International Journal of Engineering Sciences & Emerging Technologies, Dec. 2012.
ISSN: 2231 – 6604 Volume 4, Issue 1, pp: 58-65 ©IJESET

CHROMATIC DISPERSION CANCELLATION USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT

Chromatic Dispersion is a phenomenon that happens due to different spectral components of light pulse travel at different velocities because of which the pulse reaches the fiber end at different time, as a result of which the pulse gets broadened at the receiver leading to inter-symbol interferences. Chromatic Dispersion has become a major concern when deploying optical fibre for long haul communication. Hence special care must be taken to compensate this dispersion so that the optical fibers can deliver its maximum capacity. Although considerable amount of work is being carried out to compensate for chromatic dispersion, yet researches are being carried out worldwide to improve the compensation methods so as to meet the ever increasing demands for bandwidth. The wavelength dependency of the propagation constant sets an intrinsic limit to the information carrying capacity of an optical fibre resulting in bandwidth penalty. So there is a need for a simple and effective method to estimate the chromatic dispersion taking into account the various parameters affecting it. In this paper we propose a novel and a simple ANN based technique to estimate the pulse broadening caused by chromatic dispersion. Chromatic Dispersion depends on various parameters such as the operating wavelength, source spectral width and length of fiber link. And all these factor needs to be taken into consideration when designing a compensator. So our proposed method can be used as a pre- compensating stage for chromatic dispersion. The experimental results are shown for a laser source of spectral width of 0.1nm and fiber of 1km at different operating wavelengths.

KEYWORDS: *Chromatic dispersion; Single Mode Fiber (SMF); Artificial Neural Network (ANN) Inter symbol Interference Pulse broadening.*

I. INTRODUCTION

The term chromatic dispersion refers to the spreading of light pulse at the receiver due to the inherent wavelength dependency possessed by an optical channel. The dispersive properties of SMF owe their origin to the wavelength dependence of refractive indices of the core and the cladding glasses of the fiber structure, and also the dependence of modes propagation constant which depends on the fibers structural characteristics and source wavelength. Since every source exhibits some wavelength spread in its emission spectrum, therefore the above mentioned effects lead to pulse broadening. Two important types of chromatic dispersions are material dispersion and waveguide dispersion. Material dispersion is caused by the wavelength dependence of silica’s refractive index, which in turn depends on the wavelength. An information carrying signal will contain several wavelengths as light sources are never strictly monochromatic and possess a certain finite spectral width. Therefore these components of light will travel at different velocities within the fibre and reach the fibre end at different times. Waveguide dispersion occurs even if the fiber material has no dispersive properties. It merely occurs due to restricting the light within a certain structure and is relatively small in single mode fibres as compared to material dispersion.

Once upon a time, the world assumed that fiber possessed infinite bandwidth and would meet mankind's communication needs into the foreseeable future. As the need arose to send information over longer and longer distances, the fiber optic community developed additional wavelength "windows" that allowed longer transmission. The 1550 nm region, with a loss of only 0.2 dB/km, seemed like the answer. Millions of kilometers of fiber were installed around the world creating a high-speed communication network. However, as the data rates and fiber lengths have increased, limitations due to dispersion in the fiber became impossible to avoid. Dispersion was initially a problem when the first optical fibers, multimode step-index fiber, were introduced. Multimode graded-index fiber improved the situation a bit, but it was single-mode fiber that eliminated severe multimode fiber related dispersion and left only chromatic dispersion and polarization mode dispersion to be dealt with by engineers. So, in this paper we propose an ANN based approach for estimating the chromatic dispersion taking into consideration the various factors that causes it. This approach can be used as a pre- processing step for chromatic dispersion cancellation and accordingly fibers can be designed.

The rest of the paper is organized as follows. In section 2 chromatic dispersion is explained. In section 3, we have presented a brief survey of the related work in this area followed by a brief introduction of Artificial Neural Network in section 4.In section 5 the proposed approach is explained followed by the conclusion and future direction in section 6.

II. CHROMATIC DISPERSION

A single mode fibre carries only one mode and so does not experience inter-modal dispersion and therefore it is expected to have much lower dispersion than a multimode fibre. However due to its dispersive nature it experiences dispersion. The major cause of dispersion in single mode fibre is chromatic dispersion.

2.1. Basics

All forms of dispersion degrade a light wave signal, reducing the data carrying capacity through pulse-broadening. There are two different types of dispersion in optical fibers. The types are intra-modal and inter-modal dispersion. Intra-modal or chromatic dispersion occurs in all types of fibers. Intermodal, or modal, dispersion occurs only in multimode fibers. Each type of dispersion mechanism leads to pulse spreading. As a pulse spreads, energy is overlapped. The spreading of the optical pulse as it travels along the fiber limits the information capacity of the fiber. Chromatic dispersion or intra-modal dispersion is a major factor limiting the bandwidth of SMF. The basic mechanism of dispersion involves different light beams carrying light pulses arriving at the receiver at different times, causing the output light pulses to spread. This is shown in figure1 below:

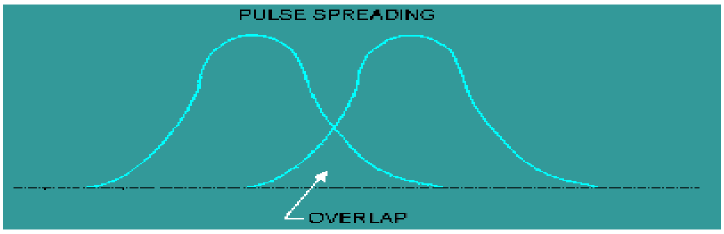

Figure1: Intra-modal dispersion

To preserve the transmission quality, the maximum amount of time dispersion must be limited to a small proportion of the signal bit rate, typically 10% of the bit time. With optical networks moving from 2.5 Gbps to 10 Gbps and onto 40 Gbps, the acceptable tolerance of dispersion is drastically reduced. For instance, the amount of acceptable chromatic dispersion decreases by a factor of 16 when moving from 2.5 to 10 Gbps, and by an additional factor of 16 moving from 10 to 40Gbps. These tight tolerances of high-speed networks mean that every possible source of pulse spreading should be addressed. Operating companies need to measure the dispersion of their networks to assess the possibility of upgrading them to higher transmission speeds, or to evaluate the need for compensation.

2.2. Origin of Chromatic Dispersion in SMF.

Light within a medium travels at a slower speed than in vacuum. The speed at which light travels is determined by the medium’s refractive index. In an ideal situation, the refractive index would not depend on the wavelength of the light. Since this is not the case, different wavelengths travel at different speeds within an optical fiber. Laser sources are spectrally thin, but not monochromatic. This means that the input pulse contains several wavelength components, travelling at different speeds, causing the pulse to spread as shown in figure 2 below.

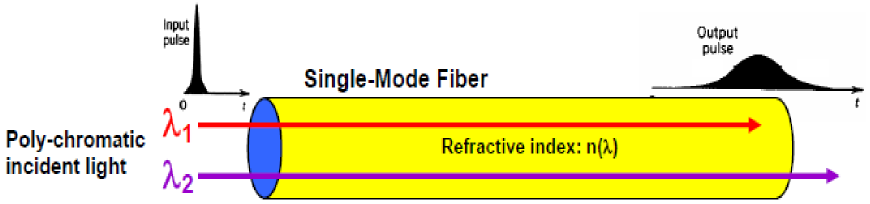

Figure2: Chromatic dispersion in single mode fibre (SMF)

The Chromatic Dispersion of a fiber is expressed in ps/(nm*km). In this section we shall focus on computing the effects of chromatic dispersion. Let's first consider non dispersion-shifted single-mode fiber, such as Corning SMF-28 CPC3 single-mode fiber. This fiber type makes up the largest percentage of the installed fiber base. Its zero-dispersion wavelength lies between 1301 nm and 1321 nm. At the zero-dispersion wavelength, the fiber bandwidth is very high. However, the fiber attenuation in this range is about 0.5 dB/km. This attenuation limits transmission distances to perhaps 60 km. It would be more desirable to operate in the 1550 nm band where attenuation is about 0.2 dB/km. This attenuation would allow transmission to about 150 km as long as dispersion does not limit performance. Equation 1 can be used to compute the dispersion of Corning SMF-28 single-mode fiber.

$$D_\lambda = S_0/4*(\lambda - (\lambda_0/\lambda^3)) \qquad (1)$$

Where,

S_0= 0.0092ps/ (nm^2·km), the zero dispersion slope.

λ_0= 1311nm, zero dispersion wavelength, (corning specifies a range of 1302-1322nm, we have taken the average of this number)

λ= operating wavelength of the Optical fibre

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III. STATE- OF- ART: AN OVERVIEW

To reduce fiber dispersion, new types of fiber were invented, including dispersion-shifted fibers (ITU G.653) and non-zero dispersion-shifted fiber (ITU G.655).The most commonly deployed fiber in networks (ITU G.652), called “dispersion-unshifted” single mode fiber, has a small chromatic dispersion in the optical window around 1310 nm, but exhibits a higher CD in the 1550 nm region. This dispersion limits the possible transmission length without compensation on OC-768/STM-256 DWDM networks. ITU G.653 is a dispersion-shifted fiber (DSF), designed to minimize chromatic dispersion in the 1550 nm window with zero dispersion between 1525 nm and 1575 nm. But this type of fiber has several drawbacks, such as higher polarization mode dispersion than ITU G.652, and a high Four Wave Mixing risk, rendering DWDM practically impossible. For these reasons, another single mode fiber was developed: the Non-Zero Dispersion-Shifted Fiber (NZDSF). NZDSF fibers have now replaced DSF fibers, which are not used anymore. The ITU G.655 Non-Zero Dispersion-Shifted Fibers were developed to eliminate non-linear effects experienced on DSF fibers. They were developed especially for DWDM applications in the 1550 nm window. They have a cut-off wavelength around 1310 nm, limiting their operation around this wavelength. A variety of methods have been stated in literature for effective compensation of chromatic dispersion.

In long distance optical communication systems, fiber group velocity dispersion degrades system performance by either limiting the maximum data rate or by requiring a shorter distance between repeaters. These limitations can be particularly serious for systems operating at 1.5 pm, where large fiber dispersion values of 15 to 20 ps/km/nm, are typical [6].Many filtering techniques have been used for compensating the effects of chromatic dispersion [7, 9, 10]. Much earlier in 1993, in [6] a waveguide grating filter was designed to compress a 60 ps pulse to 20 ps pulse. A similar method was proposed in [9,10] in which digital IIR filtering was used as a means for compensating chromatic dispersion. Though several special types of compensating fibre are available, in [11] for the first time a method was proposed for post compensation of chromatic dispersion using the Talbot effect. The main advantage was, it used the standard fibre, instead of special fibre with negative dispersion which generally suffered from high losses. In [8] a technique was demonstrated for compensation of chromatic dispersion effects in fiber wireless system using external modulators.

Recently Ming Chen and co-workers have employed the spectral shift effect of a semiconductor optical amplifier for chromatic dispersion monitoring, and a non-linearly chirped fiber Bragg grating for chromatic dispersion compensation[1].The CD compensation subsystem, demonstrated in their work had been formed by an optical circulator and an optical fiber grating with nonlinear group delay. This non-linear chirped fiber grating reflects different frequency components at different locations within the gratings. These were used for dispersion compensation when the time delay for the gratings is the inverse of the delay caused by dispersion. The proposed system can be used for CD and PMD monitoring and compensation in high speed optical fiber communication system with 40Gbit/s single channel speed CSRZ format. Experiments showed that the whole system could work synchronously and perfectly.

Seb J. Savory et al. have demonstrated 42.8Gbit/s per wavelength transmission with a record distance of 6400km over standard fiber with no optical dispersion compensation [2]. A record total dispersion of 107,424ps/nm was compensated using digital signal processing, with an OSNR penalty of 1.2dB. This was the first time that 40Gbit/s per wavelength data could be transmitted over such a distance on standard fiber, without the use of optical dispersion compensation and exceeds the distance previously reported for 10Gbit/s systems2. More recently in 2009 another group of workers have experimentally demonstrated simultaneous chromatic dispersion and self-phase modulation compensation at 10.7 Gb/s using real-time electronic digital signal processing[3]. This was achieved using a pre-distorting transmitter based on commercially available field programmable gate arrays (FPGA) and 21.4 Gb/s, 6-bit resolution digital-to-analog converters. Also similar works have been done by various researchers for compensation of PMD, and CD in optical link by employing 2X2 jones matrix, Decision feedback equalizer [4, 5].

In another work recently in 2010, a group of researchers have presented a comparative analysis of three popular digital filters for chromatic dispersion compensation: a time-domain least mean square adaptive filter, a time-domain fiber dispersion finite impulse response filter, and a frequency-domain blind look-up filter. The characteristics of these filters were compared by evaluating their applicability for different fiber lengths, their usability for dispersion perturbations, and their computational complexity [7].

These and many more works are ongoing in different parts of the world, for compensating the affects of Inter-Symbol interference caused due to pulse broadening in optical fibre link and hence increase the bandwidth of the link.

In this work we propose an approach for calculating and hence cancelling the effects of chromatic dispersion using ANN.

IV. ARTIFICIAL NEURAL NETWORK

In our work we proposed an ANN based approach. So in this section a brief introduction of ANN is given.

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements. We can train a neural network to perform a particular function by adjusting the values of the connections (weights) between elements.

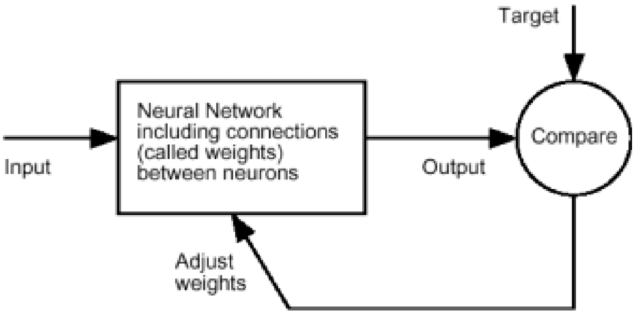

Figure3: neural net block diagram

A neuron with a single scalar input and no bias is shown below.

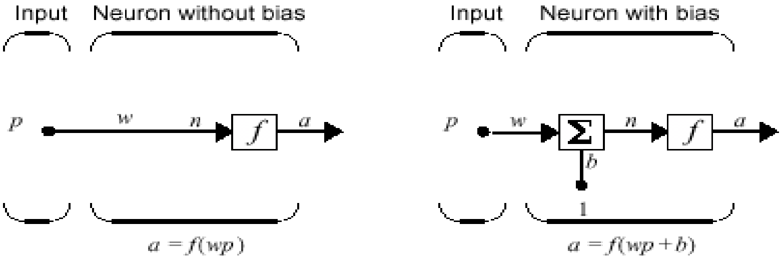

Figure4: A simple neuron

The scalar input p is transmitted through a connection that multiplies its strength by the scalar weight w, to form the product w_p, again a scalar. Here the weighted input wp is the only argument of the transfer function f, which produces the scalar output a. The neuron on the right has a scalar bias, b. You may view the bias as simply being added to the product w_p as shown by the summing junction or as shifting the function f to the left by an amount b. The bias is much like a weight, except that it has a constant input of 1. The transfer function net input n, again a scalar, is the sum of the weighted input w_p and the bias b. This sum is the argument of the transfer function f. Supervised learning is based on the system trying to predict outcomes for known examples and is a commonly used training method. It compares its predictions to the target answer and "learns" from its mistakes. The data start as inputs to the input layer neurons. The neurons pass the inputs along to the next nodes. As inputs are passed along, the weighting, or connection, is applied and when the inputs reach the next node, the weightings are summed and either intensified or weakened. This continues until the data reach the output layer where the model predicts an outcome. In a supervised learning system, the predicted output is compared to the actual output for that case. If the predicted output is equal to the actual output, no change is made to the weights in the system. But, if the predicted output is higher or lower than the actual outcome in the data, the error is propagated back through the system and the weights are adjusted accordingly. This feeding errors backwards through the network is called "back-propagation." Both the Multi-Layer Perceptron and the Radial Basis Function are supervised learning techniques. The Multi-Layer Perceptron uses the back-propagation while the Radial Basis. Function is a feed-forward approach which trains on a single pass of the data. Neural networks which use unsupervised learning are most effective for describing data rather than predicting it. The advantage of the neural network for this type of analysis is that it requires no initial assumptions about what constitutes a group or how many groups there are. The system starts with a clean slate and is not biased about which factors should be most important. Three of the most commonly used transfer functions are as shown in figure below.

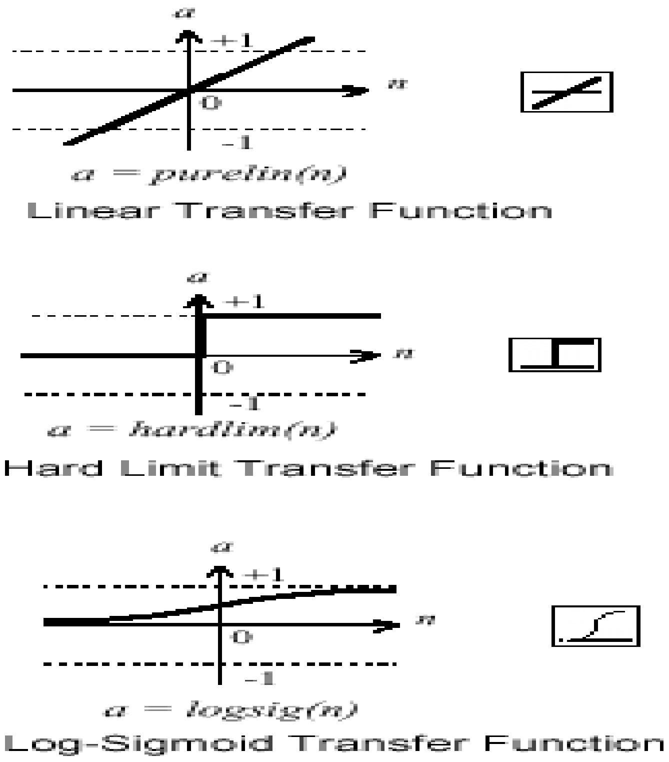

Figure5: Transfer functions

V. PROPOSED APPROACH

In this work we present a simple and an effective method for calculating chromatic dispersion using ANN. The advantage of our proposed approach is it takes into account the essential factors like fiber length, source spectral width and most importantly the operating wavelength, to calculate the increase in pulse width caused by chromatic dispersion. We created a feed forward network by taking the experimental values of chromatic dispersion at different operating wavelengths from 1250nm to 1650 nm. Based on these values, pulse dispersion has been calculated for a fiber of length 1 km and a laser source of spectral width 0.1 nm. The networks have been trained for various experimental values. It was then tested using both the same and a different set of data. Fig.6 shows wavelength versus dispersion curve obtained theotitically from (1). The graphs obtained from training data and testing data are shown below in fig. 7 & 8.

As seen in fig.6, the zero dispersion wavelengths occur at 1310nm. Similar results are obtained using our proposed approach as shown in fig. 7& 8.

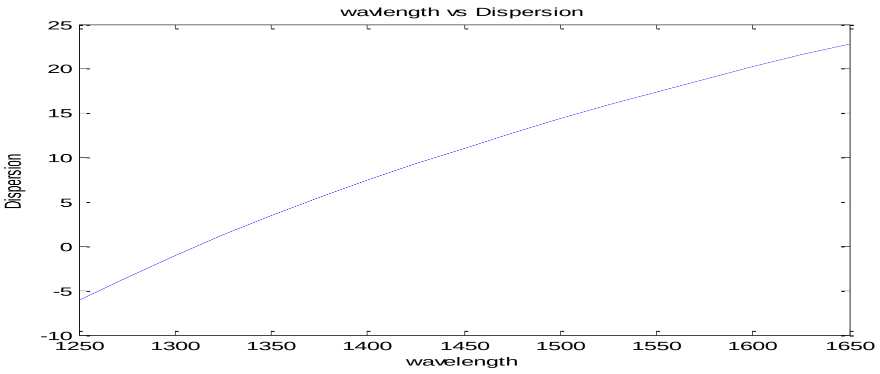

Figure6. Wavelength vs dispersion (theoretical)

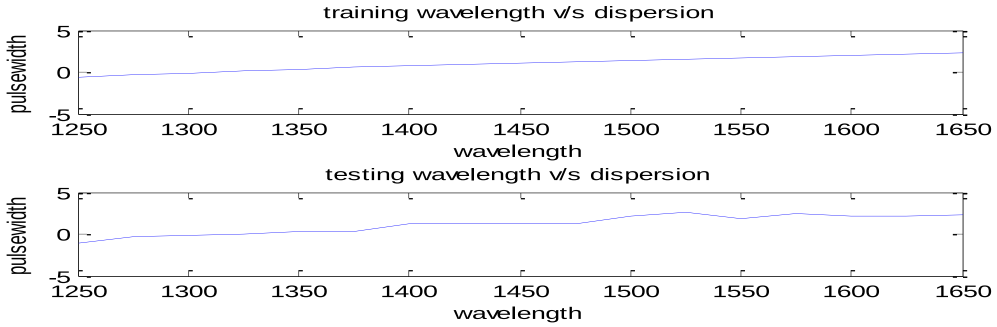

Figure7. Training and testing with same data.

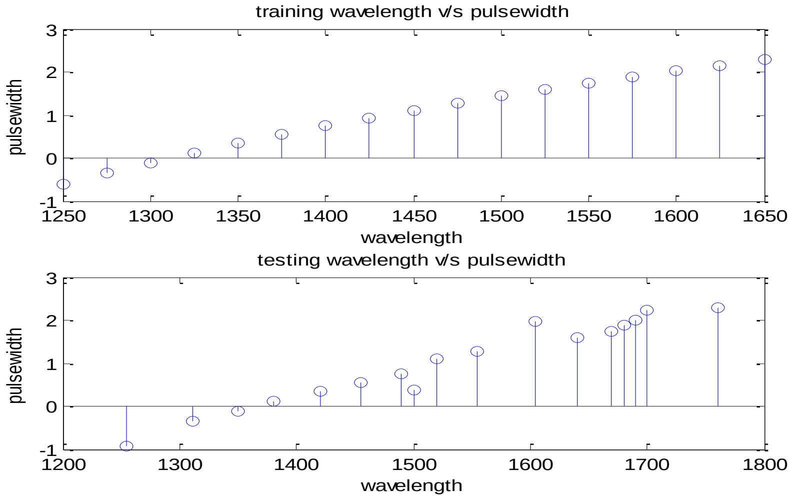

Figure8. Testing with different data

VI. CONCLUSIONS AND FUTURE DIRECTIONS

In this work a simple and an effective approach has been proposed for estimation of chromatic dispersion using ANN. A feed forward ANN have been trained to measure pulse spreading by taking into account the various factors on which chromatic dispersion depends. The network has also been tested for different operating wavelength. The experimental results show a good approximation with the theoretical data. This method can be used as a pre-processing step for chromatic dispersion cancellation. Also in our future work we intend to extend this proposed approach by compensating for the pulse broadening by using artificial neural network instead of using special fibre. This would be of great advantage as special type of compensating fibres exhibit a huge amount of losses, so by using ANN based approach we could overcome this and hence meet the ever increasing demand for bandwidth and make maximum utilization of the channel capacity.

REFERENCES

[1]. Ming Chen, Lina He, Sigang Yang, Yejin Zhang, Hongwei Chen, and Shizhong XieMing Chen, Lina He, Sigang Yang, Yejin Zhang, Hongwei Chen, and Shizhong Xie, “Chromatic dispersion and PMD monitoring and compensation techniques studies in optical communication systems with single channel speed 40Gbit/s and CSRZ format’’.

[2]. Seb J. Savory, Giancarlo Gavioli, Robert I. Killey, Polina Bayvel, “Electronic compensation of chromatic dispersion using a digital coherent receiver”.

[3]. Robert Waegemans1, Stefan Herbst, Ludwig Holbein, Philip Watts, Polina Bayvel1 “10.7 Gb/s electronic predistortion transmitter using commercial FPGAs and D/A converters implementing real-time DSP for chromatic dispersion and SPM compensation”.

[4]. Lothar Möller, “Filter Synthesis for Broad-Band PMD Compensation in WDM Systems”- IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 12, NO. 9, SEPTEMBER 2000.

[5]. Marius Ahronovich and Shlomi Arnon, Satellite and Wireless Communication Laboratory, Department of Electrical and Computer Engineering, "Optical Wireless Communication System Performance Improvement by a Decision Feedback Equalizer".

[6]. Jose E. Roman and Kim A. Winick, "Waveguide Grating Filters for DispersionCompensation and Pulse Compression"- IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 29. NO. 3, MARCH 1993.

[7]. Tianhua Xu, Gunnar Jacobsen, Sergei Popov, Jie Li,Evgeny Vanin, Ke Wang, Ari T. Friberg, and Yimo Zhang, "Chromatic dispersion compensation in coherent transmission system using digital filters"

[8]. Graham H. Smith, Dalma Novak and Zaheer Ahmed , "Overcoming Chromatic-Dispersion Effects in Fiber-Wireless Systems Incorporating External Modulators"- IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 45, NO. 8, AUGUST 1997.

[9]. Gilad Goldfarb and Guifang Li, "Chromatic Dispersion Compensation Using Digital IIR Filtering With Coherent Detection"- IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 19, NO. 13, JULY 1, 2007.

[10]. Gilad Goldfarb and Guifang Li, "Dispersion Compensation of up to 25,200ps/nm Using IIR Filtering".

[11]. S. Guizani, A. Cheriti, M. Razzak, Y. Bouslimani,H. Hamam, "A New Optical Post Compensation Technique for Chromatic Dispersion: Application to Fiber-Fed Wireless" - 2005 International Conference on Wireless Networks, Communications and Mobile Computing.

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