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Design and Analysis of 4 Port Coupler based Delay Line Filter for Dispersion Compensation

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Abstract— **Delay Line filter based dispersion compensation of an optical fiber transmission system, is implemented using 4 port couplers. The filter performance is evaluated in 90 km single mode fiber link by simulate to enable system using optisystem software. The Dispersion Compensation has resulted in improvement in Eye Opening Penalty, Transmission, Q factor and BER.**

Index Terms—**Dispersion, Dispersion compensation, Single mode fiber (SMF), Delay Line Filter(DLF),Coupler.**

I. Introduction

One of the major drawback in high bit rate optical transmissions systems is distortion which is due to dispersion. Dispersion is the phenomenon in which the phase velocity or alternatively group velocity of a wave depends on its frequency. Dispersion induces broadening and distortion of the bits, which ultimately leads to errors. Dispersion inhibits the effects of non linearity like Self Phase Modulation (SPM), Cross Phase Modulation (CPM), stimulated Inelastic Scattering and Four Wave Mixing (FWM). This puts the constraint into design of dispersion compensation techniques [1,2,9]. The distortion caused by chromatic dispersion can be eliminated by using dispersion compensating devices.

There has been an ongoing quest to find the best filter architecture that can fulfill the requirements of the modern high data rate optical fiber transmission systems. Optical delay-line circuits composed of optical delay lines and directional couplers, have filter characteristics similar to those of finite impulse response (FIR) digital filters[5,7,10,11]. Attributes of the filter architecture are its size, scalability, complexity of implementation and complexity of control.

In optical FIR filters, the transmission characteristics are expressed by polynomials whereas in optical IIR filters, they are expressed by rational functions. Optical delay line filter has several configurations i.e., transversal form and lattice form. In transversal form (Double-arrayed waveguide grating (DAWG)),getting the achievable dispersion for a given bandwidth requires bulky design with increased complexity and cost. Lattice form ([3]-[5]) is a cascade of 2x2 couplers and delay lines. They are easier to design and require less power for the tuning elements. Each stage of the lattice filter brings an individual contribution in the overall dispersion behavior of the device [2]. A large number of stages are needed to achieve the desired dispersion behavior. This makes the device large in size.

Hence, it is necessary to investigate filter architectures that can mitigate the limitations of completely serial and completely parallel approaches. Combination of these two forms gives better results. For this approach, the couplers[8,12] used to design the DLF.

The main objective of a delay line filter is to find the filter coefficients that generates the desired transfer function in which the transfer function of the delay line filter is fully controlled by their filter coefficients .

In this paper, DLF based dispersion compensation methodology with improved performance is implemented. The Delay Line Filter (DLF) is tested for a single channel system operating at a data rate of 10 Gb/s with a transmitting wavelength of 1550 nm and power of 0 dBm, over 90 km single mode fiber. The Transmission, Q factor, minimum BER and BER pattern of Delay Line Filter is analyzed based on eye opening penalty [4].

II. Filter Principles and Design

A two-stage lattice-transversal filter for dispersion compensation is a sixth-order FIR filter, composed of couplers, which are connected by delay lines embedded with phase shifting elements. The filter has a maximum time delay of 6T and six phase shifting elements. As shown in Fig. 2, one of the four input ports is used for the incoming signal distorted by chromatic dispersion. It is decomposed into four equal components after passing through a 4-port coupler. They are time delayed and phase shifted before reaching the second coupler. Summation operation of these components is performed in the second coupler. These summed components are once again split, time delayed, and phase shifted before a second addition operation is performed by the third coupler. Proposed filter architecture is shown in Fig 1.

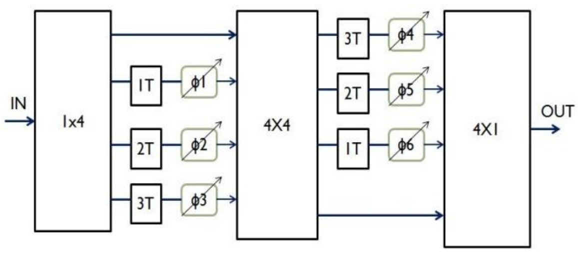

Fig. 1 A two stage lattice-transversal filter

In general terms, the input field

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$$E_i = E_0(t)e^{j\omega t} \quad (1)$$

is split into up to (N+1) different copies that are delayed individually by multiples of the unity delay $T_i = iT_0 (0 \le i \le N)$. The unity delay T_0 defines the spectral periodicity of the filter called Free Spectral Range (FSR). The filter order N is determined by the highest delay $T_N = NT_0$. These copies of the input field E_i are finally recombined. The splitting and combining ratios determine the complex weighting coefficients b_i. The output field computes to

$$E_0 = b_0 E_i + b_1 e^{j\omega T_1} E_i + b_2 e^{j\omega T_2} E_i + \cdots \quad (2)$$

Thus, the filter transfer function $H(e^{j\omega}) = Eo/E_i$ can be written as

$$H(e^{j\omega}) = \sum_{i=0}^{N} b_i e^{j\omega i T_0} \quad (3)$$

Setting $z = e^{-j\omega T0}$ produces the standard description of a FIR filter in z-transform

$$H(z) = \sum_{i=0}^{N} b_i z^{-i} \quad (4)$$

Equivalently, transfer function can be described by filter's zeros,

$$H(z) = \prod_{i=1}^{N} (1 - z_i * z^{-1}) \quad (5)$$

Considering coupling coefficient of 0.5, it is necessary to analyze BER and Q factor of optical delay line filter using 4 port coupler based on eye opening penalty (EOP) which is shown in Fig. 3 have the filter response as

$$H(z) = (1-(-1)*z^{-1})*(1-(-1)*z^{-1})*(1-(-1j)*z^{-1})*(1-(1j)*z^{-1})*(1-(-1j)*z^{-1})*(1-(1j)*z^{-1}) \quad (6)$$

The filter has six zeroes which are shown in Table 1.

Table 1. Zeroes of lattice-transversal filter

zeros	z_1	z_2	z_3	z_4	z_5	z_6
value	-1	-1	1j	-1j	-1j	1j

Then the filter response is

$$H(z) = 0.0625 + 0.125z^{-1} + 0.1875\,z^{-2} + 0.25z^{-3} + 0.1875z^{-4} + 0.125z^{-5} + 0.0625z^{-6} \quad (7)$$

The filter has seven coefficients which are shown in Table 2.

Table 2. Coefficients of lattice-transversal filter

b_0	b_1	b_2	b_3	b_4	b_5	b_6
0.0625	0.125	0.1875	0.25	0.1875	0.125	0.0625

III. Simulation Results

The Digital optical link simulation setup is shown in fig. 2.

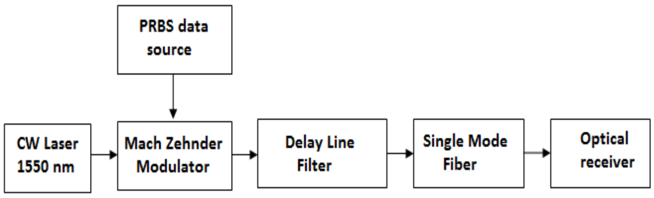


Fig. 2 Digital optical link for system simulation

The optical transmission system consists of transmitter, fiber transmission channel, Dispersion Compensator (DLF) and a receiver. A single span of Continuous Wave (CW) Laser source operating at a frequency of 193.1THz (≈1550 nm) is taken into analysis. A Non-Return-to-Zero (NRZ) wave form is generated by a pseudorandom binary sequence (PRBS) length of 128, is provided to the Mach Zehnder modulator at a data rate of 10 Gb/s. An optical fiber transmission channel comprising of 90 km of single mode fiber compensated by DLF and loss is overcome by an amplifier with a Gain of 20dB is considered.

The proposed filter architecture is implemented using optisystem which is shown in figure 4. The circled portion indicates the filter which is implemented using 4 port couplers, y couplers, delay lines embedded with phase shifters.

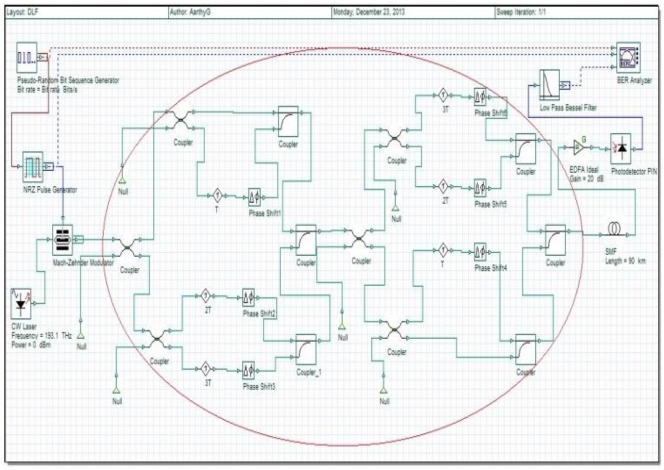


Fig. 3 Optical Delay Line Filter Architecture using 4 port Couplers

The receiver consists of a PIN photodiode and a low pass filter with a cut-off frequency of 75% of the data rate. BER Analyzer is used to analyze the performance measure of the link in terms of BER, Q factor and an Eye-Opening Penalty (EOP).The fiber optic link is simulated in OptiSystem simulation environment and the link parameters are obtained.

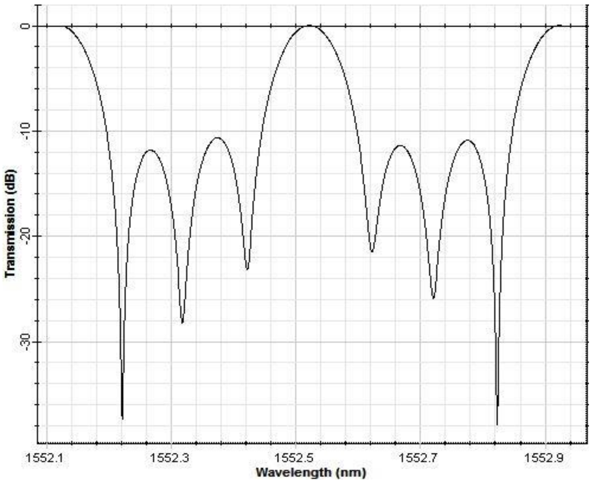


Fig. 4 Transmission function

From fig. 4 gives the transmission response of the filter.

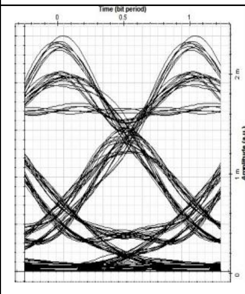
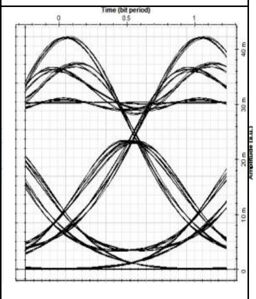
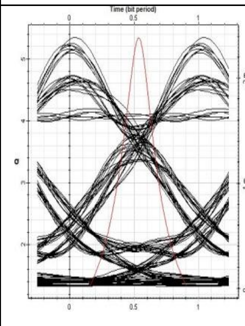
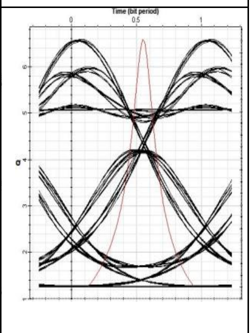
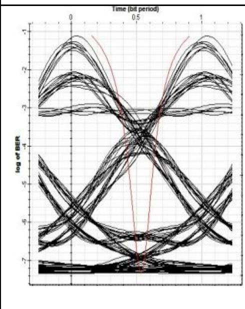
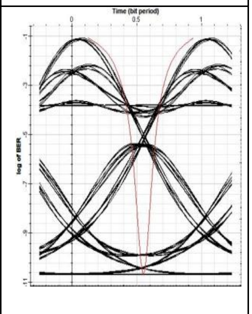
Parameters	Without DLF	DLF
Eye pattern		
Q Factor		
Minimum BER		

Fig. 5 Comparison results of BER and Q Factor

From Fig 5, shows the performance comparison among Q factor, minimum BER and BER pattern are analyzed, using eye opening penalty and it is found that Dispersion to be compensated.

Table 3. Comparison results of BER and Q factor of DLF and without DLF

Parameters	Without DLF	DLF
Q Factor	5.34	6.59
Minimum BER	4.58e-08	2.09e-011

From Table 3, it is clear that DLF (on the basics of Q factor , EOP and BER) gives improvement in the system performance.

IV. Conclusion

A single channel with 90 km Single Mode Fiber compensated by Delay Line Filter (DLF) it is found to have better Q-Factor of 6.59. The filter transfer function is completely controlled by the filter coefficients. This type of filter is implemented using couplers, compensate the dispersion.

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