OPTICAL INVERSE-RZ DUOBINARY FORMAT FOR HIGH-SPEED OPTICAL TRANSMISSION

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Keywords: optical transmission, modulation, dispersion tolerance

Abstract

We investigate a new optical modulation format, namely inverse-return-to-zero duobinary, for optical transmission. Its various methods of signal generation as well as its dispersion tolerance in optical transmission are discussed and compared.

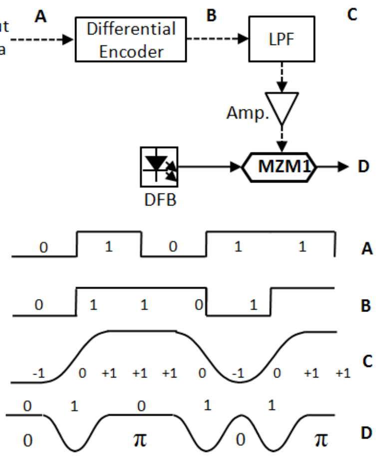
1 Introduction

Inverse-return-to-zero (IRZ) format, which is formed by inverting the intensity level of a conventional return-to-zero (RZ) signal, has recently found many interesting applications in optical transmission systems and optical access networks [1]-[7]. Its feature of carrying optical power in both "one" and "zero" bits allows superposition of different data streams. However, IRZ signal offers the advantages at the expense of requiring broader transmitter and receiver bandwidth, which is double that of the non-return-to-zero (NRZ) signal. Optical bandwidth of the IRZ signals is also two times that of the NRZ signals. As a result, optical spectral efficiency and dispersion tolerance of the IRZ signals are degraded. These drawbacks limit its practical application. On the other hand, it is well known that optical duobinary modulation format is effective in narrowing signal optical spectrum [8]. Hence, we propose bandwidth efficient IRZ-duobinary format to improve the optical spectral efficiency and dispersion tolerance of IRZ signals. In this paper, we discuss several feasible approaches and the respective transmitter design to generating IRZ-duobinary signals. Their dispersion tolerances in optical transmission are also numerically characterized and compared.

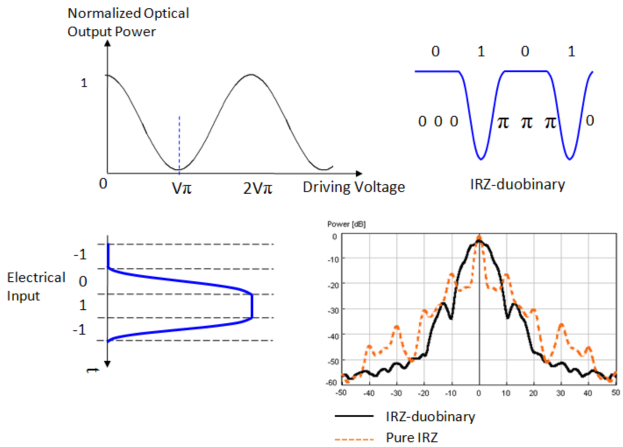
2 IRZ-duobinary modulation

2.1 Generation of IRZ-duobinary format

Fig.1 depicts the design of one of the feasible IRZ-duobinary transmitters. It consists of a differential encoder, a low pass filter (LPF), an electrical amplifier and a push-pull Mach-Zehnder modulator (MZM). The input NRZ signal is first differentially encoded before being passed through a LPF with 3-dB bandwidth of about half of the bit rate for correlation encoding. After the LPF, the input two-level



(a)



(b)

Fig.1 (a) IRZ-duobinary transmitter; (b) Illustration of the principle of optical IRZ-duobinary modulation.

electrical signal is transformed into a three-level driving signal, "+1", "0," and "-1". The original data, the differentially encoded data and the correlation encoded waveform are illustrated as inset A, B and C in Fig.1 (a), respectively. Then the three-level electric signal is amplified to a peak-to-peak voltage (V_{pp}) of $2V_{\pi}$, so as to drive the MZM for optical signal generation. To generate optical IRZ-duobinary signal, the MZM should be controlled, such that level "0" is biased at the null transmission point while levels "+1" and "-1" are biased at the maximum transmission points. Under this driving condition, the "+1" and "-1" levels in the driving signal produce the same intensities but opposite phases in the generated optical signal. Hence, an optical IRZ-duobinary signal with duty cycle of ~50% is obtained, as shown in Fig.1 (b). The inset spectrum diagram in Fig.1 (b) compares the optical spectra of the IRZ-duobinary signal and the conventional IRZ signal. It is shown that the IRZ-duobinary signal exhibits a more compact optical spectrum than the conventional IRZ case. At 10-Gbit/s, it is found that the 20-dB down bandwidth of the IRZ-duobinary signal is about 16 GHz while that of the conventional IRZ signal is up to 23 GHz.

2.2 Comparison of different configurations of IRZ-duobinary generation

Optical IRZ-duobinary signals can be generated by several different transmitter configurations. In this section, we compare four different configurations for IRZ-duobinary modulation.

The first configuration (Type 1) is identical to the one discussed in section 2.1, as depicted in Fig. 1(a). Type 2 are similar to Type 1, except the correlation encoding is realized by adding half-bit period delayed data (ADD) to the present data in order to transform differential encoded signals into three-level signals. Type 3 employs an optical phase modulator (PM) followed by a half-bit delay interferometer. The PM is driven by a differentially encoded NRZ signal. Type 4 employs dual-drive MZM, where one arm is driven by the input NRZ signal while the other is driven by the inverted signal with half-bit delay. A differential encoder is needed in each of all four configurations.

The eye diagrams in Table 1, obtained by numerical simulations at 10 Gb/s, show the back-to-back (BtB) eye diagrams (duty cycle 50%) of the four proposed transmitter configurations. The rise and the fall times of the NRZ signals are set to one quarter of the symbol duration. The rise and the fall times of the generated optical IRZ-duobinary signal in Type 1 is slower than that of the other three, as its driving signal has been shaped by the LPF. In practical applications, the shape of the LPF should be optimized to ensure optimum performance of the generated optical IRZ-duobinary signal. Since push-pull MZM is used in both Type 1 and Type 2, the generated optical IRZ-duobinary signal is not chirped, and its phase changes abruptly at "space" level. The main spectral lobe of the optical IRZ-duobinary signal generated by Type 1 is slightly wider than that by Type 2, but its spectral side lobes are more suppressed. The output signal of Type 3 and Type 4 are intrinsically the same. Their large side lobes are due to the chirp induced during the rise and the fall times.

We have also investigated and compared the dispersion tolerance in optical transmission among the IRZ-Duobinary format (generated by Type 1 transmitter), conventional RZ

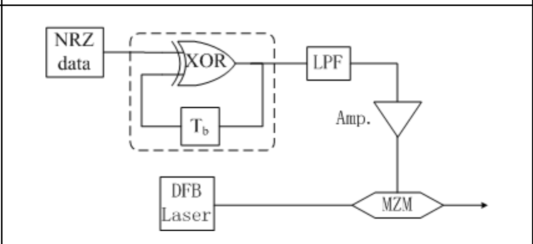
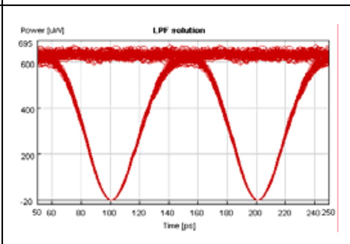
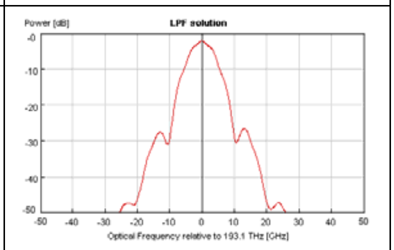
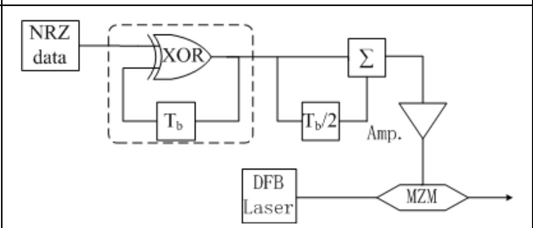
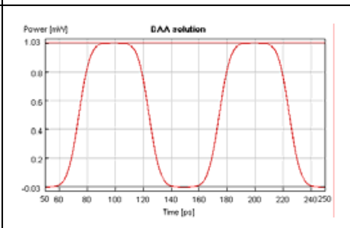
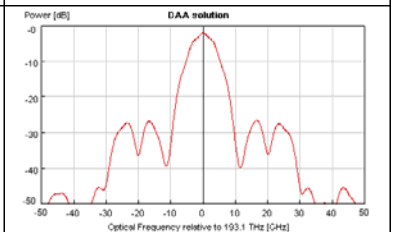
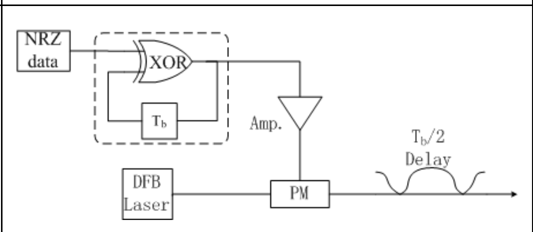
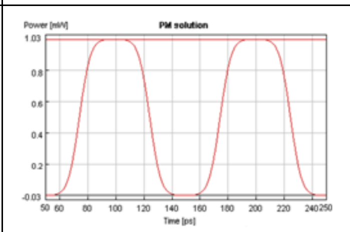
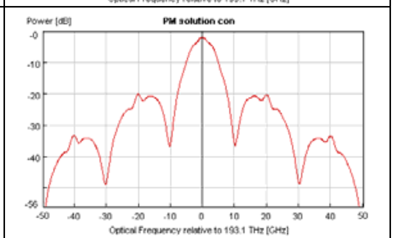
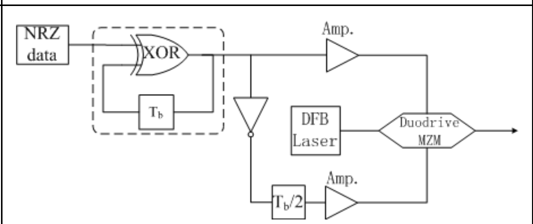
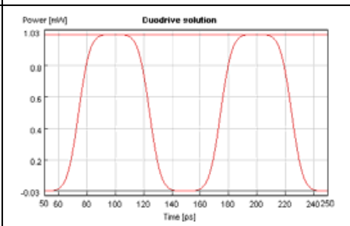
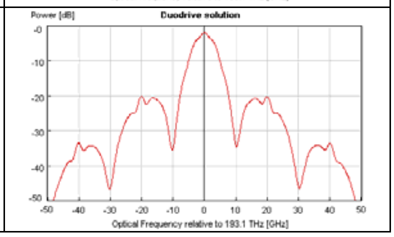
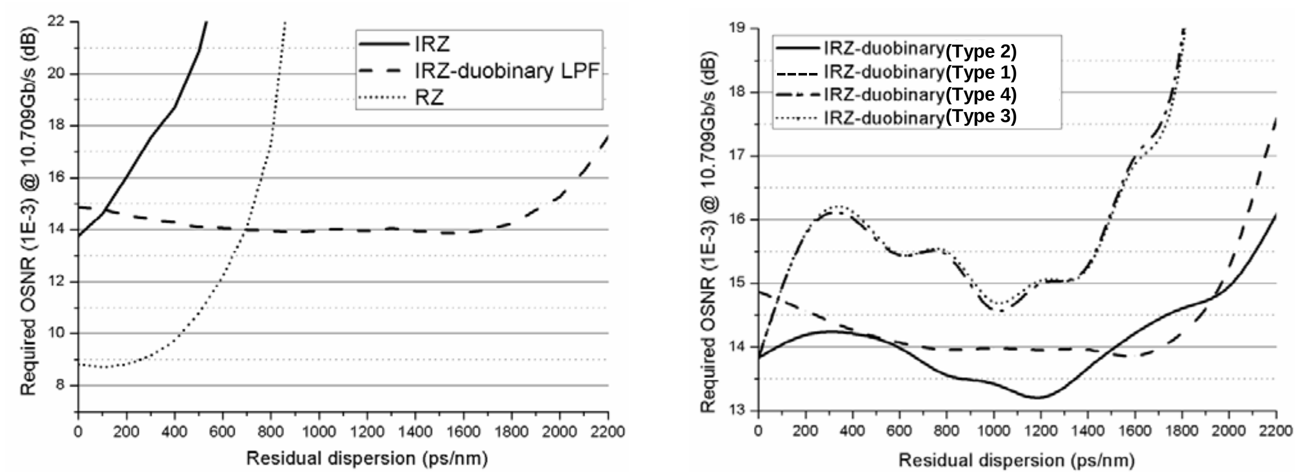
Type	Configuration for optical IRZ-duobinary generation	Eye diagrams	Optical spectra
1			
2			
3			
4			

Table 1 Comparison of different configurations of IRZ-duobinary generation



(a) (b)

Fig.2 (a) Required OSNR for BER = 10^{-3} versus residual dispersion at 10.709 Gb/s for different modulation formats: conventional IRZ (solid line, simulation), conventional RZ (dot line, simulation), and IRZ-duobinary (dash line, Type 1 configuration, simulation). (b) Required OSNR for BER = 10^{-3} versus residual dispersion at 10.709 Gb/s for different types of optical IRZ-duobinary transmitters in Table 1.

format, and conventional IRZ format through Monte Carlo simulation. Fig. 2 (a) depicts their respective required optical signal-to-noise ratio (OSNR) at BER=10^{-3}, for different residual dispersions. It is found that the conventional IRZ signal with direct detection quickly degrades in performance due to chromatic dispersion (CD) in fiber. RZ format follows a similar trend, albeit ~5 dB better initial sensitivity, and slightly better tolerance to CD. IRZ-duobinary format, as expected, shows ~10× and ~4× tolerance to dispersion, as compared with conventional IRZ and RZ formats at 2-dB OSNR penalty, respectively.

In Fig. 2(b), we have compared the CD tolerance for IRZ-duobinary signal generated by different transmitter configurations, as discussed in Table 1. Similar to the transmission performance of conventional duobinary signals [8], the optical IRZ-duobinary signals generated by Type 1 and Type 2 transmitters actually show small improvement in performance with some dispersion. At a dispersion value of 1200 ps/nm, Type 2 transmitter comes to -1.3-B improvement for the required OSNR, while Type 1 transmitter reaches -1.2-dB improvement at dispersion of 1600 ps/nm. Ideally, the optical signals generated by Type 3 and Type 4 transmitters are essentially identical. Thus, their performances show the same trend versus CD.

3 Summary

We have proposed and investigated a new optical IRZ-duobinary format for high-speed optical transmission. The relatively narrow IRZ-duobinary optical spectrum provides much better dispersion tolerance than the conventional IRZ or RZ formats. Several different transmitter configurations for signal generation have been discussed and compared.

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