40Gbit/s Modified Duobinary RZ Signal Generation, Wavelength Conversion and Transmission over 200km SMF-28 Using Mid-Span Spectral Inversion

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Abstract: W*avelength conversion for the 40Gbit/s modified duobinary RZ signal generated by using a single $LiNbO_3$ modulator is realized for the first time. Mid-span spectral inversion caused by FWM is used to realize 40Gbit/s MD-RZ signal transmission over 200km SMF-28 fiber without dispersion compensation.*

1. Introduction

Advanced modulation techniques are attractive for 40Gbit/s transmission systems [1-5]. These new modulation formats can be employed to achieve high-spectral efficiency and extend the transmission distance limited by the impairments such as fiber chromatic dispersion and nonlinear effects. Modified duo-binary return-to-zero (MD-RZ) signal format shows some promising features: 1) narrow optical spectrum enabling wider dispersion tolerance; the 20dB optical spectrum bandwidth for a 40Gbit/s MD-RZ signal is only 80GHz, which is narrower than that of 40Gbit/s regular RZ or carrier suppressed RZ signals [3]. 2) High fiber-nonlinearity tolerance; The MD-RZ format flips the phases of two groups of 'ones' that wrap an isolated 'zero', which leads to reduced ghost pulse generation caused by intra-channel four-wave mixing (IFWM). However, two optical modulators are typically needed to obtain a MD-RZ signal; one is employed to generate NRZ duo-binary signal and the other is used to carve the NRZ data to RZ signal. Hence the transmitter is much expensive relative to the NRZ signal generation. Recently we demonstrated a novel technique to generate 10Gbit/s MD-RZ signal by using only one dual-arm $LiNbO_3$ modulator (LN-MOD) [2]. By properly adjusting the time delay of the driving signals applied to the two arms of the LN-MOD, variable duty-cycle MD-RZ signal can be obtained. By this means, a cost-effective transmitter is implemented since only one LN-MOD is needed. We show 40Gbit MD-RZ signal generation by using only one LN-MOD and without any other optical components in this paper.

Wavelength conversion is considered to be a key element for future DWDM optical networks since it enables contention resolution, wavelength reuse and effective utilization of the vast fiber bandwidth. Different from conventional modulation formats such as regular RZ or NRZ signals, the phases of two groups of "1"s separated by an '0' of MD-RZ signal are different. After wavelength conversion, the phase relationship has to be maintained. Previous experiments only demonstrated wavelength conversion for phase uncorrelated signals. To our knowledge, there was no report on MD signal wavelength conversion. In this paper, we present the result of 40Gbit/s MD-RZ signal wavelength conversion based on four-wave mixing (FWM) in a high-nonlinear dispersion shifted fiber (HNL-DSF) for the first time. Chromatic dispersion in transmission fiber is one limiting factor in high-speed optical systems and networks if dispersion compensation is not applied. Wavelength conversion based on four-wave mixing (FWM) in optical fibers leads to the optical spectrum inversion and phase conjugation, this characteristic is attractive for implementing high-speed transmission without expensive dispersion compensation [6]. HNL-DSF is one promising candidate to realize wavelength conversion and phase conjugation. In this paper, we use a 1km HNL-DSF to realize mid-span spectra inversion (MSSI), which enables 40Gbit/s MD-RZ signal transmission over 200km SMF-28.

2. Experimental setup and results

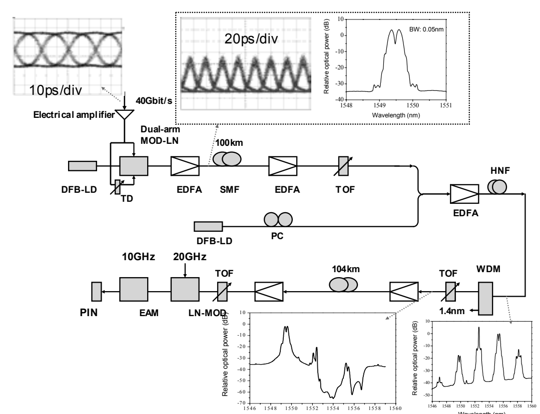

Fig. 1. Experimental setup for 40Gbit/s MD-RZ signal generation, wavelength conversion and transmission using mid-span spectral inversion. (i) Eye diagram of the 40Gbit/s electrical signal (BW: 50GHz); (ii) eye diagram of the 40Gbit/s optical signal (BW: 50GHz); (iii) optical spectrum of the 40Gbit/s optical signal (BW: 0.05nm), (iv) optical spectrum after FWM in HNL-DSF, (v) filtered and converted optical spectrum. Note: (iv) and (v) spectra were measured without transmission fiber.

The experimental setup for the generation, wavelength conversion and transmission of 40Gbit/s MD-RZ signal is shown in Fig. 1. The binary 40Gbit/s NRZ electrical signal shown in Fig 1 as inset (i), is generated by a commercial 4: 1 electrical multiplexer. The NRZ signal drives a dual-arm LN-MOD for modified duo-binary signal generation. The word length of the PRBS of the electrical signal is limited by the electrical multiplexer to 2^{10}-1. The data from the multiplexer is amplified to 6.4Vp-p by using a wideband electrical amplifier; then it is divided to two equal parts by using an electrical power divider. One divided electrical signal drives one arm of the LN-MOD after it is delayed by a tunable electrical delay line. The other one directly drives the second arm of the LN-MOD. The two divided electrical signals have the same characteristics, and their amplitudes are set to the half-wave voltage of the LN-MOD [2]. By changing the time delay, signals with different duty cycles can be obtained [2]. The optical eye diagram measured by an oscilloscope with a bandwidth of 50GHz and the optical spectrum of the 40Gbit/s MD-RZ signals are shown in Fig. 1 as inset (ii) and (iii), respectively. The MD-RZ signal possesses a duty cycle of 60% and an extinction ratio (ER) of the 16.7dB. The measured 3dB and 20dB bandwidths of the signal are 0.34 and 0.67nm, respectively indicating a compact optical spectrum.

We use a 1km HNL-DSF based on FWM to realize wavelength conversion. The HNL-DSF has a nonlinear coefficient of $10.4\times e^{-20}$ m^2/W and a zero-dispersion wavelength of 1562 nm. The peak power of the CW pump lightwave is 5dB higher than that of the 40Gbit/s MD-RZ signal, and the total input power into the HNL-DSF is 19dBm. Inset (iv) in Fig. 1 shows the output optical spectrum from the HNL-DSF. The converted signal at 1549.8nm has an OSNR of 23dB. It shows that the spectrum characteristic of the converted MD-RZ optical signal is similar to that of the original 40Gbit/s MD-RZ signal. We use a WDM filter cascaded with a tunable filter having a bandwidth of 1.4nm to suppress the pump, original signal and FWM in the longer wavelength. The optical spectrum after the cascaded filters is shown in Fig. 1 as inset (v). The original signal and pump are well suppressed. The 40Gbit/s MD-RZ original and converted signals are optical time-division de-multiplexed by using a cascaded LN-MOD and EAM. The LN-MOD and EAM are driven by 20 and 10GHz clock signals, respectively. At the receiver, a tunable optical filter (TOF) with a 3dB bandwidth of 1.4nm is used to suppress the ASE noise of EDFAs. The 10Gbit/s de-multiplexed signal is detected by a PIN receiver with a 3-dB bandwidth of 7GHz. Clock recovery circuit is also realized in the PIN receiver. The BER of the de-multiplexed 10Gbit/s signal is measured and shown in Fig. 2. The power penalty is 0.2dB.

Next, we use the spectrum inversion by FWM to realize dispersion compensation for 40Gbit/s MD-RZ signal transmission over 204km SMF28. The 40Gbit/s MD-RZ signal is transmitted over 100km SMF-28 (attenuation of 0.21dB/km, dispersion of 17ps/nm/km at 1550nm). The MSSI, which is placed in the middle of the fiber spans, is realized by using FWM in HNL-DSF. The converted signal is transmitted over a second fiber span consisting of 104km SMF. Because the converted signal suffers from smaller dispersion in SMF-28, the second fiber span is a little longer than that the first span. The input power into SMF-28 is kept to be 10dBm. The BER performance after transmission is measured and shown in Fig.2. After the 40Gbit/s MD-RZ signal is transmitted over 204km SMF, the eye diagrams before and after de-multiplexing are also inserted in this figure as inset (i) and (ii), respectively. The transmitted signal at the receiver is de-multiplexed to 10Gbit/s and BER is measured and shown in Fig. 2. The power penalty after transmission is 1.4dB, which can be attributed to wavelength conversion, uncompensated second-order dispersion [7] and OSNR degradation. The 40Gbit/s eye diagram after transmission is very clear and widely open. The cascaded LN-MOD and EAM can create sufficiently narrow switching window to suppress neighboring tributaries, thus a clear and open 10Gbit/s de-multiplexed eye diagram is obtained.

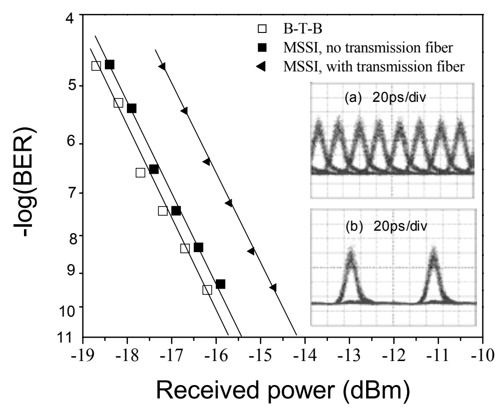

Fig. 2. Measured BER performance. (i) 40Gbit/s eye diagram after transmission over 204km; (ii) 10Gbit/s de-multiplexed eye diagram from the 40Gbit/s signal after transmission over 204km.

3. Conclusions

We have experimentally demonstrated the first 40Gbit/s MD-RZ signal generation by using only one dual-arm LN-MOD and without other optical components. The signal is wavelength converted based on FWM in the 1km HNL-DSF, which is the first time demonstration of wavelength conversion for the MD-RZ signal to the best of our knowledge. The power penalty caused by wavelength conversion is 0.2 dB. We use MSSI to realize dispersion compensation for the 40Gbit/s MD-RZ signal transmission over 200km SMF-28. The total power penalty is 1.4 dB.

Reference

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