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Dispersion Compensation in Optical Fibers Communication System Using Spectral Inversion

Tariq A.K. Al-Jumaily
Department of Computer Engineering, College of Engineering, University of Mosul, Iraq

Abstract: Computer networks and communication systems operating at optical frequencies convey their signals to the required destination through optical fibers. At long distances, periodic amplifications is required and this leads to the dependence of fiber refractive index on power fluctuations. This leads to non-linear effects and this produces non-linear waveform distortion. For long distance transmission at high data rate, this waveform must be suppressed. Spectral inversion is one method to overcome this problem. A scheme that is characterized as the combination of Optical Phase Conjugation (OPC) and spectral dispersion mapping is effective for non-linearity compensation in the absence of power symmetry.

Key words: Dispersion compensation, fibre optic transmission, inter channel non-linearity, spectral inversion, Optical Phase Conjugation (OPC), refractive index

INTRODUCTION

Spectral inversion through the use of optical phase conjunction is a promising technology to compensate for deterministic impairments in long-haul optical fiber transmission systems such as Kerr non-linearities and chromatic dispersion. By optically conjugating, the phase of the signal in the middle of the link impairments that occurred in the 1st part of the transmission link (before conjugation) can be cancelled by impairments that occur in the 2nd part of the link (after conjugation). However, the 3rd order dispersion can be compensated for using a slope compensator (Suu *et al*., 2004).

The most significant impairment that fundamentally can not be compensated for by spectral inversion is Polarization Mode Dispersion (PMD) (Jansen *et al*., 2006). Because this is a statistical impairment and as result the amount of PMD in the link changes with time and is not symmetrically distributed along the transmission line (Chowdhury *et al*., 2004).

MATERIALS AND METHODS

Spectral inversion: The propagation signal in a nonlinear dispersive and lossy medium can be expressed by the non-linear Schrodinger equation assuming a slowly varying envelope approximation (Agrawal, 2001).

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A - \frac{i}{2}\beta_2\frac{\partial^2 A}{\partial T^2} + \frac{1}{6}\beta_3\frac{\partial^3 A}{\partial T^3} + i\gamma|A|^2 A \quad (1)$$

Where:

A	=	The complex amplitude of the signal
z	=	The propagation distance in km
α	=	The attenuation coefficient in the neper per km
γ	=	The nonlinearity coefficient (Kerr effect) in 1/(W.km)
T = t - z/Vg	=	The time measured in a retarded frame
β_2	=	In ps 2nm^{-1} is term for the Group Velocity Dispersion (GVD)
β_3	=	In ps 3 nm^{-1} is term for dispersion slope

Its complex conjugate can be expressed as:

$$\frac{\partial A^*}{\partial z} = -\frac{\alpha}{2}A^* - \frac{i}{2}\beta_2\frac{\partial^2 A^*}{\partial T^2} + \frac{1}{6}\beta_3\frac{\partial^3 A^*}{\partial T^3} + i\gamma|A^*|^2 A^* \quad (2)$$

where, * denotes the complex-conjugate operation. In this equation, the signal evolution over the fiber after conjugation is still denoted by A.

In this expression, it can be seen that the sing of the chromatic term (β_2) and the Kerr effect term (γ) are both inverted. The chirp induced through GVD increases linearly along the transmission link. Since, the sing of the GVD term is inverted by OPC, the GVD induced chirp that occurs after OPC cancels the GVD induced chirp before OPC.

Thus, in a transmission link with the same fibre before and after OPC, full GVD compensation is obtained by placing the OPC at the middle of the link. The compensation of the Kerr effect is analog to that of the

GVD. However, the Kerr effect is unlike the GVD, a non-linear impairment, dependent on the optical power of the signal. As a result, the degree in which the Kerr effect is compensated for is dependent on the design of the transmission link.

Using Eq. 1 and 2, Watanabe and Shirasaki (1996) presented a general condition for perfect compensation of the Kerr effect term by making the fiber parameters α, β_2 and γ dependent on the transmission distances z. Neglecting the 3rd order dispersion, this results in:

$$\frac{\beta_2(-z_1)}{\gamma(-z_1)P(-z_1)} = \frac{\beta_2(-z_2)}{\gamma(z_2)P(z_2)} \quad (3)$$

Where:

$-z_1$ = The transmission distance before the OPC unit
$-z_2$ = The transmission distance after the OPC unit
P (z) = In Watt, the optical power at point z

OPC unit is present at z = 0. Basically, the Kerr effect can be totally compensated for when the ratio of nonlinear effect (γP) to chromatic dispersion (β_2) is equal at $-z_1$ and z_2. In such a transmission line, OPC is capable of compensating both chromatic dispersion and non-linear impairments. The sign of the attention term (α) and the dispersion slope (β_3) remain unchanged before and after inversion.

Therefore, these impairment can not be compensated for through inversion. One impairment that can not be compensated by spectral inversion is Polarization Mode Dispersion (PMD) because it is statistical impairment.

RESULTS

With the simple manipulation of Eq. 3 and following the analysis given by the equation, one can show that:

$$\frac{\sigma}{\sigma_0} = \left[\frac{\langle\tau^2\rangle}{b_0}\right]^{\frac{1}{2}} \quad (4)$$

Where:

(σ/σ_0) = The pulse broadening factor
σ = The r.m.s width of the output pulse
σ_0 = The r.m.s width of the input pulse
$\langle\tau^2\rangle$ = Determined by coefficients of the input pulse and depends on the input power an length of the line

The variation (σ/σ_o) with average input power is shown in Fig. 1-6. The values of $\langle\tau^2\rangle$ and b_0 are taken from

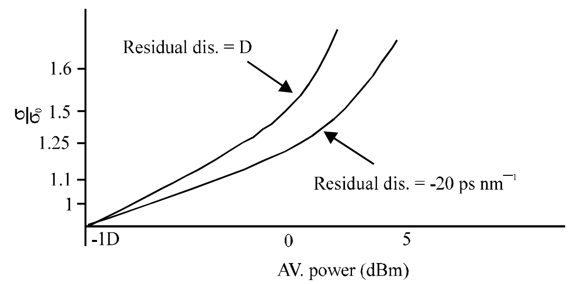

Fig. 1: Variation of pulse boarding with input signal power

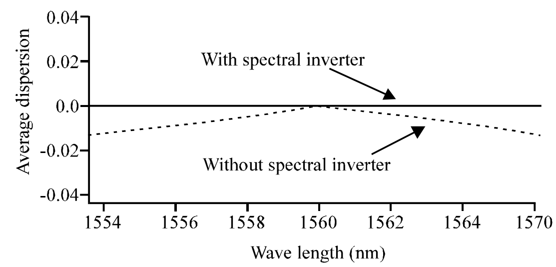

Fig. 2: Relation between dispersion and wavelength with and without spectral inverter

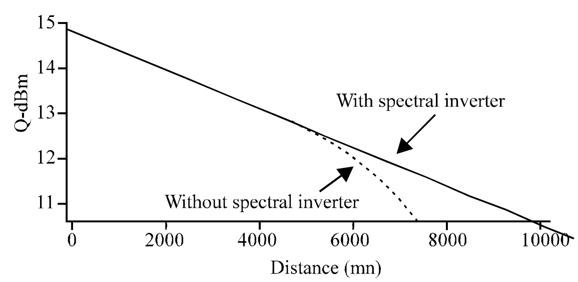

Fig. 3: The variation of the Q-factor with distance with and without spectral inverter

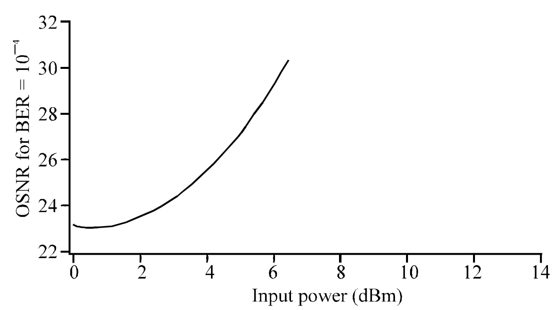

Fig. 4: Variation of OSNR with input power

Xiao *et al.* (2008). The Q-factor is obtained from the BER (Chowdhury *et al.*, 2005):

$$Q = 20 \log 10\left[2^{\frac{1}{2}} \text{erfc}^{-1}(2\,\text{BER})\right] \quad (5)$$

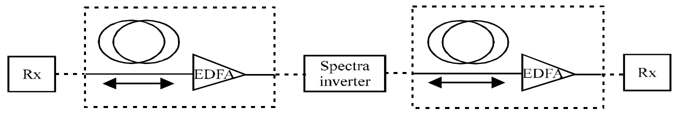

Fig. 5: Two section of transmission system with spectral inverter at the middle

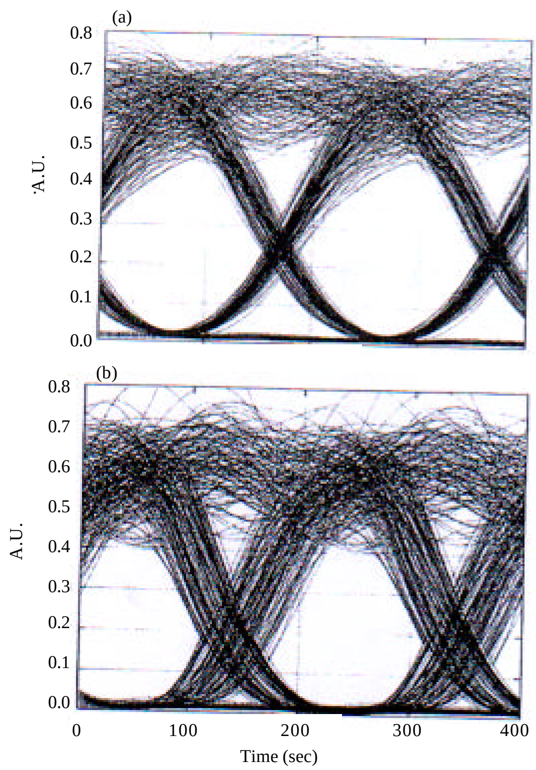

Fig. 6: Eye diagrams of the received signals at 6000 km; a) 1549 nm and b) 1551 nm

CONCLUSION

Spectral inversion through POC can be employ to significantly reduce intracranial non-linear impairment as well as impairments due to non-linear phase noise. Tired order dispersion can be compensated for using slope compensator. The most significant impairment that can not be compensated for using OPC is Polarization Mode Dispersion (PMD) because it is a statistical impairment, its amount in the link changes with time and its not symmetrically distributed along the transmission line.

The effect of periodic power variation can be suppressed by making the amplifier spacing shorter than the non-linearity of the link. In the absences of GVD fluctuation, zero dispersion yields minimum eye penalty in the Norman dispersion region.

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