Chromatic and Polarization Mode Dispersion Compensation using Delay in-Line Filter

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Abstract—In order to operate high speed optical networks efficiently with a sufficiently low BER and minimize the performance degradation caused by optical pulse distortion and broadening, dispersion compensation is needed. Dispersion compensation fiber (DCF) and Fiber Braggs Grating (FBG) are the most widely used element to compensate various types of dispersion effects links, however its performance slows down with the increase in distance and speed of transmission when different nonlinear ties are considered in system design, also when many external factors in the field of installation like temperature, stress, external load etc during installation and operation will affect the fiber optic transmission. Then it is the residual dispersion plays the leading role in signal distortion on field which is not predictable. Here, in this paper new method named delay line filter (DLF) for dispersion compensation, which offers much better performance than other most common methods of compensation, which corrects residual dispersion along with chromatic dispersion, is employed. This method offers almost negligible dispersion and very high value of synchronization by reducing jitter portion in the Eye diagram keeping non-linearity at its limit. This method also offers very high value of Q-factor in long haul optical communication networks.

*Keywords:*Chromatics dispersion (CD), Polarization Mode Dispersion (PMD), Higher Order dispersion, Dispersion compensating fiber (DCF), fixed analyzer method, Delay line filter (DLF).

I. INTRODUCTION

Telecommunications service providers have to face continuously growing bandwidth demands in all networks areas, from long-haul to access. However, most of the installed optical fibers exhibit physical characteristics that may limit their ability to transmit high-speed signals. The broadening of light pulses, called dispersion, is a critical factor limiting the quality of signal transmission over optical links. Dispersion is a consequence of the physical properties of the transmission medium. Single-mode fibers, used in high-speed optical networks, are subject to Chromatic Dispersion (CD) that causes pulse broadening depending on wavelength, and to Polarization Mode Dispersion (PMD) that causes pulse broadening depending on polarization. To preserve the transmission quality, the maximum amount of time dispersion must be limited to a small proportion of the signal bit rate, typically10% of the bit time. 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. This paper presents the causes and effects of dispersion and describes a novel ways to measure it and compensate it [1].

II. DISPERSION AND ITS EFFECT

Dispersion is the pulse distortion accumulation over fiber optic transmission. By invent of EDFAs, there was no need to use regenerators. EDFAs provided large gain, but they could not cleanup the incoming signal. Dispersion and nonlinear effects accumulate as a result.Chromatic dispersion is a result of the dependence of their refractive index on the wavelength. By compensating for each other's effects, a dispersion-shifted fiber can be produced with a0 ps/nm.km dispersion at the minimum loss wavelength is 1.55 µm. For DWDM systems using DFB lasers, the maximum length of a link before being affected by chromatic dispersion is commonly calculated with the following equation

$$L < \frac{2\pi c}{16|D|\lambda^2 B^2} \quad (1)$$

L is the link distance in km, D is the chromatic dispersion in ps/ (nm * km), and B is the bit rate in Gbps. Standard ITU G.652 fiber, having a CD coefficient of 17 ps/ (nm*km) Dispersion Compensation Fiber (DCF), with its large negative CD coefficient, can be inserted into the link at regular intervals to minimize its global chromatic dispersion. Dispersion inhibits the effects of nonlinearities like self-phase modulation (SPM), cross-phase modulation (CPM) and four-wave mixing (FWM). Therefore, dispersion should be nonzero instantaneously; dispersion should be zero at the receiving end, in the long run. This puts the constraint to form dispersion compensation techniques. Dispersion-compensating fibers (DCF) are important method of dispersion compensation. They operate by insertion of fibers with dispersion of negative slope, highabsolute value. Their lengths can be 17-20Km. Lengths are too high that nonlinear effects cause a problem. Different type of commonly used dispersion compensation techniques are can be summarized as:

1) Dispersion Compensating Fiber
2) Fiber Bragg Gratings
3) Optical Phase Conjugator
4) PMD mitigation methods

Methods 1 to 3 are mainly concentrating on compensation of chromatic dispersion compensation. [8] All other type of dispersion compensation are used for PMD equalization and not used extensively due to the certain disadvantages. In recent years there has been a lot of work on dispersion-compensating fibers (DCFs), which are being used extensively for upgrading the installed 1310nm optimized optical fiber links for operation at 1550nm [3].

Currently, there are several mature measurement techniques such as fixed analyzer method, Jones matrix Eigen analysis (JME) method and Interferometric method. However, most of the PMD compensation efforts have been limited to low-order (first- and second-order) approximation [4].

1) Fixed analyser method
2) Jones Matrix Eigen analysis (JME) method
3) Interferometric method

Measurement of the Jones matrix involves stimulating the test path with a set of three known polarization states and measuring the corresponding output states. In fixed analyzer mean DGD is obtained from the number of peaks and valleys in the optical power spectrum as the wavelength is scanned and calculated as per the equation

$$\Delta\tau = \frac{kN_e\lambda_{start}\ \lambda_{stop}}{2(\lambda_{start}\ -\lambda_{stop}\ )c} \qquad (2)$$

In the Interferometric method average DGD of the fiber is calculated from the width of a Gaussian curve fitted to the interferogram, or from the statistical second moment of the data [4].

III. SYSTEM MODELING

By considering the disadvantages of present compensation techniques such as the one which arise due to implementation in bulk optics, which induces loss due to coupling and has high waveguide loss and non-negligible PDL, a new approach to the dispersion compensation system is employed. The main points considered are: the one must provide a fixed /tunable amount of dispersion, it can easily be inserted into a fiber-optic link, and (insertion losses may be compensated with a fiber amplifier). In some cases, optical nonlinearity can be relevant. (This is minimized e.g. by using strongly dispersive fiber, where a shorter length is sufficient).Tight winding of the compensating fiber can be a solution, but is limited by bend losses. Optical implementation fully in optical domain is better.

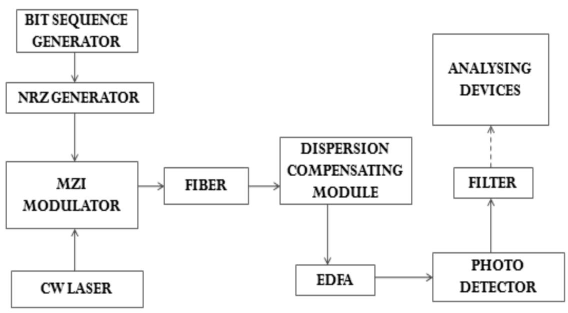

Fig. 1: Block diagram of optical communication link

Expect residual dispersion at every point, unless propagate through the fiber with chromatic dispersion at its limits. Consider higher order dispersion compensation to the maximum possible limit, effect of dispersion slope (higher-order dispersion) can strongly limit the usable bandwidth especially for WDM. The link designed for the analysis is shown in the block diagram in Fig. 1. [1]

IV. DELAY LINE FILTER ARCHITECTURE

Dispersion compensation is critical for high bitrate Lightwave systems. Because of the large number of channels in dense WDM systems, periodic filters are advantageous compared to single channel devices, requiring a unique filter for every WDM channel. While there are several periodic compensators that rely on feed forward filters, such as cascaded Mach-Zehnder and phased array interferometers, we focus on optical all pass filters. All pass filters are unique in their ability to provide a flexible phase response that can approximate any desired dispersion over a bandwidth which is large relative to the filter period and, in the limit of low feedback path losses, which is decoupled from the magnitude response. [1]

A delay line filter with tunable group delay for residual dispersion compensation is presented. The device is suitable for high channel bit rates and consists mainly of fiber couplers connected in series. Due to the all-fiber implementation, it has low polarization sensitivity and can be directly inserted in the transmission line. Fig.2. shows the basic schematic of the proposed DLF model: An all fiber delay line filter which compensates Residual dispersion and is suitable for WDM systems. The implemented block diagram of the system is given as shown in the Fig. 2.Which is suitable to correct PMD as well as chromatic dispersion.

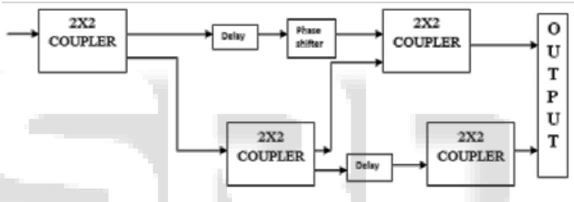

Fig.2: Block diagram of DLF system

The components and the operating principle of the system are summarized below.

1) 2x2 couplers: These are X couplers which can couple the light into and from the link. This is an all fiber implementation of the network Delay line.
2) Delay line: Delay-line circuits are widely used in the field of optical signal processing. Provides delay of the signals as per the amount of delay provided on to the systems. These are related to the network so that these provides delay on to the system based on the network characteristics
3) Phase shifters: All Fiber Phase Shifters achieve optical phase modulation directly on a section of optical fiber. No optical waveguides or fiber pigtails are used. There is no epoxy in the optical path. The standard model is polarization independent, although polarization-maintaining versions are available. The Phase Shifter uses no mechanical moving components.

Functionally it consists of:

1) Optical interleaver: The optical interleaver is systems which are used to mix channels in DWDM network, which corrects burst errors.
2) A flat band pass filter: They are composed of optical waveguides operating as optical delay lines, directional couplers, and phase shifters. Lot of functions can be realized with these circuits by adjusting their directional couplers and phase shifters, their

transmission characteristics are the same as those of electric digital filters. Several useful devices have been reported including add/drop multiplexing filters, an EDFA gain equalization filter, a polarization mode dispersion equalizer, and a variable group-delay equalizer.

3) Delay line: Provides delay of signals. A typical 2x2 circuit configuration of FIR optical filters in the lattice form which is composed of cascaded 2x2Mach–Zehnder interferometers (MZI's) with a unit path length difference of ΔL.

Parameter set in the DLF:

1) Coupling ratio is .25, .5, and .25 for the three successive lines in order.
2) Delay=1 for the second link
3) Delay= 2 for the third link
4) Varied instantaneously(expecting better at 120)

In the set up signal connection port is from the second input to the fifth output portFirst link is direct link. Chromatic dispersion is a limiting factor in fast optical networks with channel bitrates of 40 GB/s or higher. The main part of the dispersion is usually compensated by a Dispersion-compensating fiber that has a fixed dispersion value. But the residual dispersion, caused by environmental changes, rerouting, and power variations has to be compensated adaptively. [1-8]

V. SIMULATION MODELING

The proposed model for the compensation delay line filter is implemented in a point to point network.

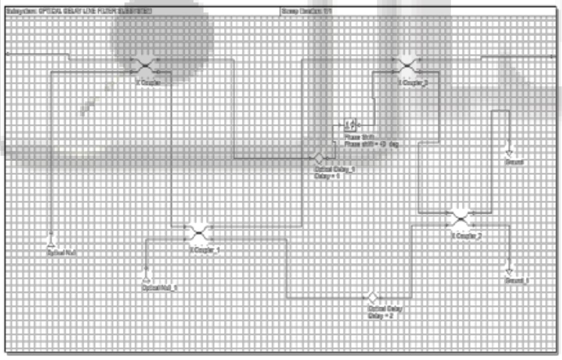

Fig.3: DLF in Optisystem V.12

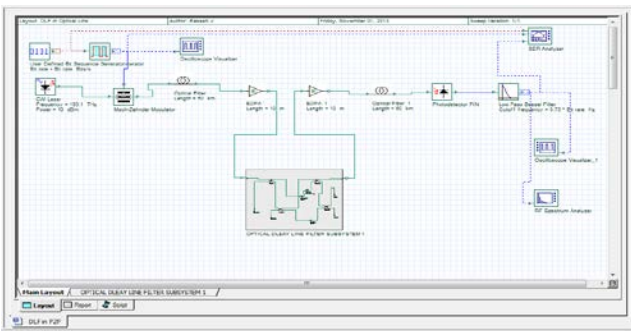

Fig. 4: DLF in point to point link

The system is analyzed first keeping the distance constant with the varying bitrates from 1 Gbps through 10Gbps to 40Gbps and taking the eye diagram, Q factor and BER on each run the results tabulated. Spectrum of the signal is also taken to do further analysis on pulse broadening. The simulation diagram of the proposed DLF model alone isshown in Fig. 3.This is implemented with Optisystem Simulation software. In the Fig.4.Shows the communication link created with the subsystem shown in the Fig. 3.

VI. RESULTS AND DISCUSSIONS

Dispersion and its effect are simulated in a point to point link at different distance and different links and the output are analyzed. All the analysis is done after the detailed analysis of dispersion effects in optical links. Different analysis on WDM, DCF-DLF analyses etc are done on different networks. The system is also simulated in the same way on the point to point link with and without compensation.

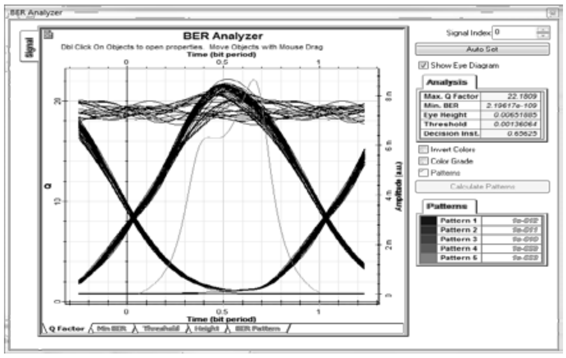

Fig.5: Eye diagram for DLF implementation

Fig. 5.Shows the eye diagram from the simulation. This eye diagram is used to evaluate the Q factor and various other parameters of the link in communication systems which helps in understanding and evaluating the particulars in the communication links created.

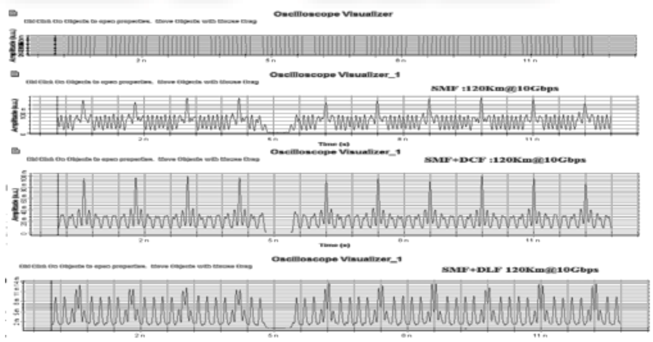

Fig.6: Oscilloscope output

Oscilloscope output with three different states of simulation is shown in Fig. 6.Which shows the correction of dispersion effects occurred in data bits. In the top most signal, it is the input signal bits, after that the one distorted with dispersion, the third one corrected with DCF, and the fourth is the one corrected with DLF.

The PMD measurement on different output spectrum was done with the fixedanalyzer method. In the Fig. 7.Shows the spectrum of the DCF and DLF mix combination with PMD emulator. By calculating with this spectrum different values of Δτ are obtained.

The tabulated result of different spectrum analysis and obtained group delay (Δτ) values are obtained bycalculating with the help of equation 2 is given in Table 1. All the simulation was done with the PMD emulation at certain distance and then the spectrum was calculated.

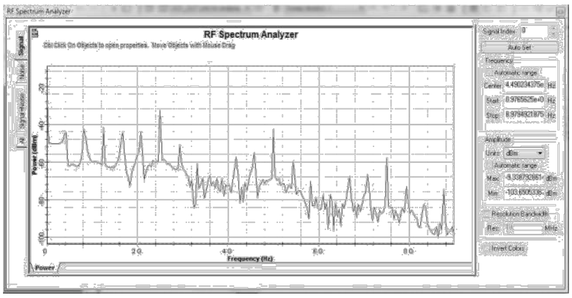

Fig. 7: Spectrum of simulation used for dispersion measurement

The tabulated result of different spectrum analysis and obtained group delay (Δτ) values are obtained bycalculating with the help of equation 2 is given in Table 1. All the simulation was done with the PMD emulation at certain distance and then the spectrum was calculated.

120Km at 10GBps (No comp.)	DCF-120Km at 10GBps	DLF-120Km at 10GBps	DCF + DLF 120Km at 10GBps	DCF-100Km at 20GBps	DLF-100Km at 20GBps	DCF + DLF 100Km at 20GBps
.875	.765	.695	.5876	.865	.789	.5798

Table. 1: Pmd Measurement Values

It is observed from the values in the tabulation column that the group velocity was getting corrected with the implementation of DLF on the communication system as per the ITU-T specification. The allowed value is about .5 ranges, is found with the mix combination of DCF and DLF. So from all the simulation and results analysis, the formulations of the DLF systems are shown in the Fig. 8. And Fig. 9.

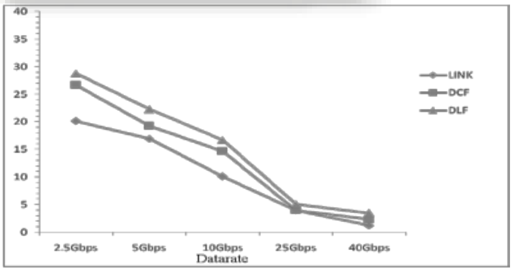

Fig. 8: Q factor Vs Data rate

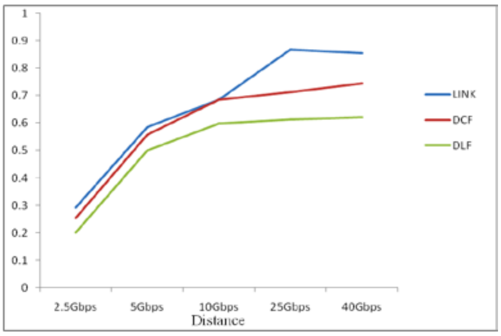

Fig. 9: Δτ values due to PMD for Point to point link(Link)-DCF-DLF

Representation of the Qfactor obtained from different datarates in all the three systems like a point to point link(link), one with DCF and one with DLF. In the Fig. 9.Shows the delay value graphical representation of all the systems explained above. From both observations of the two graphs it is evident that DLF provides much more results when compared with other models of compensation. On implementing a hybrid system with a mix combination of DLF along with DCF it is suitable for high data rates in a long distance transmission around 2000Kms.

VII. CONCLUSION AND FUTURE WORK

A different method of Dispersion compensation is presented, with its theoretical concepts and results, when implemented. Due to its all fiber implementation gives much valuable analysis results to compete with existing techniques in optical communication and expecting more results. The delay line filter with all fiber implementation gives good response when it is analyzed with different parameters. The dispersion value of the device can be easily controlled by one single phase shift. The easy integration in a transmission system is a benefit that is not obtained by planar- or bulk-optic components.

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