System Performance of 2x2 Coupler-Based All-Optical OFDM System

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Abstract: Fiber optic Fourier transform devices for all-optical OFDM systems show critical crosstalk penalties against phase errors in the device. We report active phase control can effectively mitigate crosstalk significantly even under existent of loss errors.

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1. Introduction

At data rates of 100 Gbps or higher, optical orthogonal frequency division multiplexing (OFDM) becomes a promising technique to mitigate major impairments including chromatic dispersion, polarization modal dispersion, and nonlinear phase modulation of amplified fiber transmission systems [1]. An OFDM symbol is generated by inverse discrete Fourier transform (DFT) circuit and demultiplexed by forward DFT circuit. Conventional optical OFDM systems utilize electrical DFT circuit which limits processing speed and cost [2]. The transmission data rate is bounded by the throughput limits of optical modulators and electrical circuitry for DFT processes. In order to overcome such limitations, all-optical DFT schemes can be adopted, which use passive optical components. One method of fabricating all-optical DFT circuit is cascading 2x2 3dB couplers with phase shifters [3-5]. Outputs of a 2x2 coupler is equivalent to a second-order DFT recognized by Siegman in [3].

$$\begin{bmatrix} S_{\mathrm{out},1} \\ S_{\mathrm{out},2} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} S_{\mathrm{in},1} \\ S_{\mathrm{in},2} \end{bmatrix}, \tag{1}$$

where $S_{\mathrm{out},1}$, $S_{\mathrm{out},2}$ ($S_{\mathrm{in},1}$, $S_{\mathrm{in},2}$) are the field representation of optical signals at output (input) ports 1 and 2, respectively. Eq. (1) implies that a proper combination of 3dB couplers with a good choice of phase shifters can form a 2^N-th-order Siegman DFTs [3].

Figure 1 shows a schematic of 100Gbps Siegman DFT all-optical OFDM circuit as an example. An optical RZ pulse train which is generated from a CW laser splits to four 25Gbps modulators and then the four modulated subcarrier channels are feds into an inverse Siegman DFT circuit. Each subcarrier signal goes through different path lengths for allocating time slot respectively [2]. An OFDM symbol is coined by summation of subcarrier signals. After propagating over a fiber transmission system, an OFDM symbol is fed into different waveguides with different time delay and then demultiplexed by a forward Siegman DFT circuit. In the process of inverse and forward DFTs, every optical path has to maintain exact phase relations, as well as uniform path losses, not to break orthogonality of OFDM subcarriers. Therefore, it is meaningful to investigate phase errors in DFT circuits and propose phase compensation methods.

2. Phase error and loss in All-optical DFT circuit

There are always errors in controlling relative phase relation among waveguides between couplers due to manufacturing accuracy limit. Little differences of waveguide lengths and modal areas cause loss ununiformity and phase errors in a DFT circuit. Especially, our study shows that phase errors generate crosstalks between subcarriers so that leakage of a subcarrier affects adjacent subcarrier channels. As a result, such crosstalk destroys the orthogonality of OFDM symbol and degrades system performance. In order to investigate such effects of phase error and loss in a Siegman DFT circuit, we model all-optical OFDM transmission with Matlab simulations. Dispersion and nonlinear propagation is not considered in this paper, because we focus on phase error and loss unumiformity penalties in a DFT circuit. We introduce reasonable phase and loss error distributions before all couplers that introduce interferences. We assume normal distributions of both errors with standard deviations of phase and loss errors observed in the state of the art. The tails of distributions over twice the standard deviations are removed. Fig. 2 shows system performance as functions of phase and loss errors, while keeping, respectively, the loss error of 0.1 dB and the phase error of λ/30 constant. The slope decreases relatively rapidly in Fig.2(a), which manifests that phase error shows more serious penalty than loss error in a Siegman DFT OFDM system.

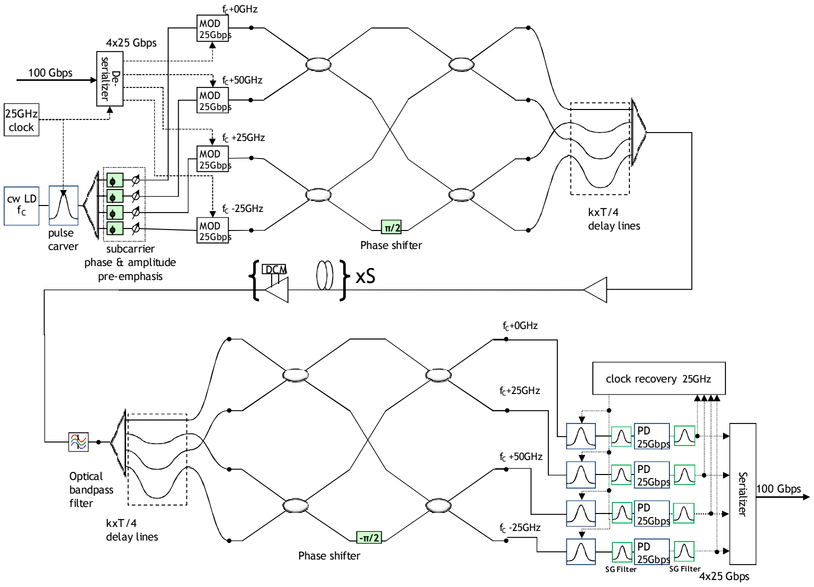
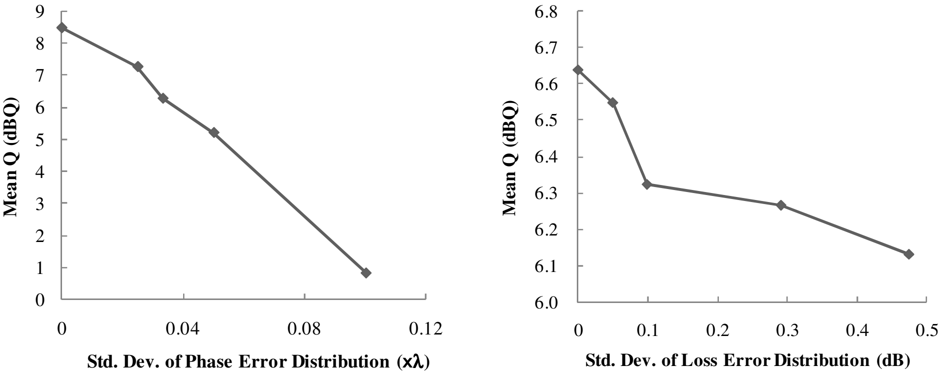


Fig. 1. A schematic of coupler based All-optical OFDM circuit.



(a) **(b)**

Fig. 2. Comparison of system performance with respect to phase error, (a), and loss error, (b), in Siegman DFT circuits

3. Proposed compensation technique

Fig.3 illustrates the phase compensation model in a 4x4 Siegman DFT circuit. The phase compensation control consists of slow phase modulators and phase controllers, signal detectors. In order to compensate phase error, first we take slow phase modulation as a pilot tone at the specific path in inverse DFT circuit at the transmitter. When the pilot tone is added on to signal, only one input port of a coupler is used. Phase modulated pilot tone allows channel monitoring without cross-gain modulation [6]. Pilot-tone-modulated signal which causes crosstalk can be extracted by using 10/90 tap coupler in the receiver. Finally, crosstalk can be removed by controlling the phase until the modulated signal is not detected. As a result, OFDM symbol can maintain orthogonality among subcarriers. It is note that phase controlling for keeping orthogonality should be proceeded in an order of center to outer in this design, i.e. in a sequence of pilot tones (f_{21}, f_{22}) and (f_{11}, f_{12}).

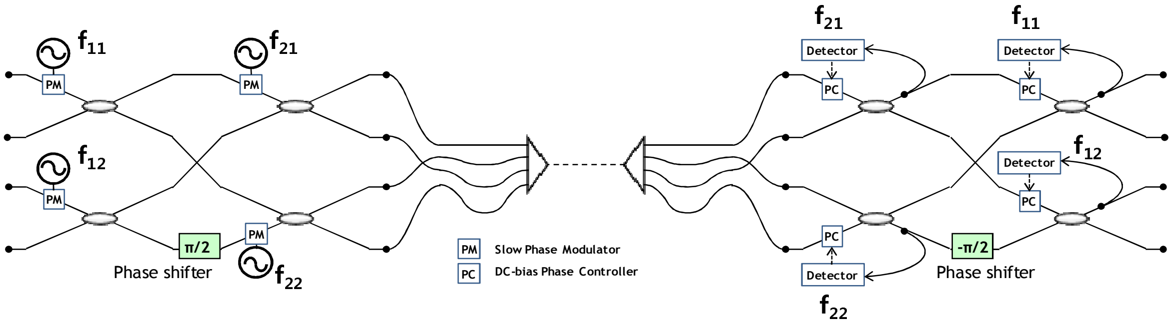


Fig. 3. Phase compensation control schematic design in a 4x4 Siegman DFT circuit.

Fig.4 compares the Q-factor distributions before and after phase compensation. After phase compensation, most Q-factors are populated in the reasonable Q-factor range with an average of 8.49dB, which is improved from 6.27dB for the case of an uncompensated Siegman DFT system.

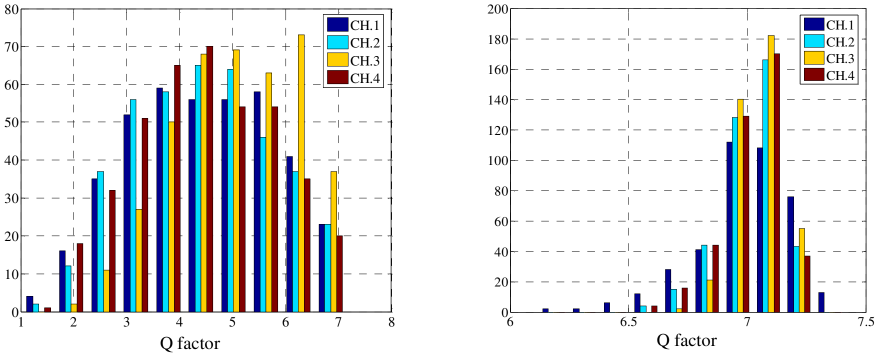


Fig. 4. Q factor distributions of subcarrier channels with (a) loss and phase error standard deviations of 0.1dB and λ/30, and (b) loss standard deviation of 0.1dB after phase error compensation. Q factors are shown in linear scales.

4. Summary

In this paper, we have investigated system penalties of loss and phase error of 100 Gbps all-optical OFDM system using a coupler-based Siegman DFT. The simulation results reveal that phase error introduce more serious penalty rather than loss, where the phase error causes crosstalk between subcarriers so that orthogonality among subcarrier channels is destroyed. Then we also propose a phase error compensation method by using phase modulation pilot tones launched at a transmitter and detected at a receiver as an indication of phase error in a 4x4 Siegman DFT. We show that the Q-factor of a system performance is fairly restored after phase compensation. Proposed compensation method is not limited 4x4 DFT. Therefore, this compensation method is expected to apply high speed all-optical OFDM systems beyond 100Gbps and to enhance the system performance significantly.

Acknowledgement

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5. References

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