Alternate-phase return-to-zero transmitter based on integrated dual-parallel Mach-Zehnder modulator

J. Gao and Y. Su

A simple 20 Gbit/s alternate-phase return-to-zero (APRZ) transmitter is demonstrated using a 10 Gbit/s integrated dual-parallel Mach-Zehnder modulator (DPMZM). Two RZ streams are time-multiplexed with stable and adjustable phase relation. Simulation results show that the APRZ generated by this transmitter is robust to nonlinear transmission impairments.

Introduction: In high-speed systems, the major nonlinear transmission penalties generally come from intrachannel interactions such as intra-channel cross-phase modulation (IXPM) and intrachannel four wave mixing (IFWM) [1–3]. IXPM can be effectively suppressed by optimum dispersion management [4], but IFWM remains a limiting factor in long-haul high-bit-rate systems where short pulses may significantly overlap through transmission. It has been reported that $\pi/2$ alternate-phase return-to-zero (APRZ) can effectively reduce the IFWM effect owing to the phase shift between its neighbouring bits. To date the most cost-effective scheme to realise APRZ transmitters is reported in [5–8] where a dual-drive Mach-Zehnder modulator (DDMZM) is used to produce phase alternate pulses, followed by a second intensity modulator for data modulation, resulting in an APRZ signal.

In this Letter we propose a simple 20 Gbit/s APRZ transmitter by using one 10 Gbit/s dual-parallel Mach-Zehnder modulator (DPMZM). With RZ coding, two 10 Gbit/s data streams are combined in the integrated modulator with stable and adjustable phase relation. This method eliminates an additional alternate-phase pulse generator, thus effectively reducing the system complexity. We experimentally show the transmitter's feasibility, and perform simulations to prove its enhanced nonlinear performance.

Operation principle: The schematic diagram of our proposed APRZ transmitter is shown in Fig. 1*a*. A continuous-wave light is modulated by an integrated DPMZM, which comprises a pair of sub-MZMs in each arm of the main MZM structure. The two sub-MZMs have the same structure and performance and the main MZM combines the output signals from the two sub-MZMs. In this scheme, the two sub-MZMs, MZM A and MZM B, are modulated independently. Optical RZ signal is obtained if a sub-MZM is biased at the transmission peak and driven by nonreturn-to-zero (NRZ) electrical data with an amplitude of $2V_\pi$ [9], as shown in Fig. 1*b*. The duty-cycle of the generated optical RZ signal is dependent on the transition time between the '0' and '1' of the input electrical NRZ signal. The obtained optical RZ signal is a differentially coded version of the input NRZ signal, and an electrical differential coder is needed in the drive circuitry. By setting the time delay to a half-bit between the two drive signals, time multiplexing can be accomplished for the two generated RZ tributaries of RZ 1 and RZ 2, as illustrated in Fig. 1*c*. The phase difference $\Delta\phi = \phi_1$ (phase of RZ 1) $-$ ϕ_2 (phase of RZ 2) between adjacent bits of the multiplexed signal can be continuously adjusted through the voltage of bias C, and a $\pi/2$-APRZ can be achieved with a proper bias voltage.

Experiment and results: An experimental setup was implemented based on Fig. 1. The transmitter consists of a distributed feedback (DFB) laser and a $LiNbO_3$ DPMZM (COVEGA, Mach-10060). The DPMZM has a 3 dB bandwidth ~10 GHz, and a V_π of ~7.5 V at 10 GHz. Two 10 Gbit/s pseudorandom binary sequence (PRBS) tributaries, data and $\overline{\text{data}}$ with a word length of $2^{11} - 1$, are provided by a pulse pattern generator (PPG). An electrical delay line is used to achieve 40.5-bit delay between the two data streams. No encoder circuitry is used for the PRBS sequence. The two data tributaries are amplified by electrical drivers with a peak-to-peak value of 11.5 V and rise/fall times of ~1/3 bit period. The eye-diagrams of two optical RZ tributaries, and the generated APRZ, are shown in Figs. 2*a*, *b* and *c*, respectively. The spectrum of the APRZ signal is shown in Fig. 2*d*. The fluctuation on the APRZ can be attributed to the imperfect electrical NRZ driving signal, the amplitude of which is lower than the desired value of $2V_\pi$.

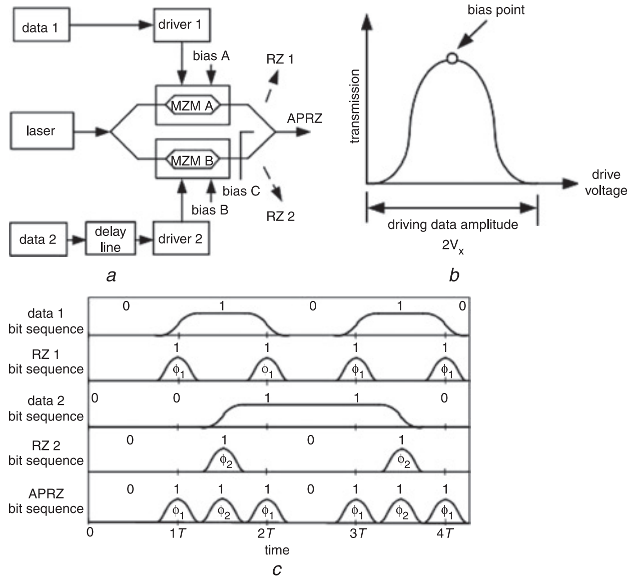

Fig. 1 *Schematic diagram of proposed APRZ transmitter*

a Implementation
b Bias condition
c Principle illustration

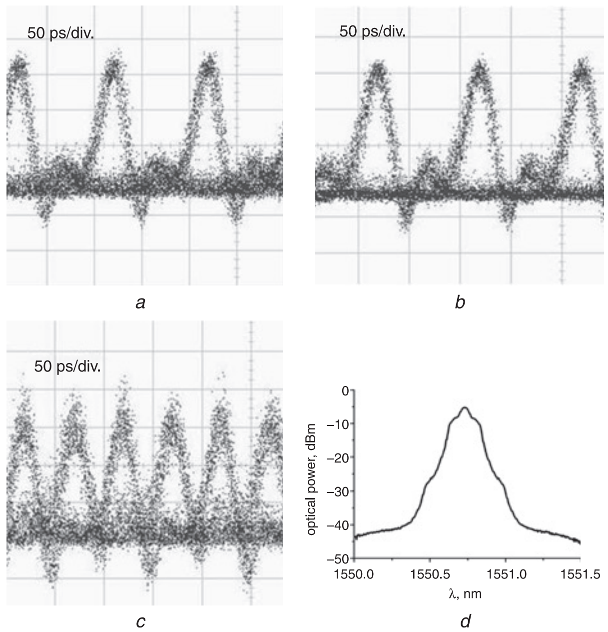

Fig. 2 *Signal eye-diagrams and spectrum*

a RZ 1 eye-diagram
b RZ 2 eye-diagram
c APRZ eye-diagram
d APRZ spectrum (0.07 nm resolution)

Simulations: To study the transmission performance of this proposed transmitter, a simulation was performed with VPI TransmissionMaker. Two calculated 20 Gbit/s data streams with rise/fall times of 1/3 bit duration are used to generate a 33% duty-cycle 40 Gbit/s APRZ signal with a data pattern of PRBS $2^{11} - 1$. The back-to-back eye-diagram is shown in Fig. 3*a*. The transmission line has ten spans, each consisting of an erbium-doped fibre amplifier (EDFA), an 80 km standard single-mode fibre (SSMF), a second EDFA and a 16 km dispersion compensating fibre (DCF). The SSMF has a dispersion $D = 16$ ps/nm/km, a dispersion slope $S = 0.06$ ps/nm^2/km, a nonlinear index $\gamma = 1.31$ W^{-1}/km, and a loss $\alpha = 0.2$ dB/km. The DCF parameters are: $D = -80$ ps/nm/km, $S = -0.18$ ps/nm^2/km, $\gamma = 2.64$ W^{-1}/km and $\alpha = 0.6$ dB/km, respectively. Dispersion pre-compensation of -180 ps/nm is placed before transmission. The launch powers into the SSMF and DCF are set to be 6 and 2 dBm, respectively. After transmission, the received eye-diagrams of the signals with alternate-phases of 0, $\pi/2$, and π are shown in Figs. 3*b*, *c* and *d*, respectively. It can be seen that, with $\pi/2$ phase alternation, ghost pulses in bits of '0' can be greatly reduced, and for certain applications, where tight filtering is experienced, carrier suppressed RZ can be employed by controlling the phase difference between adjacent bits to be π.

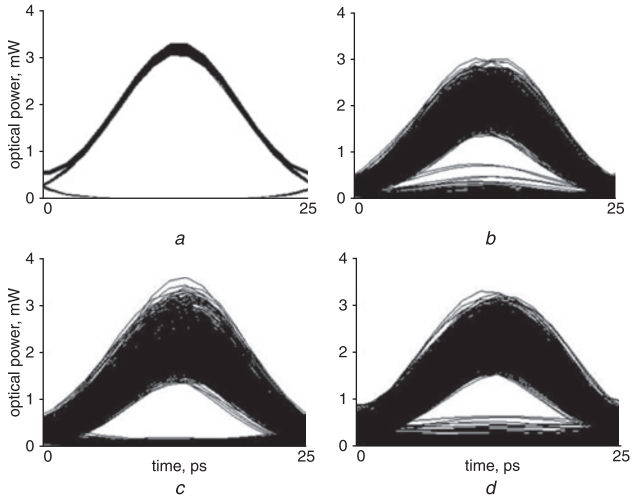

Fig. 3 *Received eye-diagrams*

a Back-to-back, and after transmission with alternate-phase of *b* 0, *c* $\pi/2$ and *d* π, respectively

Conclusion: We have proposed and experimentally demonstrated an APRZ transmitter based on single DPMZM that does not require a pulse carver. The transmission performance of the generated signal is investigated through simulations.

13 May 2008
Electronics Letters online no: 20081332
doi: 10.1049/el:20081332

J. Gao and Y. Su (*State Key Lab of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, People's Republic of China*)

E-mail: yikaisu@sjtu.edu.cn

References

1 Mamyshev, P.V., and Mamysheva, N.A.: 'Pulse-overlapped dispersion-managed data transmission and intrachannel four-wave mixing', *Opt. Lett.*, 1999, **24**, pp. 1454–1456
2 Mecozzi, A., Clausen, C.B., and Shtaif, M.: 'Analysis of intrachannel nonlinear effects in highly dispersed optical pulse transmission', *IEEE Photonics Technol. Lett.*, 2000, **12**, pp. 392–394
3 Essiambre, R.-J., Mikkelsen, B., and Raybon, G.: 'Intra-channel cross-phase modulation and four-wave mixing in high-speed TDM systems', *Electron. Lett.*, 1999, **35**, pp. 1576–1578
4 Killey, R.I., Thiele, H.J., Mikhailov, V., and Bayvel, P.: 'Reduction of intrachannel nonlinear distortion in 40-Gbit/s-based WDM transmission over standard fiber', *IEEE Photonics Technol. Lett.*, 2000, **12**, pp. 1624–1626
5 Gill, D.M., Liu, X., Wei, X., Banerjee, S., and Su, Y.: 'pi/2 alternate phase on-off keyed 40-Gbit/s transmission on standard single-mode fiber', *IEEE, Photonics Technol. Lett.*, 2003, **15**, pp. 1776–1778
6 Gill, D.M., Gnauck, A.H., Liu, X., Wei, X., and Su, Y.: 'p/2 alternate phase on-off keyed 42.7 Gbit/s long-haul transmission over 1980 km of standard single-mode fiber', *IEEE Photonics Technol. Lett.*, 2004, **16**, pp. 906–908
7 Forzati, M., Iyer, S., Berntson, A., and Mårtensson, J.: 'Experimental study of single-MZM APRZ transmitters for fibre-optic communications', *Electron. Lett.*, 2008, **44**, pp. 148–149
8 Forzati, M., Berntson, A., and Mårtensson, J.: 'IFWM suppression using APRZ With Optimized', *IEEE Photonics Technol. Lett.*, 2004, **16**, pp. 2368–2370
9 Veselka, J.J., Korotky, S.K., Mamyshev, P.V., Gnauck, A.H., Raybon, G., and Froberg, N.M.: 'A soliton transmitter using a CW Laser and an NRZ driven Mach-Zehnder modulator', *IEEE Photonics Technol. Lett.*, 1996, **8**, pp. 950–952