Dispersion Penalty Mitigation Using Polarization Mode Multiplexing in Phase Diverse Analog Optical Links

S. Gupta, O. Boyraz[1], and B. Jalali
University of California Los Angles, Los Angeles, CA 90095
[1]University of California Irvine, Irvine, CA 92697
Tel: +1-310-206-455; Fax: +1-310-206-2239; Email: shalabh@ee.ucla.edu

Abstract: Polarization mode multiplexing of phase diverse Mach-Zehnder modulator outputs to mitigate dispersion penalty in band limited analog optical links and related systems is demonstrated. Link SNR is also improved by up to 3dB.

OCIS Codes: (060.2360) Fiber optics links and subsystems; (060.5625) Radio frequency photonics;

1. Introduction

Analog optical links have become very important in a variety of applications like antenna remoting, phased array antennas, radio-over-fiber, CATV links, and Time-Stretch Analog-to-Digital Converter (TS-ADC) systems [1,2]. However, these links commonly suffer from power penalty caused by optical fiber dispersion [3]. Dispersion compensation solutions are costly, not always adaptable, and add additional loss to the links. In certain systems, dispersion compensation by optical means is not viable at all. For example, the TS-ADC relies fundamentally on dispersion for the process of stretching, and hence it cannot use such dispersion compensation techniques.

In this paper, we propose and demonstrate a technique to overcome the dispersion penalty problem in band limited analog optical links. The proposed technique exploits the phase diversity caused by chirped modulation in Z-cut $LiNbO_3$ Mach-Zehnder modulators which results in complementary fading characteristics [4] for the two Mach-Zehnder outputs. Experimentally we show that the polarization mode multiplexing of the phase diverse Mach-Zehnder modulator outputs mitigate the dispersion penalty in band limited analog optical links and can provide seamless ~6GHz analog communication window for a 160 km long single mode fiber. Additionally, the proposed technique is adaptable for different RF frequency bands and for different fiber optic dispersion values. Due to polarization filtering of the optical ASE noise, 3dB improvement in OSNR is also expected.

2. Phase Diversity Modulation

When a Z-cut Mach-Zehnder modulator (MZM) with a single electrode (shown in Fig. 1) is used for intensity modulation, a signal dependent chirp (i.e. phase modulation) is also added to the optical fields at the two MZM outputs. In the presence of dispersion, this chirp results in a modified frequency response at the photodetector. The two outputs of the MZM have opposite chirps and hence show a complementary frequency response due to dispersion penalty [4]. When one of the outputs has a frequency null, the other output has a maximum for the same frequency. Using the mathematical framework shown in [4], the transfer function for the two modulator outputs after dispersion through a fiber of length L and dispersion parameter β_2 can be written as:

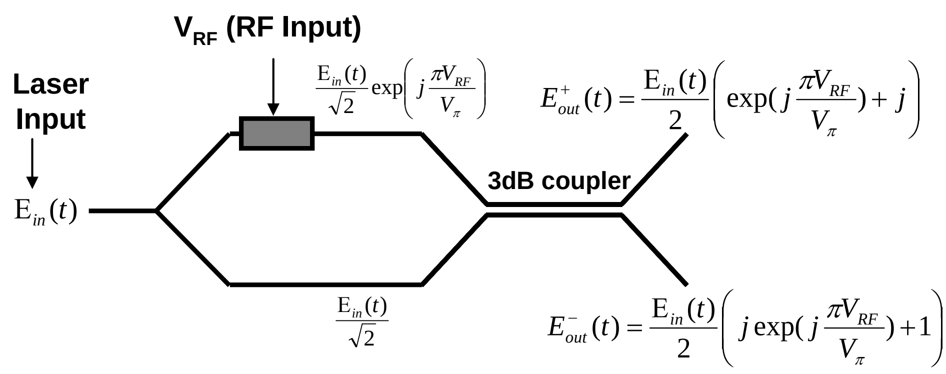

Fig. 1. Single electrode (Z-cut) Mach-Zehnder modulator that has opposite chirps at the two outputs

$$H_{out}^{+}(f_{RF}) = \cos\left(2\pi^2\beta_2 L f_{RF}^2 + \frac{\pi}{4}\right) \quad (1)$$

$$H_{out}^{-}(f_{RF}) = \cos\left(2\pi^2\beta_2 L f_{RF}^2 - \frac{\pi}{4}\right) \quad (2)$$

Ideally, to avoid dispersion penalty, the outputs should be combined. By combining the outputs in electronic domain, all the frequency components of the signal can be recovered. However, this requires use of two fibers and two detectors and combination in electronic domain which may not always practically be feasible at high frequencies. Alternatively, all-optical beam combining is hindered by the interference and stability. Since photodetectors are polarization insensitive, here, we use polarization multiplexing to facilitate all optical beam combining and full utilization of the MZM output power.

3. Experimental Setup

Fig. 2 illustrates the experimental setup we used to demonstrate the dispersion penalty mitigation technique in an analog optical link. The setup consists of a CW laser emulating the transmitter launched into a Z-cut Mach-Zehnder modulator (MZM) after passing through a polarization controller (PC). Variable optical attenuators (VOAs) are used at the two outputs of the MZM to give desired weights to the intensity signal outputs, and also to correct for unequal losses in the two signal paths. The delays from the two channels are closely matched by selecting appropriate length patch-cords and then fine tuned by using a tunable optical delay. Polarization controllers at the two outputs are used to linearly polarize the optical fields and put them in orthogonal directions. The outputs are then polarization multiplexed into a single fiber by using a polarization beam combiner. After dispersion, the intensities due to these two fields add linearly at the detector, giving an overall transfer function as the summation of the two individual transfer functions. A dispersion compensating fiber (DCF) provides a dispersion of -2700 ps/nm, which is roughly the dispersion corresponding to 160 kilometers of SMF-28 fiber but with opposite sign, is used for signal transmission. The signal is directly detected by an amplified photodetector (PD) and fed into an RF spectrum analyzer.

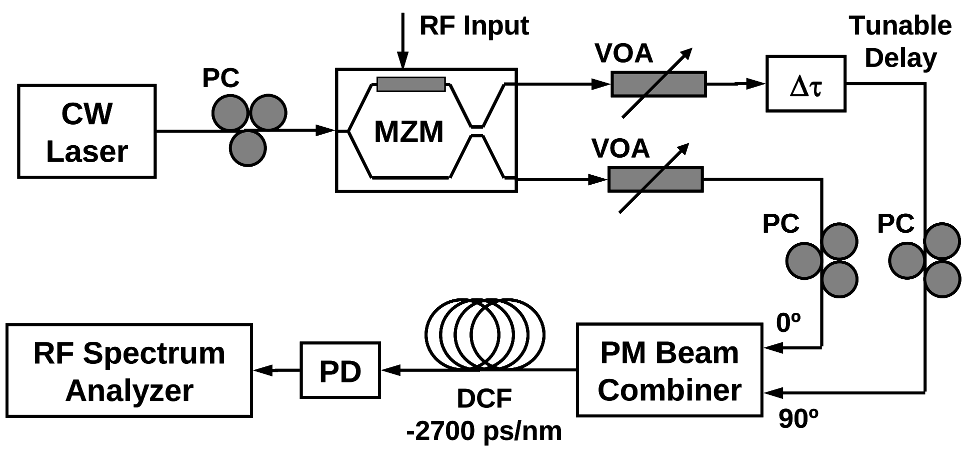

Fig. 2. Experimental setup for polarization mode multiplexing of phase diverse outputs

4. Results

The dispersion penalty of the analog link is measured by swept RF signal generator up to 10GHz. In the experiment, the RF signal is swept from 100 MHz to 10 GHz to record the dispersion penalties under various conditions. Fig. 3 illustrates the transmission characteristics recorded from two different outputs of the MZM. The dispersion penalty nulls the transmission at 3.75GHz and 5.25GHz. After polarization multiplexing, the two intensity outputs are 180º out of phase at low frequencies, resulting in a null at DC. However, the first null is moved to 6.25GHz providing a seamless ~6GHz dispersion penalty free transmission window. Since most of the RF links operate in frequency bands that do not extend to DC, this technique very attractive to use at high frequencies. The observed amplitude reduction presented in Fig. 3 is produced by the roll-off in frequency response of the Mach-Zehnder modulator and the detector, which is natural and did not affect our measurements. The same technique can be extended to analog links with different fiber lengths. Figure 4 illustrates the transmission characteristics of an analog link with 20km SMF fiber. Polarization multiplexing will move the null frequency to beyond 18GHz and facilitate broadband analog transmission.

Another important aspect of the technique is that by adjusting the weighting coefficients in combining the two MZM outputs, the dispersion penalty nulls can be removed from any particular frequency of interest. If one of the weights is made zero, the dispersion penalty transfer function corresponding to the non-zero weight output is obtained. This could particularly be very useful in removing frequency nulls due to dispersion in millimeter wave radio-over-fiber links. Also, since the intensities are combined coherently in terms of signals from the two polarizations, where as noise components add incoherently, there is an improvement of up to 3dB in SNR of the link. The same technique can also be used in the TS-ADC to enhance its bandwidth or improve the response at a particular frequency of interest.

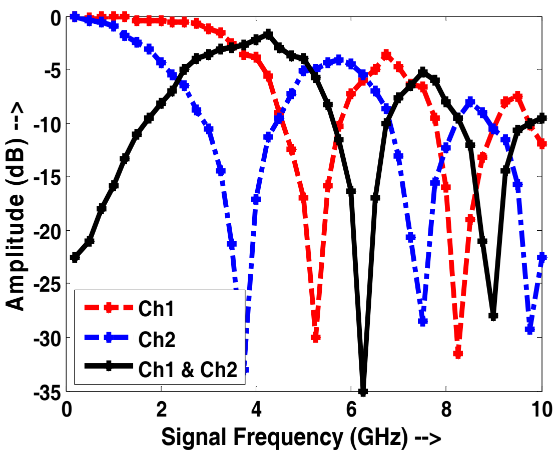

Fig. 3. Measured dispersion penalty for -2700 ps/nm DCF.

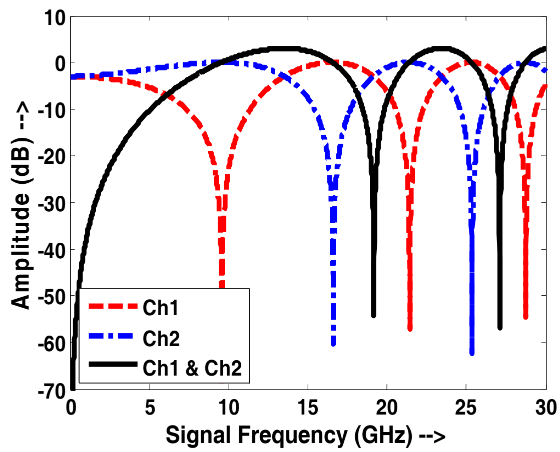

Fig. 4. Simulated dispersion penalty for 20 km SMF-28 fiber link

5. Summary

We propose and demonstrate a technique to overcome the dispersion penalty problem in band limited analog optical links by polarization multiplexing of Z-cut $LiNbO_3$ Mach-Zehnder modulator outputs. Experimentally we show ~6GHz analog communication window in an equivalent of 160km SMF link. Due to polarization filtering of the optical ASE noise, 3dB improvement in OSNR is also expected.

6. References

[1] A. S. Bhushan, F. Coppinger, and B. Jalali, "Time-stretched analogue-to-digital conversion," *Electronics Letters*, Vol. 34 (no.11), pp. 1081-3, May 1998.

[2] B. Jalali and F. Coppinger, "Data Conversion Using Time Manipulation," US Patent number 6,288,659, Granted 09/11/01.

[3] G. H. Smith, D. Novak, and Z. Ahmed, "Overcoming chromatic-dispersion effects in fiber-wireless systems incorporating external modulators," IEEE Transactions on Microwave Theory and Techniques, vol. 45, no. 8, part 2, pp. 1410-1415, Aug 1997.

[4] Y. Han, O. Boyraz, and B. Jalali, "Ultrawide-band photonic timestretch A/D converter employing phase diversity," *IEEE Transactions on Microwave Theory Techniques*, vol. 53, no. 4 part I, pp. 1404–1408, April 2005.