# A Multi-Format Transmitter Using a Single Dual-Parallel Mach-Zehnder Modulator

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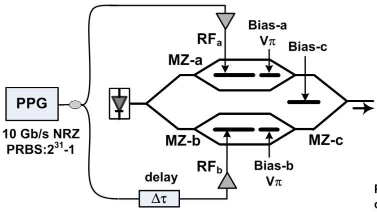
**Abstract** *We propose a novel scheme for generating duobinary, RZ-AMI and Manchester formats using a dual-parallel Mach-Zehnder modulator at 10 Gb/s. The performance of the generated signals is investigated for back-to-back operation and after transmission.*

## Introduction

Novel optical modulation formats are attractive for their various advantageous features. For example, the duobinary format provides a narrow spectral bandwidth and large chromatic dispersion tolerance [1-2], while the return to zero-alternate mark inversion (RZ-AMI) signal is more robust to fibre nonlinearity induced transmission impairments [3]. Furthermore, Manchester code shows zero DC contents and enables simple clock recovery, verifying itself as a promising modulation format for burst mode transmission [4].

In this paper, we demonstrate that the three modulation formats can be generated using a single dual-parallel Mach-Zehnder modulator. The signals are encoded in the optical domain, thus eliminating any complex high speed electronic processing stage. Our method enables multi-format generation using only one modulator unit by simply switching driving and biasing conditions, which offers great flexibility for various format-related application scenarios.

## Duobinary and RZ-AMI signal generation



(a)

| a(t) | 1 | 1 | -1 | -1 |
|---|---|---|---|---|
| a(t-Δτ) | 1 | -1 | 1 | -1 |
| PS=0 Eq.2, Δτ=T Duobinary | -1 | 0 | 0 | 1 |
| PS=π Eq.3, Δτ<T RZ-AMI | 0 | -1 | 1 | 0 |

PS: phase shift between the two optical paths, controlled by Bias-c

(b)

Fig.1 (a) experimental setup (b) principle of duobinary and RZ-AMI signal generation

Fig.1 (a) shows the configuration of the proposed duobinary and RZ-AMI transmitter. The dual-parallel modulator consists of a pair of X-cut Mach-Zehnder modulator (MZ-a, MZ-b) embedded in the two arms of a primary MZ structure (MZ-c). It was designed for differential quadrature phase-shift keying (DQPSK) [5] and frequency shift keying (FSK) [6] signal generations. Here we demonstrate that this modulator can be used for other multiple-format generations. As shown in Fig.1(a), the resulting waveform at the output of MZ-c is:

$$E_{out} = \frac{1}{2}\cos\left[\frac{\pi}{2V_\pi}(A\cdot a(t)+V_{b1})\right] \pm \frac{1}{2}\cos\left[\frac{\pi}{2V_\pi}(A\cdot a(t-\Delta\tau)+V_{b2})\right] \quad (1)$$

where A is the voltage amplitude of the driving signal, $V\pi$ is the half-wave voltage of the Mach-Zehnder modulator, $V_{b1}$ and $V_{b2}$ are the DC biases of MZ-a and MZ-b, respectively, a(t) is the driving signal in the binary form (-1, 1), and $\Delta\tau$ is the differential delay between the driving signals for MZ-a and MZ-b. The signs "±" represent the phase difference between the two optical paths, which is controlled by the DC bias of MZ-c. Given $V_{b1}=V_{b2}=A=V\pi$, Eq.1 is simplified to:

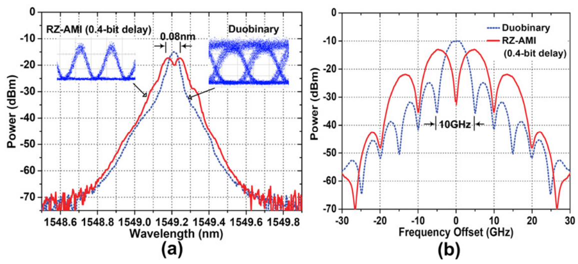
$$E_{out}^{+} = \cos\left[\frac{\pi}{4}(a(t)+a(t-\Delta\tau))+\frac{\pi}{2}\right]\cos\left[\frac{\pi}{4}(a(t)-a(t-\Delta\tau))\right] \quad (2)$$

and

$$E_{out}^{-} = -\sin\left[\frac{\pi}{4}(a(t)+a(t-\Delta\tau))+\frac{\pi}{2}\right]\sin\left[\frac{\pi}{4}(a(t)-a(t-\Delta\tau))\right] \quad (3)$$

Fig. 1(b) lists the resulting output based on Eq.2 and Eq.3 for all the four possible combinations of the two driving signals, where T is the bit period. It can be seen that when there is 1-bit delay between the driving signals, the duobinary format is generated (Eq.2), showing three possible states. If the delay time is less than 1 bit, the RZ-AMI format is produced (Eq.3). By changing the delay time between the driving signals, the pulse width of the generated RZ-AMI signal can be adjusted.

In the experimental implementation, the peak-to-peak value of the driving signal is ~7V, which is about twice $V\pi$. This driving condition enables either 0 or $\pi$ phase shift in each optical path depending on the binary values of the driving signals. No precoding section is used in this experiment because of the nature of pseudo random bit sequence (PRBS) signals. The phase shift between the two optical paths is adjusted by the bias port of MZ-c, which is set to be 0 or $\pi$.



(a) (b)

Fig.2 optical spectra of duobinary and RZ-AMI signals (0.4-bit delay): (a) measured @0.07-nm RB. Eye diagrams are also shown (b) simulated @1-GHz RB.

Fig.2 (a) shows the measured optical spectra of the generated duobinary and RZ-AMI signals at a resolution bandwidth (RB) of 0.07 nm. The measured eye diagrams are also shown as the insets. For the purpose of comparison, the simulated optical spectra at a resolution bandwidth of 1 GHz are shown in Fig.2 (b). It is clearly seen that there is no carrier in the spectrum of the RZ-AMI signal, and the dips occur every 10 GHz because of the delay-induced filtering effect.

The dispersion tolerance of the generated duobinary signal is experimentally evaluated. The differential delay is set to be 0.8 bit instead of 1 bit, which ensures a duty cycle >100% for a typical duobinary signal and better performance can be achieved [7]. Fig.3 shows the bit-error rate (BER) curve taken after transmission over 100-km single-mode fibre (SMF) at a launched power of 5.3 dBm. It indicates that the sensitivity penalty after 100-km SMF is around -1 dB, which shows the dispersion tolerant ability of the duobinary signal. The back-to-back performance of the generated RZ-AMI signal is also presented, with a receiver sensitivity of -20.5 dBm.

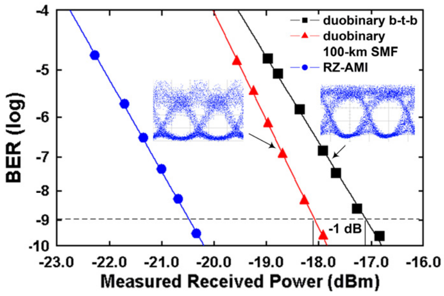



Fig.3 BER performance of generated signals for 0.8-bit delay

## Manchester code generation

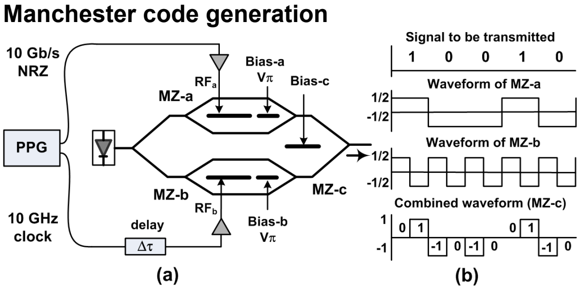



Fig.4 (a) experimental setup and (b) principle of Manchester code generation

The dual-parallel modulator can also be used to implement Manchester coding. In principle, the Manchester format is encoded through an XOR operation on an NRZ and a clock signal. Such an XOR operation can be achieved by the dual-parallel Mach-Zehnder modulator. Fig.4 (a) shows the configuration for Manchester signal generation, where MZ-a is driven by a 10-Gb/s NRZ signal ($2^{31}$-1) while MZ-b is driven by the corresponding clock signal with the DC ports biased at V$\pi$. The bias voltage of MZ-c ensures $\pi$ phase shift between the two optical paths. Fig.4 (b) shows the expected waveform of the coded output, which can also be verified by Eq.3.

Based on the configuration in Fig.4 (a), a 10-Gb/s Manchester code is generated. Fig.5 (a) shows the measured optical spectrum at a resolution bandwidth of 0.07 nm. The eye diagram and the waveform of a

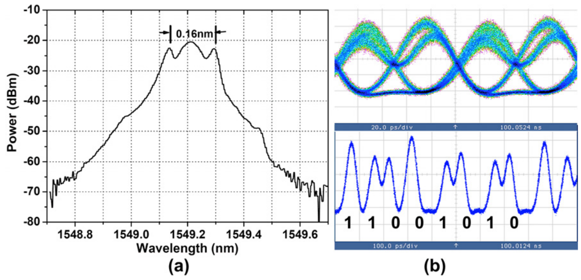



Fig.5 (a) optical spectrum (@0.07-nm RB), (b) eye diagram and bit pattern for the 10-Gb/s Manchester code.

bit pattern "1100 1010" are shown in Fig.5 (b). The amplitude dips in the eye diagram are caused by the phase change at the mark (space) to space (mark) transition edge. Fig.6 shows the back-to-back performance of the generated Manchester code along with an NRZ signal. Their transmission performances over 100-km SMF without dispersion compensation are also evaluated. For a fair comparison, the data rate of the Manchester code is 5 Gb/s while that of NRZ is 10 Gb/s, because it is mainly the pulse width that determines the pulse spreading. As indicated in Fig.6, the Manchester code has a back-to-back sensitivity of -22.4 dBm, which is 2 dB better than the NRZ format. After the 100-km SMF, the sensitivity penalty is ~2.3 dB for the Manchester code and ~3.6 dB for the NRZ format. The improvement in chromatic dispersion tolerance can be attributed to the bipolar characteristics of the generated Manchester code.

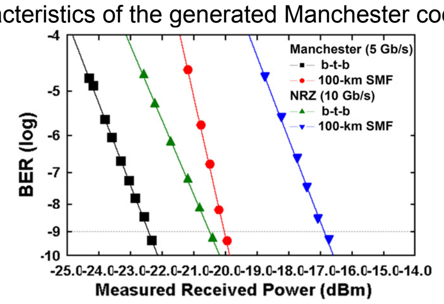



Fig.6 BER performances of the generated Manchester code along with an NRZ signal

## Conclusions

We have experimentally demonstrated a multi-format transmitter, where only a single modulator is needed for duobinary, RZ-AMI and Manchester format generations by simply changing the driving and biasing conditions. The proposed transmitter would be suitable as a compact source in applications requiring different modulation formats.

**Acknowledgement**: this work was supported by the national natural science foundation of China, 863 Program of China, Shanghai Optical Sci & Tech Program, and Shanghai Rising Star Program.

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