Narrowband 20 Gbit/s Quaternary Intensity Modulation Generated by Duobinary 10 Gbit/s Modulation in 2 Quadratures

S. K. Ibrahim, S. Bhandare, and R. Noé
Univ. Paderborn, EIM-E, Warburger Str. 100, D-33098 Paderborn, Germany
ibrahim/suhas@ont.upb.de; noe@upb.de

Abstract *Two duobinary 10Gbit/s data streams and a QPSK modulator allow to generate 20Gbit/s quaternary intensity modulation having ~6GHz bandwidth. Sensitivity, CD, and PMD tolerance of this novel scheme are –21.5dBm, –20...+140ps/nm and 20ps, respectively.*

Introduction

Upgrading of existing DWDM systems to higher bit rates requires a high spectral efficiency [1, 2]. Duobinary modulation is important in this context because it is not only spectrally efficient (~0.8 bit/s/Hz) but also simple to implement. So far, (D)QPSK and/or polarization multiplex are needed to increase spectral efficiency beyond that of duobinary modulation, but considerable technical effort at the receive end is needed for their implementation (interferometer and its stabilization, polarization control), which reverberates in the cost budget. On the other hand, quaternary intensity modulation (4-IM) [3] is easy to detect but its spectral efficiency does not surpass that of duobinary modulation. However, the general class of quadrature amplitude modulation (QAM) [4] can also be used to increase spectral efficiency. Here, we report for the first time on 2x10Gbit/s optical 9-QAM signal generation, which is detected as a 4-IM signal and generated using two duobinary signals.

Operation principle

The optical QPSK modulator shown in Fig. 1 contains two Mach-Zehnder modulators (MZMs), placed in the two arms of another interferometer that forms a Mach-Zehnder superstructure. The superstructure has quadrature control electrodes in both arms for an active phase control. We are using a fiber-pigtailed Bookham GaAs/AlGaAs DQPSK modulator [5].

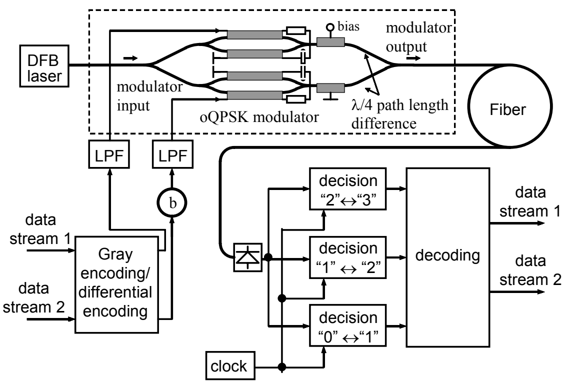

Fig. 1: Schematic of the optical 9-QAM modulation using duobinary low pass filtering (LPF) at the transmitter and the 4-IM receiver

The two MZMs are driven by duobinary signals. Open stubs with single-path delays of 50 ps and 25 Ohm characteristic impedance are attached to each 50 Ohm modulator drive cable. These stub filters (LPF) respond to an impulse by two impulses of equal height and 100 ps mutual delay, thereby forming idealized duobinary filters. Bessel filters could also be used. The modulation constellation diagram is shown in Fig. 2. The two optical field quadratures are modulated with different amplitudes 1 and *a*. Due to the duobinary modulation the generated fields are 0, ±*j*, ±*a*, and ±*a*±*j*. For $a=\sqrt{2}$ the corresponding intensities are 0, 1, 2, 3. This is achieved by driving one of the MZ modulators by a full $2V_\pi$ signal swing and the other only by a V_π signal swing (electrical attenuator setting *b* = 1/2 in Fig. 1).

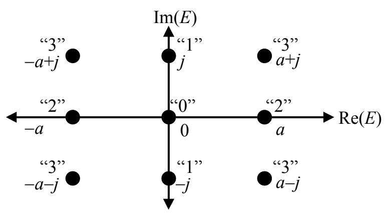

Fig. 2: Electrical field modulation constellation ($a=\sqrt{2}$). A quaternary intensity modulation results.

The generated 9-QAM constellation represents a 4-IM but the spectrum is just as broad as for duobinary modulation although capacity is doubled. Obviously the signal can be detected by a standard optical receiver with 3 decision circuits. Gray and differential encoding is needed at the transmitter side, and suitable decoding at the receiver side [3].

Transmission setup

Fig. 3 shows an experimental 2x10Gbit/s transmission setup for this scheme. The DFB transmitter laser has a frequency of 193.5THz. Two 2^7-1 PRBS signals are transmitted. A mutual delay of 31-bit duration emulates decorrelated patterns. Encoding function was not implemented. The data streams are amplified to ~10 Vpp, then attenuated to ~8 Vpp and ~4 Vpp, respectively, passed through the duobinary filters and then fed to the modulator inputs.
The receiver employs an optical preamplifier followed by a DWDM AWG DEMUX of Gaussian type with 100GHz spacing of its 40 channels, which acts as a narrow band pass optical filter. The detected

photocurrent of an optical front end (PIN-TIA) is stabilized by a feedback loop that controls the pump current of the last EDFA. An electrical amplifier amplifies the received signal before it feeds an oscilloscope or an error detector. The error detector is programmed, using different thresholds, to receive all the three patterns, corresponding to the top, middle, and bottom eye diagram. Proper BER averaging is performed to represent the mean BER of the received patterns. Fig. 4 shows the 4-level optical eye diagram of the quaternary intensity modulated signal, back-to-back, at 10 Gbaud (20Gbit/s) and the driving electrical duobinary signal. The corresponding sensitivity is –21.5 dBm for a BER of 10^{-9}. The top eye, which represents the intensity levels "2" and "3", dominates the whole BER.

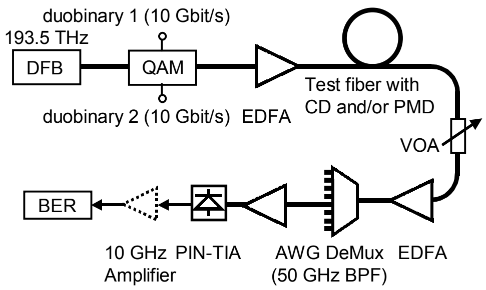

Fig. 3: 20 Gbit/s 9-QAM (4-IM) transmission setup

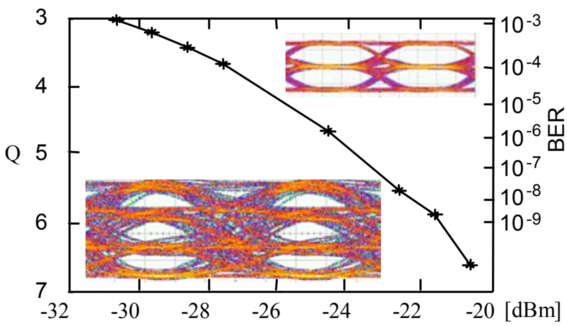

Fig. 4: Back-to-back receiver sensitivity and corresponding eye diagram for 2x10Gbit/s QAM signal (inset: electrical duobinary eye diagram (top)).

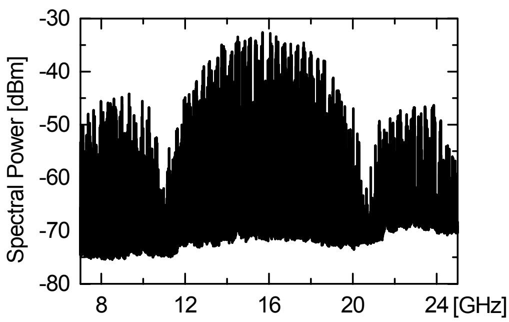

Fig. 5: Heterodyned electrical spectrum of the 2x10Gbit/s 9-QAM = 4-IM signal (RB: 100KHz)

Fig. 5 shows the heterodyned electrical spectrum of the 10 Gbaud optical 9-QAM signal. There is no carrier, and the 3-dB bandwidth is ~6 GHz. The CD tolerance was measured. Fig. 6 shows the ONSR after the optical preamplifier needed for a BER of 10^{-9} versus CD. An optical attenuator was used to vary the ONSR. The 1-dB tolerance window stretches from –20 to +140ps/nm. Fig. 6 also shows the 1st-order PMD tolerance under worst-case polarization alignment. PMD of 20 ps (35.5 ps) causes a penalty of 1 dB (4.5 dB), and this is better than for binary 20Gbit/s signals. Transmission through an available dispersion-compensated 80-km SSMF link with Raman amplification was error-free.

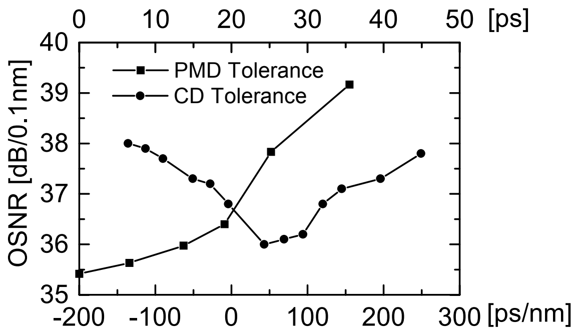

Fig. 6 OSNR needed for a BER of 10^{-9} versus CD in ps/nm and PMD in ps.

Discussion

The two quadratures with duobinary modulation need not necessarily belong to the same polarization. Fig. 7 shows as an alternative duobinary modulation in two polarizations. In principle, both generation schemes could be combined to generate 16-ary intensity modulation by duobinary modulation in 4 quadratures with relative field amplitudes of $1, \sqrt{2}, 2, 2\sqrt{2}$.

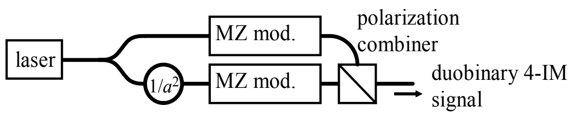

Fig. 7: Alternative generation of duobinary 9-QAM by using quadratures belonging to different polarizations.

Conclusions

This duobinary 9-QAM scheme with a simple receiver is believed to represent intensity modulation with the narrowest reported spectrum reported to date. The measured 20ps PMD tolerance is larger than for binary modulation.

Acknowledgement

We would like to thank Dr. R. Griffin (Bookham) for the DQPSK modulator and Mrs. B. Milivojevic for designing the duobinary LPFs.

References

1. S. Bigo et al., ECOC, Th2.5.1(2004), 872-875
2. J. M. Kahn et al, *IEEE JSTQE* 10 (2004), 259-272
3. S. Walklin et al, IEEE JLT 17(1999), 2235- 2248
4. K. P. Ho et al *IEEE JLT*, 23(2005), 764-770
5. R. A. Griffin et al OFC, WX6(2002), 367-368