# Novel Duobinary RZ Modulation Format for High-Speed Transmission

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**Abstract:** A novel duobinary RZ modulation format having a compact spectrum, complete removal of the carrier and significant suppression of both the side-lobes and discrete components is proposed, with the best immunity to fiber nonlinearities and dispersion.

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## 1. Introduction

A number of different return-to-zero (RZ) modulation formats were proposed recently [1-5]. The most popular among them are chirped RZ (CRZ) and carrier suppressed RZ (CSRZ). CRZ [5] is generated using bit-synchronous phase modulation of the RZ signal. Though highly tolerant to fiber nonlinearities, its spectrum is much broader than conventional RZ. On the other hand, narrower spectrum RZ formats, like CSRZ, are required for higher immunity to residual dispersion. The phase modulation can also be used for high-order dispersion compensation [1]. Recently proposed duobinary RZ (D-RZ) and modified duobinary RZ (MD-RZ) [2] are able to significantly suppress (but not completely as claimed by authors [2], see Fig. 2) the discrete components, responsible for creation of ghost pulses coming from four-wave-mixing (FWM). Unfortunately, their spectra although compact have very high sidelobes what increases the linear crosstalk, and prevents closer packaging of channels for WDM applications. CSRZ has much better suppression of sidelobes, suppress the carrier completely, but the discrete components remain.

## 2. Proposed Modulation Format

An alternative modulation format can be realized by combining the good properties of both duobinary transmission and CSRZ modulation format.

Transmitter may be implemented using either push-pull March-Zehnder (MZ) modulators, Fig. 1 (a), or single-drive ones, Fig. 1 (b). The first variant consists of a differential pre-coder, a continuous wave (CW) laser, an electrical delay line and two MZ modulators. One arm of the first MZ modulator is driven by a signal from differential pre-coder ($Q_k = Q_{k-1} \oplus \bar{d}_k$), and the other by one bit period ($T$) delayed complementary version of pre-coder output. The second MZ modulator is driven by sinusoidal signals of the same amplitude $V$, phase shifted $\pi$ rad, and frequency equal to the half of a bit-rate, biased at zero transmission point. If the amplitude of sinusoid is equal to $V_\pi$ CSRZ results, otherwise the pulse shape follows the expression $\sin[0.5\quad m \sin(\ Bt)]$, with $B$ being the bit rate and $m=V/V_\pi$ the amplitude depth.

In the second variant the pre-coder performs the same function as in the first variant, while the encoder performs the function $y_k = Q_k + Q_{k-1} - 1$, with $y_k$ being the encoder output and $Q_k$ the precoder output. The second MZ is driven by a sinusoid of frequency B/2 and amplitude $2V_\pi$.

The power spectral density of the proposed modulation format is shown in Fig. 2 for 40 Gb/s bit rate (and full modulation depth), together with CSRZ, D-RZ and MD-RZ signal formats. The spectrum is the most compact among different RZ formats with the side lobs and the discrete components significantly suppressed, and the carrier is completely suppressed.

To simulate Nx40 Gb/s WDM system the influence of four neighboring channels on observed channel is taken into consideration [3]. The transmission system consists of four spans of SMF (every 80 km long, giving 320 km of total length), each followed by corresponding DCF section to compensate both dispersion and dispersion slope. Two EDFAs (with Nf=6dB) are put after SMF and DCF sections to compensate corresponding losses. The channel spacing was 0.5 nm, the optical filter bandwidth 60 GHZ (0.64 bits/s/Hz of spectral efficiency) and average power per channel was 3 dBm. The comparison of the proposed RZ modulation format and the best RZ modulation format proposed so far [3], CSRS, is shown in Fig. 3. Our modulation format outperforms the CSRZ for 2.7 dB in Q–factor for the optimum electrical filter bandwidth.

Since the spectrum, shown in Fig. 2, for the proposed modulation format possesses two identical parts around the carrier frequency, the spectral efficiency can be increased up to 1.28 bits/s/Hz by utilizing single side-band transmission.


Fig. 1. Schematic diagram of the two variants for the proposed modulation formats

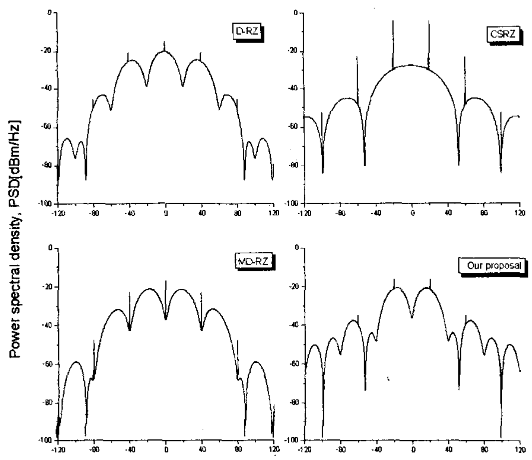


Fig. 2. Power Spectral densities of different RZ signals.

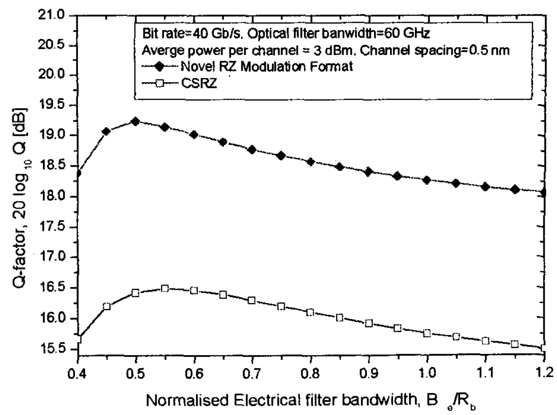


Fig. 3. Novel RZ modulation format vs. optimized CSRZ.

## 3. Conclusion

A novel duobinary RZ modulation format with compact spectrum and significant suppression of side-lobes is proposed. Among many recently proposed RZ formats the closest channel packaging for WDM systems is possible with this format. The proposed modulation format completely suppresses the carrier and significantly the discrete components, and demonstrates high immunity to both residual dispersion and fiber nonlinearities.

## References

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