Effect of Modulator Chirp on Ultra-Long Haul Transmission with NRZ

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Abstract— **Single-drive Mach-Zehnder lithium niobate modulators are commonly used to apply NRZ modulation in long-haul WDM transmission systems. Modulators based on *x*-cut $LiNbO_3$ are typically preferred to *z*-cut devices since they have a zero chirp parameter. However, we show that lower transmission penalties are achieved with *z*-cut modulators which have a chirp parameter of 0.7.**

Keywords: optical fiber communication, optical propagation in dispersive media, optical propagation in nonlinear media.

I. INTRODUCTION

Although non-return to zero (NRZ) modulation in light-wave transmission systems does not give as good receiver sensitivities as more complex formats, such as RZ [1] and DPSK [2], it is far simpler and lower cost to implement and provides better spectral efficiency. The preferred method for implementing NRZ for long-haul transmission is with external Mach-Zehnder modulators (MZMs) based on lithium niobate ($LiNb0_3$) as these guarantee a well defined and stable phase characteristic [3]. Changes in phase over the pulse, or chirp, is an important signal characteristic for transmission over optical fiber since it interacts with the fiber's dispersion, as well as its nonlinearity, to alter transmission. Consequently modulators that have a zero chirp are often preferred for long haul transmission with NRZ [4]. A zero chirp can be obtained in dual–drive MZMs by driving the arms in anti-phase but this requires the complexity of a differential driver. It is more convenient to use single drive modulator although they require higher drive voltage. There are two basic types of Mach-Zehnder modulators determined by the $LiNbO_3$ crystal axis orientation in the waveguide: *x*-cut and *z*-cut [3]. Single drive *x*-cut MZMs are easier to manufacture and provide a zero chirp. The benefit of *z*-cut MZMs require ~20% lower drive voltage but have an inherent chirp.

In this paper, we compare the ultra-long transmission performance for NRZ at 10 Gb/s achieved with each of these modulator types. Our results show that NRZ generated from the lower drive *z*-cut modulators, that typically have a chirp parameter of 0.7, actually gives superior transmission performance compared to chirp free NRZ generated from *x*-cut modulators.

II. MODULATOR CHIRP

A voltage applied to the modulator electrode induces an index change in each branch of the MZM due to the electro-optic effect in the $LiNbO_3$ crystal. The chirp parameter for a MZM is defined as [4]

$$\upsilon = \frac{\eta_1 + \eta_2}{\eta_1 - \eta_2} \tag{1}$$

where η_1 and η_2 represent the index change per volt for each branch in the MZM. A time-varying drive signal $V(t)$ applied to the MZM then produces a time-varying frequency chirp on the optical signal given by [4]

$$\alpha_{MZ} = \frac{d\phi}{dt} = -\upsilon \cot\left(\frac{\pi}{2}\frac{V(t)}{V_\pi}\right) \tag{2}$$

where V_π is the switch voltage (magnitude of voltage required to switch the modulator between on and off states).

In *x*-cut MZM the hot electrode is placed symmetrically between the waveguides of each branch. This shifts the phase in each arm equally, but in opposite directions, which produces zero chirp. However, in the *z*-cut modulator the electrode is placed directly over one of the waveguides and the resultant asymmetry in the drive produces a non-zero chirp parameter with typical magnitude of 0.7. Depending on the slope the modulator is biased on this can be either +0.7 or -0.7. It has been shown using a negative chirp parameter produces frequency chirp with the direction that offsets a small amount of dispersion in anomalous fiber [5]. However, for long-haul transmission a zero chirp is often preferred and effort has gone into reducing the chirp inherent in *z*-cut MZMs [6].

III. SYSTEM SIMULATION

We use simulation to investigate the difference in performance due to chirp parameters of 0 and ±0.7 produced from these two types of MZMs for transmission of 10 Gb/s NRZ modulated WDM signals with 50 GHz channel spacing over 30 x 100 km spans of non-zero dispersion shifted fiber (NZDSF).

The NRZ waveform driving each MZM is a 128-bit PRBS that is passed though a filter with 8 GHz bandwidth to account for the finite bandwidth of the MZM drive. The NZDSF used had dispersion of 4 ps/nm/km, loss of 0.22 dB/km and nonlinear coefficient of 1.5 /W/km. The launch power per channel at the start of each span is 0 dBm. We measure the transmission performance of one channel in the in the presence of eight neighboring channels to account for multi-channel nonlinear interaction. Detection is done on a receiver with 7.5 GHz bandwidth and Q-penalty is determined from the received eye diagrams as for a system that is ASE limited from accumulated EDFA noise [7].

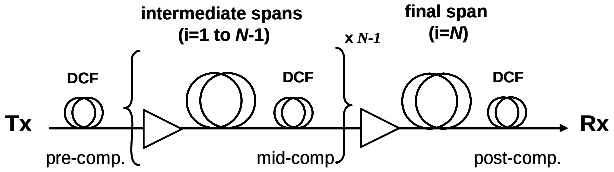


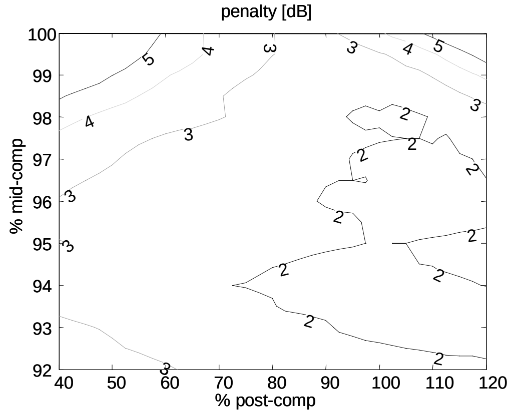
Figure 1. Dispersion compensation scheme used.

Transmission in a nonlinear system is very dependent on the amount and location of dispersion compensation ("dispersion map"). Since each modulator produces different chirp, and chirp interacts with dispersion, it may be expected that the optimum dispersion map could change with modulator chirp parameter. Consequently, to make an accurate and fair comparison, we determine system performance over a wide range of possible dispersion compensations. The dispersion compensation strategy used is shown in Figure 1. Varying amounts of dispersion compensation can be applied before the first span (pre-compensation), at the end of every intermediate span (mid-compensation) and at the end of the final span (post-compensation). Finding the optimum dispersion map involves simulating transmission throughout this three dimensional space. We express the amounts of dispersion compensation used as the percentage of a single 100 km span it compensates.

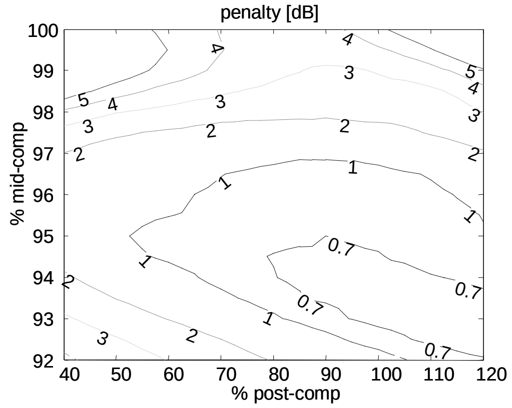
IV. RESULTS

Transmission with a chirp parameter of 0.7 is generally poor so we present results only for chirp parameters of υ=0 and -0.7. Transmission was investigated for pre-compensation ranging from 0 to 100%. For both cases, $\upsilon = 0$ and $\upsilon = -0.7$, the lowest penalty transmission was achieved with pre-compensation at about 40%. The performances for each of these cases are shown in Figure 2. The transmission penalties are plotted as constant contours as functions of mid-compensation and post-compensation. These results show how, at optimum dispersion compensation, the transmission penalty achieved using a modulator with chirp parameter of $\upsilon = -0.7$ is more than 1 dB lower than a modulator with $\upsilon = 0$.

The eye diagrams provide insight into why this is. The received eyes for the point of optimum transmission in each case are plotted in Figure 3. The eye diagram for transmission with $\upsilon = -0.7$ has a superior extinction ratio. Having a low level on the zeros, and not just a good eye opening, is important in systems that are ASE noise dominated [7]. A modulator with $\upsilon = -0.7$ chirps the edges of the NRZ pulses in a direction such that they interact with the chirp induced by self-phase modulation and the fiber's anomalous dispersion so as to shift the pulse edges to cause flattening of isolated zeros and peak up the isolated ones. This produces received signals having eyes with opening and extinction ratio that is superior to that which is achieved when there is no initial chirp on the pulse edges ($\upsilon = 0$).

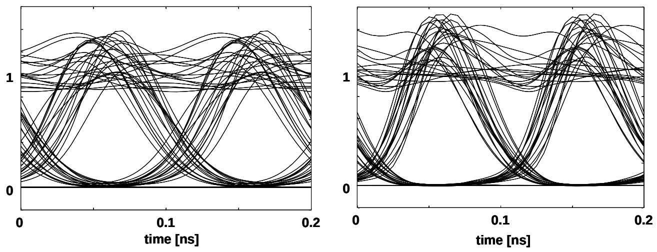


i) chirp parameter $\upsilon = 0$



i) chirp parameter $\upsilon = -0.7$

Figure 2. Transmission penalties with 40% pre-compensation for modulator with chirp parameter υ = *i*) 0 and *ii*) -0.7.



i) $\upsilon = 0$ *ii) $\upsilon = -0.7$*

Figure 3. Received eye diagrams at 3000 km for *i*) modulator with no chirp $\upsilon = 0$, and *ii*) modulator with chirp parameter $\upsilon = -0.7$.

V. CONLUSION

We have investigated the impact of Mach-Zehnder modulator chirp parameter has on ultra-long haul transmission of NRZ. We have found that the chirp produced from *z*-cut devices (which require lower drive) actually enhances transmission and provides lower transmission penalties than that from zero chirp *x*-cut devices.

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