It is used for generating bit sequence in NRZ format.as shown in Fig-5

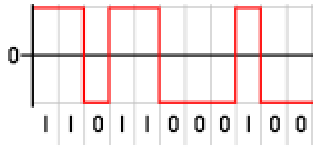


Fig-5 Bipolar NRZ format

Optical bandpass filter (OBPF):
It is used to suppress amplified spontaneous emission (ASE) noise from EDFA-1 and EDFA-2 (black box).

Mach-zehnder modulator:
It is used for converting electrical signal to optical signal.

Photo detector:
It is used to convert optical signal to electrical signal.

TABLE.1 SIMULATION PARAMETERS FOR MSSI

EDFA	Gain	17.5dB
HNLF	Zero Dispersion Wavelength	1550nm
	Fiber Length	0.5km
	Attenuation	0.65dB/km
	Dispersion Slope	$0.032 ps/nm^2 km$
	Nonlinear Coefficient γ	$12.6 W^{-1} km^{-1}$
BPF	Bandwidth	0.6nm (narrow band)

TABLE.2 SIMULATION PARAMETERS FOR SIGNAL TRANSMISSION

EDFA black box noise figure = 6 dB and insertion loss = 4dB		
SIGNAL	wavelength	1500nm
	Laser power	2dBm
PUMP	wavelength	1550nm
	Laser power	5dBm
EDFA BLACK BOX-1	Gain	11 dB for rz signal 8 dB for nrz signal
BPF-1	Bandwidth	5nm
SSMF-1	Length	50km,75km,100km
	Attenuation	0.1dB/km
	Dispersion	15 dB/nm km
EDFA BLACK BOX-2	Gain	15 dB for 50km ,18dB for 75km,22dB for 100km
BPF-2	Bandwidth	5nm
SSMF-1	Length	50km,75km,100km
	Attenuation	0.1db/km
	Dispersion	13 dB/nm km

Block diagram:

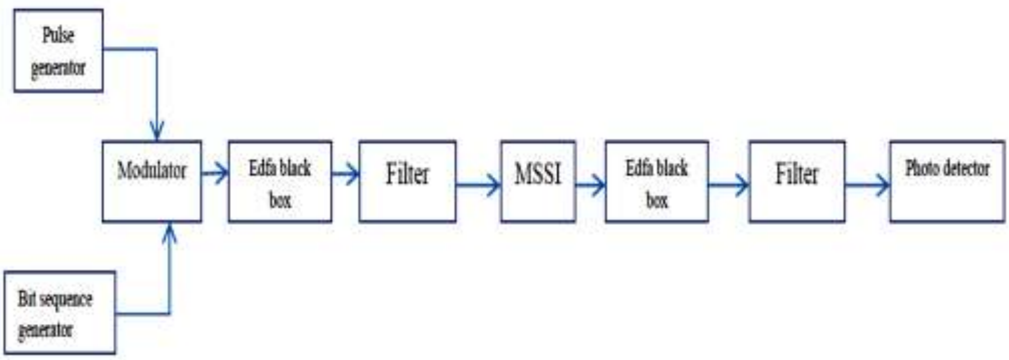


Fig-6

Simulation setup:

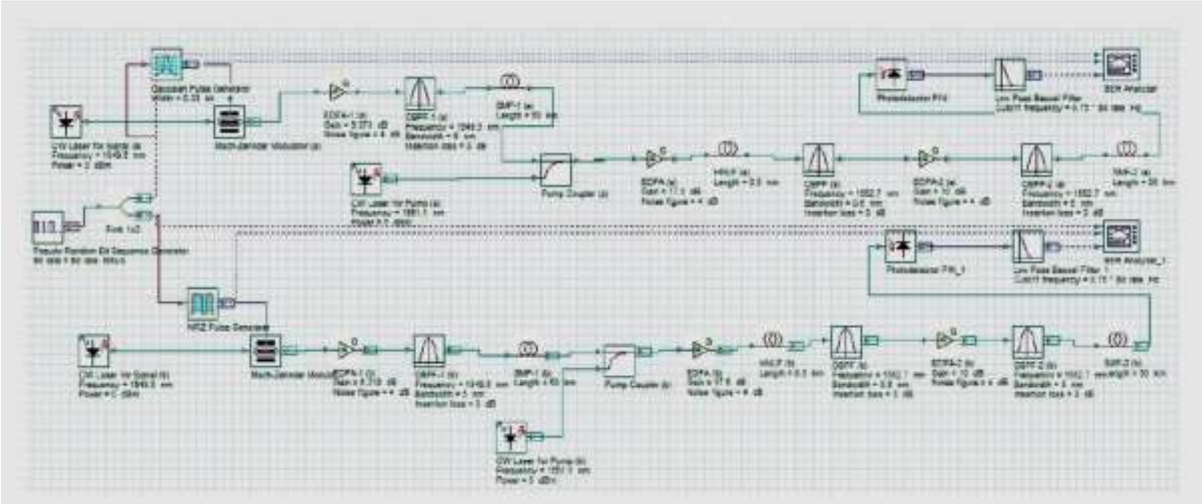


Fig-7

IV.PERFORMANCE COMPARISON OF DISPERSION COMPENSATION IN RZ AND NRZ FORMATS

1) Power penalties:

	RZ	NRZ
100KM	0.485 dB	0.035 dB
150KM	0.87 dB	0.4 dB
200KM	1.17 dB	0.97 dB

From the power penalties table, it is observed that the RZ signal suffers from more severe power penalty than the NRZ signal due to the fact that the RZ signal has larger bandwidth than the NRZ signal making it broaden more rapidly by chromatic dispersion than NRZ signal.

2)Bit error rate:

	RZ	NRZ
100KM	0.042	0.035
150KM	0.054	0.045
200KM	0.067	0.053

From BER table, it is observed that BER of RZ is greater than NRZ. Intersymbol interference is more in RZ format.

3) Quality factor:

	RZ	NRZ
100KM	1.63	2.1
150KM	1.58	1.66
200KM	1.51	1.59

From the Q-factor table, it is observed that the RZ signal quality factor is less than NRZ quality Factor. Than quality factor affects With Increase in distance.

SIMULATIONS:

Analysing Power penalties:

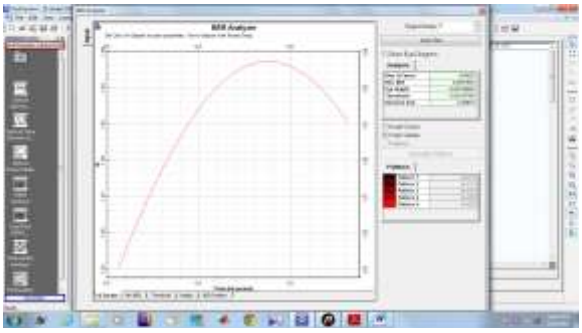
100KM RZ

100KM NRZ

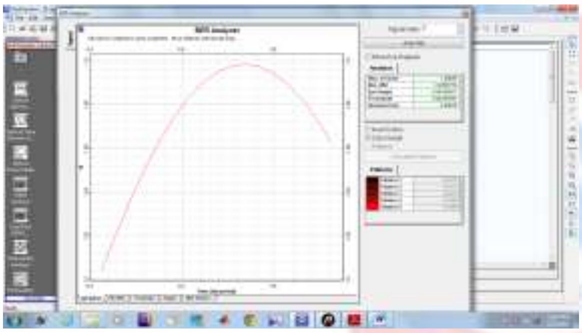
From the above simulation result for 100km it is observed that RZ power penalties are greater than NRZ.

Analysing BER and Q-factor:

150KM NRZ



150KM RZ



From the above simulation result for 150km it is observed that RZ BER is more than NRZ. The NRZ as high quality factor than RZ.

V.CONCLUSION

This work has accomplished the dispersion compensation for signals by using mid-span spectral inversion technique for three transmission distances. A simulation model is presented for a single channel in both OOK modulation formats (RZ and NRZ signals). The results show that 0.9 dB power penalty is achieved in NRZ format and 1.17dB power penalty is achieved in RZ format for 200 km transmission. Therefore, it is observed that NRZ signal is more efficient than RZ signal in MSSI-based chromatic dispersion compensation.

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