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Increasing Dispersion Tolerance for Quaternary Optical ASK-DPSK by Chirp-Free Modulation

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***Abstract*— We show that the dispersion tolerance of quaternary ASK-DPSK can be significantly increased by chirp-free modulation. We compare our results to DQPSK, an alternative quaternary modulation format and consider both NRZ and RZ impulse shaping.**

I. INTRODUCTION

In recent years multilevel optical modulation formats like differential quadrature phase-shift keying (DQPSK) [1] or quaternary combined amplitude- and differential binary phase-shift keying (ASK-DPSK) [2] have attracted quite some attention due to their greater spectral efficiencies and tolerances towards chromatic dispersion (CD) and polarization-mode dispersion (PMD) than binary modulation formats. In this paper we investigate the influence of different methods of signal generation on the CD and PMD tolerances of ASK-DPSK and compare the results with DQPSK, another quaternary modulation format.

II. ASK-DPSK SIGNAL GENERATION

The ASK-DPSK transmitter (TX) in Fig. 1(a) consists of two external modulators, which are both driven by binary electrical signals. The drive signals $c(t)$ and $d(t)$ are generated from the bit sequence c_k and the differentially encoded bit sequence d_k by time-domain raised cosine (RC) impulse shapers with a roll-off factor of 0.5. The first modulator modulates the amplitude of the optical signal from the continuous-wave laser $E_{\mathrm{CW}}(t)$, resulting in the signal $E_{\mathrm{AM}}(t)$ with two different amplitudes a and b. The second modulator is a dual-drive MZM modulating the phase of the optical input signal, such that the TX output signal $E_{\mathrm{TX}}(t)$ obtains two different phase angles 0 and π, respectively [2]. The output signal of this modulator is in the case of an infinitely large extinction ratio given by [3]

$$E_{\mathrm{TX}}(t) = E_{\mathrm{AM}}(t)\cos\left(\frac{\pi(d_1(t)-d_2(t))}{2V_\pi}\right)\exp\left(\frac{j\pi(d_1(t)+d_2(t))}{2V_\pi}\right), \tag{1}$$

where $d_1(t)$ and $d_2(t)$ are the modulator drive signals and V_π is the drive voltage required for a π-phase-shift. From (1) we observe that there are two principal operation modes of the dual-drive MZM, namely $d_1(t) = d_2(t) = d(t)$ and $d_1(t) = -d_2(t) = d(t)$. In the first case, when both drive-signals are equal, the cos-part in (1) is equal to 1 and the MZM is operated as PM. Therefore, we will call this method ASK-DPSK-PM in the following. It results in a TX output signal $E_{\mathrm{TX}}(t)$ whose complex envelope has a time-varying phase $\phi(t)$. Hence, $d\phi/dt \neq 0$ and the signal contains chirp. In the second case, when $d_1(t)$ and $d_2(t)$ have opposite signs, the exp-part in (1) equals 1 and $E_{\mathrm{TX}}(t)$ is chirp-free, i.e. $d\phi/dt = 0$. This method will be called ASK-DPSK-MZM in the following. Figs. 1(b)-(d) show the resulting constellation diagrams including a plot of the complex envelope of $E_{\mathrm{TX}}(t)$ showing all possible transitions between the signal points. Fig. 1(b) shows the case of NRZ impulse shaping for ASK-DPSK-PM and in Fig. 1(c) the same is shown for RZ impulse shaping. For RZ we can observe that the chirp is reduced since the edges of the symbol durations where the phase transitions mainly occur are cut off. Finally, Fig. 1(d) shows the constellation diagram with transitions for ASK-DPSK-MZM for both NRZ and RZ impulse shaping. As expected from (1) in this case the TX output signal is chirp-free and the plot shows no difference between NRZ and RZ.

III. DISPERSION TOLERANCE

In this section we investigate the CD and PMD tolerance of ASK-DPSK-PM and ASK-DPSK-MZM for both NRZ and RZ impulse shaping and compare the results to DQPSK. The considered bit rate is 40 Gb/s. Using a semi-analytical method similar to [4] we calculate the required OSNR to achieve a bit error probability (BEP) of 10^{-9}. For DQPSK we use a TX with two parallel MZMs as in [1], which shows superior CD tolerance than other possible TX configurations [5]. The receiver (RX) for ASK-DPSK is built up by an amplitude- and a phase-branch [2]. The demodulation in the amplitude-branch is performed by a single photodiode, whereas the phase-branch consists of a delay & add filter (DAF) followed by a balanced detector (BD) with two photodiodes, as it is common practice for DPSK. The DQPSK RX is composed of two DAF each followed by a BD. For both ASK-DPSK and DQPSK the RX use a 2$^{\mathrm{nd}}$ order optical Gaussian band-pass and 3$^{\mathrm{rd}}$ order electrical Bessel low-pass filters. The 3 dB-bandwidths (BW) $\Delta f_{3\mathrm{dB,opt}}$ and $f_{3\mathrm{dB,el}}$ of the RX filters have been optimized in order to achieve lowest possible required OSNR for BEP $= 10^{-9}$ in the back-to-back (b2b) case. The optimal bandwidths (normalized to the symbol rate R_s) are given in Table I. The amplitude ratio (AR) b/a between the two amplitudes of ASK-DPSK is set to $b/a = 3$ throughout this paper. We expect that an optimization of the AR according to the amount of CD can further improve the CD tolerance

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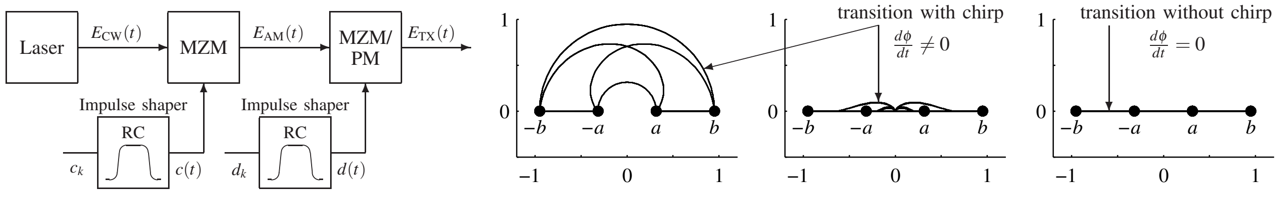


(a) (b) (c) (d)

Fig. 1. (a) ASK-DPSK TX and constellation diagrams with transitions for (b) NRZ-ASK-DPSK-PM, (c) RZ-ASK-DPSK-PM, and (d) ASK-DPSK-MZM.

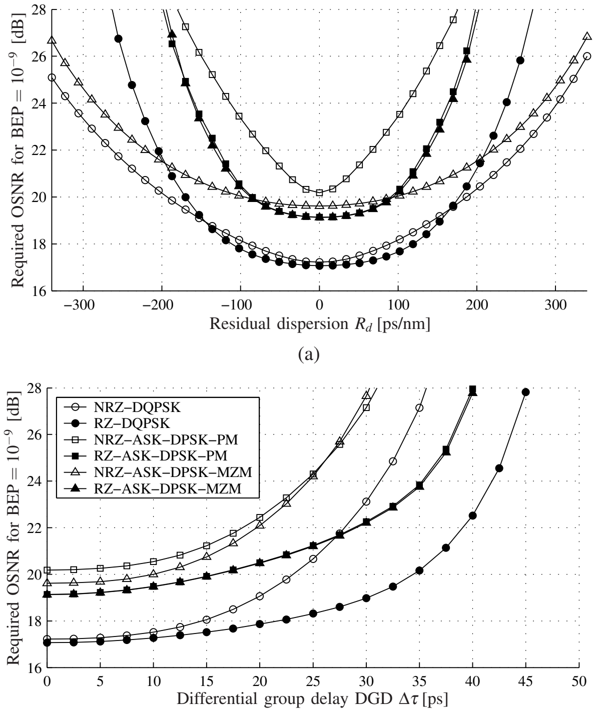
TABLE I

OPTIMAL OPTICAL AND ELECTRICAL RX FILTER BANDWIDTHS AND TOLERABLE CD ΔR_d AND DGD $\Delta\tau$ FOR OSNR PENALTY OF 3 dB

	DQPSK		ASK-DPSK-PM		ASK-DPSK-MZM	
	NRZ	RZ	NRZ	RZ	NRZ	RZ
$\Delta f_{3\,\mathrm{dB,opt}}/R_s$	1.2	2.2	1.5	2.1	1.5	2.1
$f_{3\,\mathrm{dB,el}}/R_s$	1.10	0.70	0.75	0.95	0.70	0.95
ΔR_d [ps/nm]	397	361	190	267	486	276
$\Delta\tau$ [ps]	23.8	34.7	22.2	29.5	21.4	29.6

especially for NRZ impulse shaping as shown in [6].

In Fig. 2 we show CD and PMD tolerances for ASK-DPSK-PM and ASK-DPSK-MZM and also for DQPSK for comparison. In case of PMD we have restricted ourselves to first order effects and the PMD is measured in terms of the differential group delay (DGD) $\Delta\tau$. First of all we can observe that the RX sensitivity of ASK-DPSK is worse than that of DQPSK for both NRZ and RZ independent of the ASK-DPSK TX variant. This can be explained by the distance of the signal points which is larger for DQPSK than for ASK-DPSK. For NRZ we need about 3 dB more OSNR for ASK-DPSK-PM and about 2.4 dB more OSNR for ASK-DPSK-MZM as compared to DQPSK. For RZ the difference is only about 2 dB for both ASK-DPSK variants. As expected and explained earlier we can observe from Fig. 2(a) and (b) that the two ASK-DPSK variants have almost identical performance for RZ. Opposed to that the CD tolerance of NRZ-ASK-DPSK-MZM is significantly larger than that of NRZ-ASK-DPSK-PM as shown in Fig. 2(a). It is even larger than that of NRZ-DQPSK. This advantage of ASK-DPSK-MZM over ASK-DPSK-PM may not be observed for the PMD tolerance in Fig. 2(b). In addition, ASK-DPSK has a smaller PMD tolerance than DQPSK for both NRZ and RZ. As a summary the tolerable residual dispersion ΔR_d and DGD $\Delta\tau$ for 3 dB OSNR penalties with respect to the b2b-values are given in Table I.



(a)

(b)

Fig. 2. Required OSNR for BEP $= 10^{-9}$ vs. (a) residual dispersion R_d and (b) differential group delay $\Delta\tau$.

IV. CONCLUSION

We have investigated the CD and PMD tolerances of two different TX setups for ASK-DPSK. It turned out that the CD tolerance may be significantly increased for NRZ by chirp-free modulation. Compared to DQPSK ASK-DPSK has lower RX sensitivity and smaller PMD tolerance for both NRZ and RZ. However, NRZ-ASK-DPSK-MZM shows an about 20% larger 3 dB-tolerance towards CD than NRZ-DQPSK. Due to its simpler RX structure with only one DAF and three photodiodes – compared to two DAF and four photodiodes for DQPSK – ASK-DPSK-MZM may be an interesting and cost-effective alternative to DQPSK.

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