Comparison of Different DQPSK Transmitters with NRZ and RZ Impulse Shaping

Michael Ohm and Torsten Freckmann
Institute of Telecommunications, University of Stuttgart
70569 Stuttgart, Germany
Email: ohm@inue.uni-stuttgart.de

***Abstract*— We compare three different differential quadrature phase-shift keying (DQPSK) transmitters: One with parallel Mach-Zehnder modulators (MZM), one with a MZM and a phase modulator (PM) in series and a new one with a single PM. Although they all generate optical DQPSK signals, it turns out that their performance differs with respect to bit error probabilities, chromatic dispersion and nonlinearity tolerance for nonrectangular impulse shaping.**

I. INTRODUCTION

Differential quadrature phase-shift keying (DQPSK) is a quaternary phase modulation format [1] which has recently been attracting attention because of its greater spectral efficiency compared to binary formats such as intensity modulation (IM) or differential binary phase-shift keying (DPSK) [2]. As a quaternary format, DQPSK transmits 2 bit/symbol as opposed to only 1 bit/symbol for the binary formats. Different DQPSK transmitters have been proposed [1] [3]. We compare the performance of three different DQPSK transmitters (TX) at bit rate $R_b = 40\,\mathrm{Gbit/s}$ with respect to bit error probabilites (BEP), chromatic dispersion (CD) tolerance and nonlinearity tolerance with computer simulations.

II. SYSTEM SETUPS

The three DQPSK TX are shown in Fig. 1. The first one uses two parallel Mach-Zehnder modulators (MZM) to generate the four phase levels [1]. The second one uses a MZM and a phase modulator (PM) in series [3]. The third one uses only one PM. The electrical drive signal $a_3(t)+b_3(t)$ takes on four different values as the amplitude of $b_3(t)$ is twice the amplitude of $a_3(t)$. The PM is biased such that it produces the optical output signal $E_3(t)$ with phase levels $\varphi_{k,3} \in \left\{0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\right\}$. The input sequences $a_{k,i}$ and $b_{k,i}$, $(i = 1,2,3)$ are differentially encoded. The time-domain raised cosine (RC) impulse shapers have impulse responses

$$h(t) = \begin{cases} 1 & ,\ |t| \le \frac{T}{2}(1-\alpha) \\ \cos^2\left[\frac{\pi}{4}\frac{2|t|-T(1-\alpha)}{\alpha T}\right] & ,\ \frac{T}{2}(1-\alpha) < |t| < \frac{T}{2}(1+\alpha) \\ 0 & ,\ |t| \ge \frac{T}{2}(1+\alpha) \end{cases} . \tag{1}$$

$T = 1/R_s$ is the symbol duration, α is the roll-off factor. $R_s = R_b/2$ is the symbol rate. The three signals $E_i(t)$, $(i = 1,2,3)$ differ in their phase transitions. Only for $\alpha = 0$ (rectangular impulse shaping with hard switching between phase levels), the DQPSK signals become the same, apart from the absolute phase values, which are not important in a differential format. Return-to-zero (RZ) impulse shaping is done by modulating the amplitudes of the respective nonreturn-to-zero (NRZ) signals in a subsequent MZM with a periodic sequence of electrical Gaussian impulses. Their full widths at half maximum correspond to the RZ duty cycle. The receivers are the same for all cases [1]. We use a 2nd order optical Gauss bandpass and 3rd order electrical Bessel low-pass receiver filters.

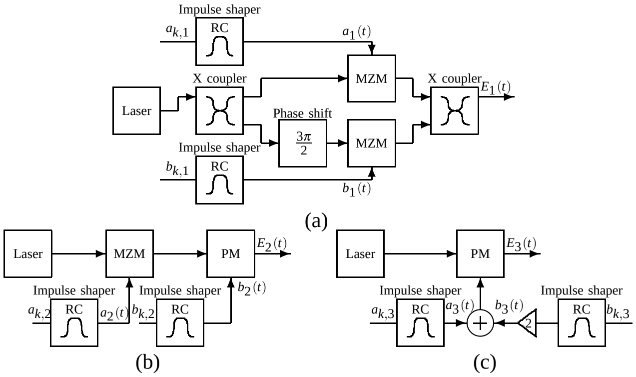

Fig. 1. DQPSK transmitters with (a) parallel modulators, (b) serial modulators, and (c) one single modulator.

III. PERFORMANCE COMPARISON

In our studies bit error probabilities (BEP) are computed using a semi-analytical method [4]. We set the roll-off factors of the RC impulse shapers to $\alpha = 0.5$ as an example for nonrectangular impulse shaping. Other nonrectangular impulse shapers lead to qualitatively similar results. DQPSK and DPSK with rectangular impulse shaping ($\alpha = 0$) are included as references. We optimized optical and electrical receiver filter bandwidths for all three DQPSK transmitters and the references in order to achieve minimum possible back-to-back BEP. These filter bandwiths are given in Table I and are used for all further investigations. Fig. 2 shows NRZ eye diagrams at the receiver for all three DQPSK transmitters. Obviously, the DQPSK signals from the serial TX and the single TX are more susceptible to intersymbol interference (ISI) caused by the receiver filters than the signal from the parallel TX. This leads to larger optimum bandwidths.

BEP vs. optical signal-to-noise ratio (OSNR) is shown in Fig. 3(a) and (b). For NRZ, the parallel TX requires about 1.2 dB OSNR less than the serial TX and about 2 dB less than

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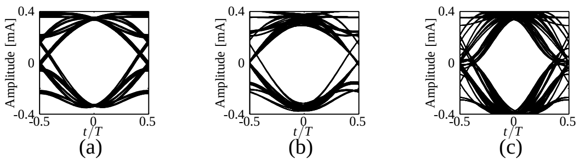
TABLE I

OPTIMIZED OPTICAL AND ELECTRIAL RECEIVER FILTER BANDWIDTHS

DQPSK Tx	$\Delta f_{3\,\mathrm{dB,opt}}/R_s$			$f_{3\,\mathrm{dB,el}}/R_s$		
	NRZ	RZ 0.5	RZ 0.3	NRZ	RZ 0.5	RZ 0.3
Parallel	1.2	2.05	3.1	1.05	0.6	0.9
Serial	1.95	2.15	3.1	0.65	0.6	0.9
Single	2.05	2.15	3.1	1.05	0.85	0.9
DQPSK $\alpha = 0$	1.2	—	—	1.05	—	—
DPSK $\alpha = 0$	1.15	—	—	1.35	—	—



(a) (b) (c)

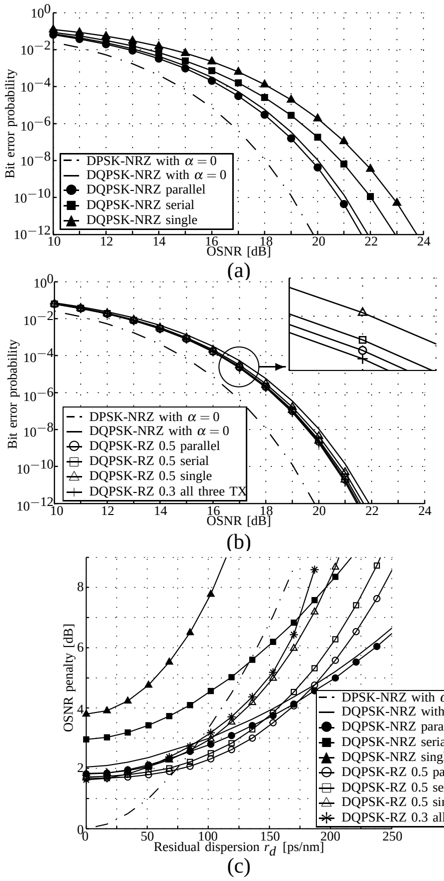
Fig. 2. Eye diagrams at receiver for (a) parallel, (b) serial and (c) single modulator transmitter with NRZ impulse shaping

the single TX at $\mathrm{BEP} = 10^{-9}$. For RZ with duty cycle 0.5, BEP of the parallel TX is only slightly lower than for serial and single TX. With duty cycle 0.3 there is no difference between the three TX within the computational accuracy. RZ BEP are approx. the same as for the NRZ parallel TX. The reason for all three TX having approx. the same performace for RZ is, that the RZ impulses cut out the middles of the symbol durations, where the transitions between the phase levels have already occured. Fig. 3(c) shows OSNR penalties at $\mathrm{BEP} = 10^{-9}$ vs. residual dispersion r_d for linear fiber transmission. Penalties are referenced to DPSK back-to-back transmission. For NRZ, parallel TX shows greater tolerance than serial TX and single TX. For RZ 0.5, all three curves start at approx. the same point for $r_d = 0$. However, parallel TX shows greater CD tolerance than serial and single TX, although the differences are not that significant as for NRZ. For RZ 0.3, there are no differences between the three TX. In all RZ cases, CD tolerance is greater than for NRZ with single TX. NRZ single TX is much more susceptible to ISI from dispersion than the other TX.

For single-channel transmission over 80 km standard single-mode fiber (SSMF) and optimized pre- and post-dispersion compensation, Fig. 4 shows eye-opening penalties (EOP) vs. SSMF input power. For NRZ, parallel TX shows greater nonlinearity tolerance and thus allows greater SSMF input powers than serial and single TX for remaining below a specific EOP. For RZ, EOP for all three TX is almost identical up to 18 dB SSMF input power. Then again, EOP is less for parallel TX than for serial and single TX.

IV. CONCLUSION

The comparison of different DQPSK TX shows, that the most complex TX with parallel MZM leads to lower bit error probabilities and greater CD and nonlinearity tolerances than simpler TX with serial MZM and PM or a single PM if NRZ impulse shaping is used. For RZ impulse shaping, however, the performances of all three TX are similar, so that the simpler TX are preferable because of reduced hardware efforts.



(a)

(b)

(c)

Fig. 3. Bit error probabilities vs. OSNR for (a) NRZ and (b) RZ impulse shaping and (c) OSNR penalties at $\mathrm{BEP} = 10^{-9}$ vs. residual disperison r_d

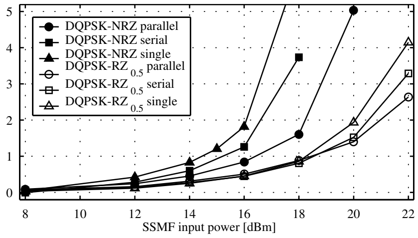


Fig. 4. EOP vs. SSMF input power for NRZ and RZ impulse shaping

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