Generation of Dispersion Tolerant Manchester-Duobinary Signal Using Directly Modulated Chirp Managed Laser

Zhixin Liu, *Student Member, IEEE*, and Chun-Kit Chan, *Senior Member, IEEE*

***Abstract*—A novel scheme of generating optical Manchester-duobinary signal format using a directly modulated chirp managed laser is proposed and experimentally demonstrated at 10 Gb/s. The generated optical Manchester-duobinary signal has narrow spectrum and has shown to achieve three times more chromatic dispersion tolerance in optical fiber transmission than that of the conventional Manchester signal. The impact of the optical spectrum reshaper on the dispersion tolerance of the directly modulated optical Manchester-duobinary transmitter is also experimentally characterized.**

***Index Terms*—Chirp managed laser, direct modulation, duobinary format, Manchester code, optical transmitter.**

I. Introduction

MANCHESTER code, in which the encoding of each data bit has at least one level transition at the midpoint of each bit period, is an attractive modulation format for various applications in optical fiber communication systems [1]. Compared with conventional nonreturn-to-zero (NRZ) code, its main advantages are self-clocking, easy timing extraction, no laser pattern dependency, and zero dc component. Furthermore, its capability to employ differential detection makes it highly tolerant to signal intensity fluctuation [2], [3]. Recently, it has also been employed as the downstream signal format in a wavelength division multiplexed passive optical network (WDM-PON) to facilitate data remodulation at the optical network unit (ONU) for upstream transmission [4], [5] and has also shown effective suppression of optical beat noise [6], [7]. One of its variants, phase-shift-keying-Manchester signal has also shown much strong tolerance to the beat interference in PONs [8]. Nevertheless, Manchester format has twice broader signal bandwidth than that of the NRZ signal, resulting in degradations in both spectral efficiency and chromatic dispersion tolerance in practical applications [9]. The latter issue could be alleviated by employing Manchester-duobinary format [10], of which the transmitter required high-speed electronic encoders and was quite power inefficient. In this letter, we propose and demonstrate a 10-Gb/s optical Manchester-duobinary transmitter using a directly modulated chirp-managed laser (CML) [11]. By properly modulating the CML with an electrical Manchester-coded driving signal, optical Manchester-duobinary signal can be obtained. This eliminates the need for complex electronic encoders and the costly and bulky external modulators. Thus, the complexity and the cost of the Manchester-duobinary transmitter are greatly reduced. The experimental result has showed that its chromatic dispersion tolerance is increased by nearly three times compared with that using conventional Manchester code. In this letter, the conventional Manchester signal refers to Manchester signal without any phase transition. The proposed CML-based Manchester-duobinary transmitter has also been experimentally characterized.

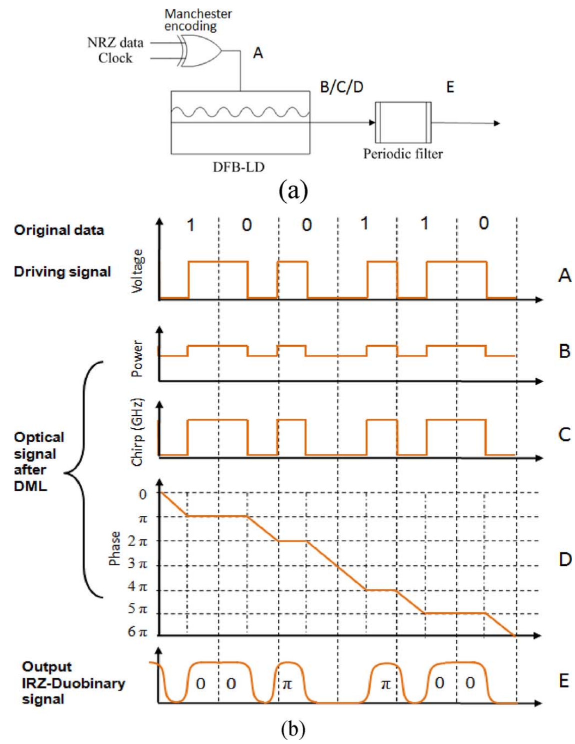

Fig. 1. (a) Schematic of CML-based Manchester-duobinary transmitter. (b) Illustration of the generation of the Manchester-duobinary signal.

II. Principle of Operation

Fig. 1(a) shows the schematic of the proposed CML-based Manchester-duobinary transmitter, which comprises an electronic XOR gate and a CML. The CML comprises a distributed feedback laser (DFB-LD) followed by an in-line optical spectrum reshaper (OSR) filter in a butterfly package [11]. Fig. 1(b) illustrates the principle of operation in time, frequency and

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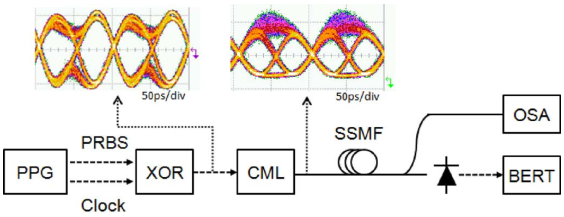
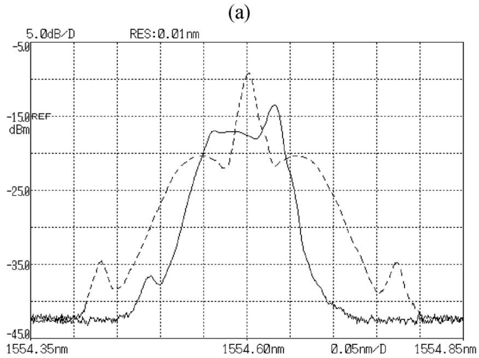


(a)



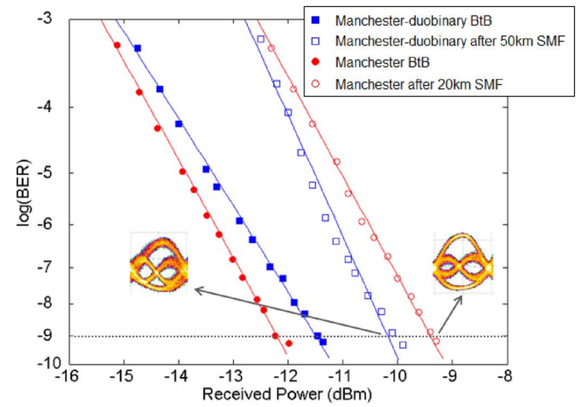
(b)

Fig. 2. (a) Experimental setup. (b) Optical spectra of 10-Gb/s conventional Manchester (dashed line) and Manchester-duobinary (solid line) signals.

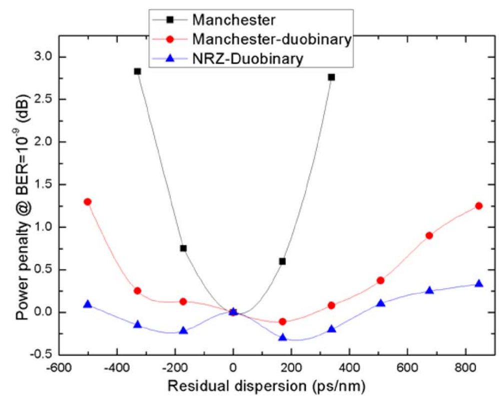
phase domains. The XOR gate converts the input NRZ signal into Manchester format before directly modulating the DFB-LD in the CML. The driving signal (trace **A**) is an electrical Manchester signal and its driving amplitude V_{pp} is adjusted to generate blue adiabatic chirp of $\Delta f = 1/T$, where T is the bit period at the high-intensity level in each bit. Such frequency shift results in a phase shift of $\Delta\phi = 2\pi\int_0^{T/2}\Delta f(t)dt = \pi$, to the low intensity level, in each bit. The DFB-LD is biased around five times above the laser threshold current so as to minimize the transient chirp but results in low extinction ratio (ER) in the DFB-LD output. The intensity, chirp and phase of the output optical signal from the DFB-LD are shown schematically as traces **B**, **C**, and **D** in Fig. 1(b), respectively. The laser wavelength is aligned on the transmission edge of the OSR filter, so as to pass the blue-shifted high intensity level and attenuate the red-shifted low intensity level. The intensity modulated signal accompanied with frequency modulation is then converted into a Manchester-duobinary signal with relatively high ER by the OSR filter (trace **E**), Besides, the OSR edge also converts the adiabatic chirp to flat-top chirp with abrupt phase transitions at the lower intensity level.

III. Experimental Results and Discussion

A standard CML module (Finisar DM80-01) was employed in our experimental setup, shown in Fig. 2(a). The DFB-LD at 1554.60 nm was biased at 75 mA and was modulated by an 10-Gb/s electrical Manchester signal with pseudorandom binary sequence (PRBS) and a word length of $2^{31}-1$. The V_{pp} of the driving signal was 2.25 V. Different lengths of dispersion-compensation module or standard single-mode fiber (SSMF) with ~ 17 ps/(nm $\cdot$ km) chromatic dispersion were utilized to study the chromatic dispersion tolerance of the optical Manchester-duobinary signals. The optical power of the Manchester-duobinary signal was kept below 0 dBm, in order to avoid the impact from fiber nonlinearity. Single photodetector (PD) was used for signal detection.



(a)



(b)

Fig. 3. Measured (a) BER performance, and (b) chromatic dispersion tolerance for 10-Gb/s Manchester-duobinary signal and conventional Manchester signal.

Fig. 2(b) shows the optical spectrum of the generated 10-Gb/s CML-based Manchester-duobinary signal (solid line) and it was compared with the 10-Gb/s conventional Manchester signal (dashed line). The tone of CML-based Manchester duobinary signal was shifted and the carrier was suppressed. The 20-dB bandwidths of the Manchester-duobinary signal and conventional Manchester signal were measured to be 18 GHz and 29 GHz, respectively. The Manchester-duobinary signal exhibited relatively more compact spectrum, as compared with that of a conventional Manchester signal. Thus it gave better tolerance against fiber chromatic dispersion in optical fiber transmission. The insets in Fig. 2(a) shows the eye diagrams of the electrical driving signal and the output optical signal. The ER of the output optical signal was 8.7 dB. The relative low ER was attributed to the low slope of the OSR in the CML ($\sim$ 11 GHz@3 dB).

As shown in Fig. 3(a), the back-to-back sensitivities (at the BER of 10^{-9}) for 10-Gb/s Manchester-duobinary signal and conventional Manchester signal were -11.45 dBm and -12.23 dBm, respectively. The 0.78-dB difference was mainly attributed to relatively low ER and overshoot of the Manchester-duobinary signal. The relatively low receiver sensitivities were mainly due to the insufficient electrical preamplifier gain in the photodetector. The power penalty of the Manchester-duobinary signal after 50-km SSMF transmission was 1.31 dB while that of the conventional Manchester signal after only 20-km SSMF transmission was 2.80 dB, showing the much longer optical reach for the Manchester-duobinary signal.

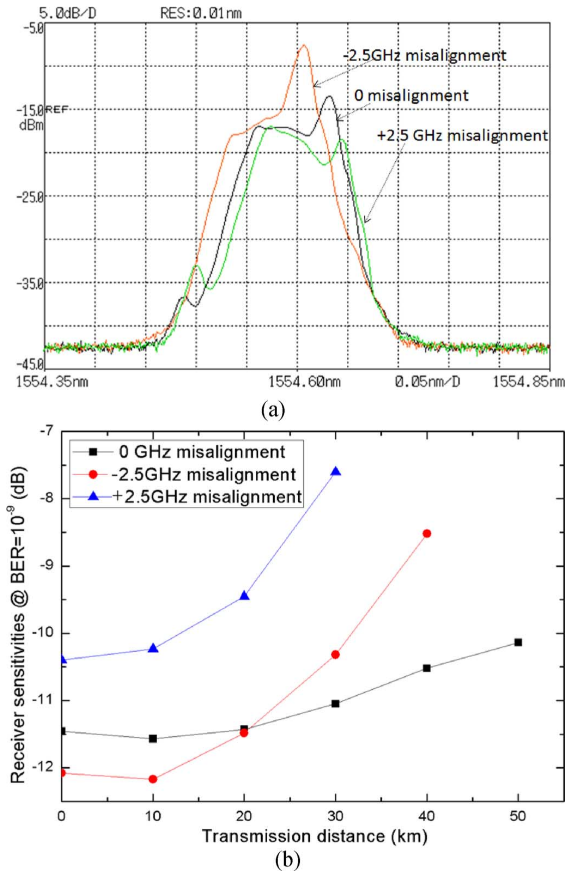


Fig. 4. (a) Optical spectra of the output Manchester-duobinary signal under different OSR operating points. (b) Receiver sensitivities as a function of transmission distance for different OSR operating points.

We have also investigated and compared the chromatic dispersion tolerance between the Manchester-duobinary format and the conventional Manchester format. Fig. 3(b) depicts their respective power penalties (at BER $= 10^{-9}$) measured at different residual chromatic dispersions. It was found that the 10-Gb/s Manchester-duobinary signal exhibited dispersion tolerance from -460 ps/nm to $+720$ ps/nm, at 1-dB power penalty. However, under the same condition, the 10-Gb/s conventional Manchester signal only exhibited dispersion tolerance from -190 ps/nm to $+200$ ps/nm, at 1-dB power penalty. The measurements showed that dispersion tolerance of the Manchester-duobinary format was around three times superior to that of the conventional Manchester signal.

The spectral property and transmission performance of CML-based Manchester-duobinary format varied with the OSR operating point in the CML. The optical spectra of the output Manchester-duobinary signal under different OSR operating points were shown in Fig. 4(a). The reference operating point (denoted as zero misalignment) was obtained by experimentally optimizing the OSR operating point such that the generated Manchester-duobinary signal gave the largest dispersion tolerance and exhibited a relatively flat top spectrum. Any small deviation from this reference operating point, say ± 2.5-GHz misalignment, shown in Fig. 4(a), led to tilting of the top portion of the optical spectra. Fig. 4(b) shows the chromatic dispersion tolerance curves measured under these three OSR operating points. It was shown that $+2.5$-GHz OSR misalignment would lead to quick degradation of the dispersion tolerance, which could be attributed to the large induced chirp when the mark bit was transmitted. For the case of -2.5 GHz misalignment, it also exhibited similar trend in the dispersion tolerance degradation, albeit with ~ 0.6 dB better back-to-back sensitivity, which could be attributed to the relatively higher ER resulted from the filtering at the OSR.

IV. Summary

A simple and effective optical transmitter has been proposed to generate optical Manchester-duobinary signal, via directly modulating a CML with an electrical Manchester-coded signal. The proposed CML-based Manchester-duobinary transmitter has low complexity and is cost-effective in practical realization. Experimental results have indicated that the optical Manchester-duobinary signal generated by the proposed CML-based optical transmitter exhibited three times larger chromatic dispersion tolerance than that of the conventional Manchester signal. Besides, proper OSR control in the CML is needed to assure good signal quality and transmission.

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