Optical 8-DPSK and Receiver with Direct Detection and Multilevel Electrical Signals

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***Abstract*— This paper presents a differential 8-level phase-shift keying (8-DPSK) modulation format with a simple new receiver for transmission of 3 bit/symbol. The receiver with direct detection is based on a differential quadrature phase-shift keying (DQPSK) receiver with binary decision devices and a combinational network for estimating the transmitted bit sequences from the detected multilevel electrical signals. The 8-DPSK transmitter is based on a differential quadrature phase-shift keying (DQPSK) transmitter with an additional phase modulator. Spectral properties of 8-DPSK and chromatic dispersion tolerance are investigated.**

I. Introduction

The most wide spread modulation format in optical fiber transmission systems is binary intensity modulation (IM). Differential phase-shift-keying (DPSK) has also been suggested for dense wavelength-division multiplexing (DWDM) systems because of a higher robustness in the case of fiber nonlinearities [1]. Both formats transmit only 1 bit/symbol, leading to rather poor spectral efficiencies. New quaternary optical modulation formats such as combined amplitude and phase-shift keying (ASK-DPSK) [2] and differential quaternary phase-shift-keying (DQPSK) [3] allow the transmission of 2 bit/symbol. In [4] a differential 8-level phase-shift keying (8-DPSK) modulation format for transmitting 3 bit/symbol was presented. However, the receiver was rather complex using three delay & add filters (DAF) and nonlinear analog signal processing for obtaining binary electrical output signals. The new 8-DPSK receiver presented in this paper is based on a DQPSK receiver. Binary decision devices and a combinational network are used to process the multilevel electrical outputs of the DQPSK receiver part.We review the 8-DPSK transmitter and present the new 8-DPSK receiver in section II. We investigate spectral properties and chromatic dispersion tolerance of 8-DPSK and compare it to DQPSK and DPSK in section III.

II. 8-DPSK Transmitter and Receiver

The 8-DPSK transmitter is given in Fig. 1. The inner part with parallel Mach-Zehnder modulators (MZM) corresponds to a DQPSK transmitter [3]. The optical signal $E_c(t)$ thus has four possible phase levels. In the following phase modulator (PM) the binary electrical signal $c(t)$ induces an additional phase shift of $\pi/4$ for bit 1 or leaves the optical signal unaltered for bit 0, producing the optical 8-level phase-shift keying signal $E(t)$ with possible phase angles $\varphi_n = \left\{n\frac{\pi}{4}; n = 0, \ldots, 7\right\}$ The transmitter also includes a differential encoder.

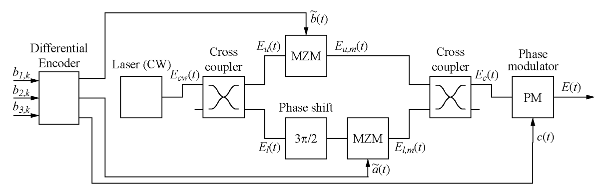

Fig. 1. (a) 8-DPSK constellation diagram and (b) 8-DPSK transmitter

The new 8-DPSK receiver is shown in Fig. 2(a). The gray shaded part is a standard DQPSK receiver with 2 DAF and balanced detectors. However, for 8-DPSK the two electrical output signals i_1 and i_2 are multilevel. A typical eye diagram for i_1 or i_2, is shown in Fig. 2(b). The electrical signals have five levels. The upper two and lower two levels represent the same logical levels. Thus, there is an upper and a lower eye opening as marked in the figure. The thresholds of the four binary decision devices lie in the middles of these eye openings. From the binary decision device outputs e_{11} to e_{22} the transmitted bit sequences are determined by a combinational network with the functions:

$$\begin{aligned} \hat{b}_1 &= \bar{e}_{12}\bar{e}_{21} + e_{11}e_{22}, \\ \hat{b}_2 &= e_{12}e_{21} + \bar{e}_{11}\bar{e}_{22}, \\ \hat{b}_3 &= e_{21} + \bar{e}_{11}e_{22}. \end{aligned} \tag{1}$$

All electronics at the transmitter and at the receiver operate at the symbol rate R_s, which is one third of the bit rate R_b.

III. Performance of 8-DPSK

Fig. 3 compares the 8-DPSK spectrum to DQPSK and DPSK for $R_b = 40\,\mathrm{Gbit/s}$. As the symbol rate R_s of 8-DPSK is by factor 3 lower than for DPSK and by factor 1.5 lower than for DQPSK, the width of the main lobe in the 8-DPSK spectrum is by factor 3 lower than for DPSK and by factor 1.5 lower than for DQPSK. This allows for a potentially closer channel spacing in DWDM.

Dispersion tolerance of 8-DPSK is evaluated for transmission over 80 km standard single-mode fiber (SSMF) or nonzero dispersion-shifted fiber (NZDSF), respectively, and pre- and postcompensation with dispersion-compensating fibers (DCF). Pre- and postcompensation ratios are optimized. Fig. 4 shows eye-opening penalties (EOP) vs. residual dispersion for 8-DPSK compared to DPSK and DQPSK for 15 dBm SSMF or

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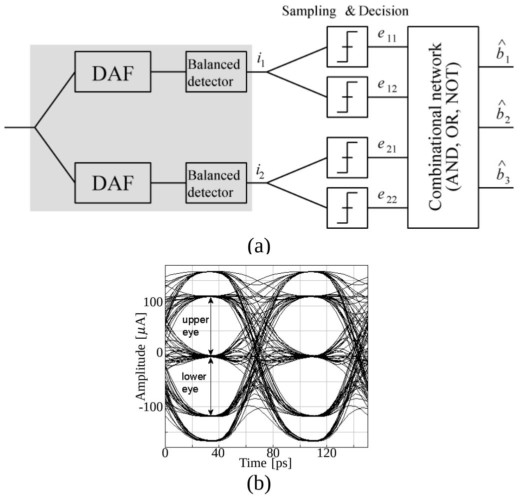

Fig. 2. (a) 8-DPSK receiver and (b) multilevel eye diagram for i_1 or i_2

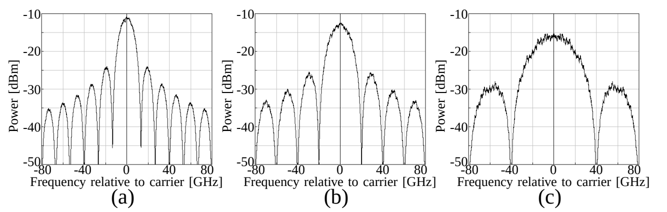

Fig. 3. Spectra of (a) 8-DPSK, (b) DQPSK, and (c) DPSK ($R_b = 40\,\mathrm{Gbit/s}$)

NZDSF input power. DCF input power is -2 dBm. Nonreturn-to-zero (NRZ) and return-to-zero (RZ) impulse shaping with duty cycle 0.5 are considered. For NRZ, EOP of 8-DPSK is greater than for DPSK and DQPSK with both fiber types. For RZ, however, 8-DPSK has the lowest EOP for both SSMF and NZDSF. RZ-8-DPSK EOP curves are much wider than RZ-DQPSK and RZ-DPSK EOP curves, stating a greater dispersion tolerance. Further, NZDSF leads to a 1 dB lower EOP than SSMF. Obviously, 8-DPSK is more susceptible to residual dispersion and fiber nonlinearties than DQPSK and DPSK. However, this can be overcome by RZ instead of NRZ impulse shaping. Negative EOP for RZ-8-DPSK in Fig. 4(b) result from impulse compression on the fiber as shown in Fig. 5 for 15 dBm RZ-8-DPSK single span NZDSF transmission. The impulses of the received signal in Fig. 5(b) have reduced temporal width but increased amplitude compared to the reference in Fig. 5(a), although the mean powers are equal.

IV. Conclusion

We presented a differential 8-level phase-shift keying modulation format for transmitting 3 bit/symbol and a simplified receiver similar to the DQPSK receiver. The lower symbol rate at a given bit rate leads to a narrower spectrum for 8-DPSK than for DQPSK and DPSK and also to transmitter and receiver electronics with reduced bandwidth requirements. We further studied single channel transmission over one span of SSMF or NZDSF, respectively. Although 8-DPSK with NRZ impulse shaping is very susceptible to intersymbol interference caused by dispersion and fiber nonlinearities, 8-DPSK with RZ

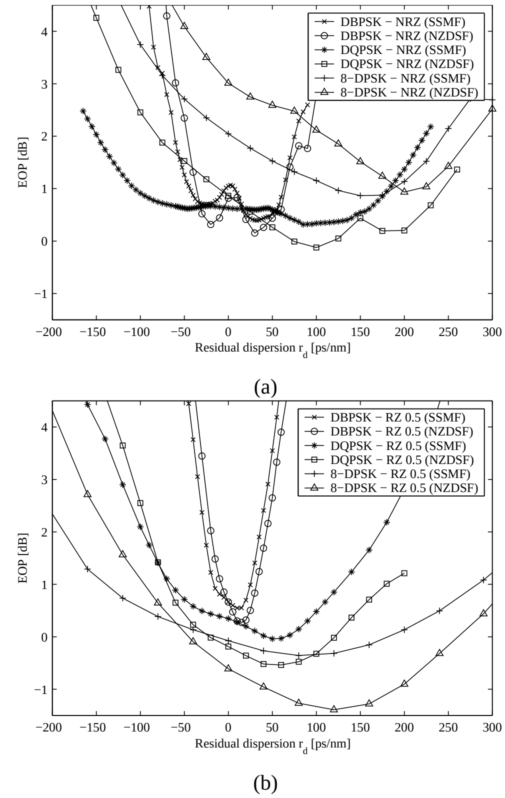

Fig. 4. EOP vs. residual dispersion for one pre- and post compensated fiber span with 15 dBm fiber input power and (a) NRZ and (b) RZ impulse shaping.

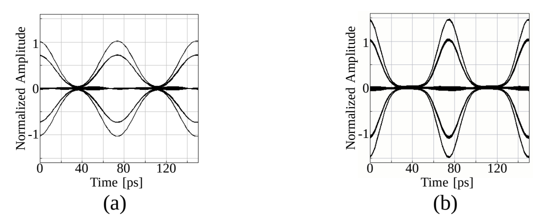

Fig. 5. RZ-8-DPSK eye diagrams: (a) reference and (b) after single span transmission with 15 dBm NZDSF input power

impulse shaping exhibits a greater dispersion and nonlinearity tolerance than DQPSK and DPSK.

Acknowledgment

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