Optical Time Division Multiplexing of RZ-ASK and RZ-DPSK Signals and Their Detection without Optical Demultiplexing

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Abstract *We propose and demonstrate optical time interleaving of an optical RZ-ASK signal with an optical RZ-DPSK signal to form a hybrid OTDM signal, which does not require optical time demultiplexing at the receiver for detection.*

Introduction

With the ever-increasing demand on communication bandwidth, time division multiplexing (TDM), either in electrical or optical domain, is an effective approach to upgrade the capacity of each wavelength channel in current optical systems [1-3]. Although recent research has achieved remarkable progress in high-speed electronics [2], optical TDM (OTDM) is still a promising alternative for ultrahigh-speed operation. However, the OTDM signal has to be demultiplexed at the receiver, which requires complicated optical processing, and thus hinders its practicability [3].

In this paper, we propose to multiplex an optical RZ-ASK signal with an optical RZ-DPSK signal in time, to form a hybrid OTDM signal. We show that the separation of these two tributaries does not require any optical time demultiplexing. With simple direct detection, the system complexity and requirements could be greatly relaxed.

Principle of Operation

The ASK/DPSK hybrid OTDM signal format and its transmitter and receiver are depicted in Fig. 1. Two optical tributaries, one in ASK format while the other in DPSK format, are first individually generated at the same bit rate, say *m* b/s. Both of them are then time-interleaved, via an optical delay line circuit, to form an ASK/DPSK hybrid OTDM signal, at a doubled aggregate data rate of *2m* b/s. At the receiver, no optical time demultiplexing technique is required to separate the two tributaries before simple direct detection at each tributary's bit rate of *m* b/s. In each detection time period (1/*m* seconds), there are two bits present, one is RZ-ASK bit and the other is RZ-DPSK bit. As every RZ-DPSK bit has an optical pulse, and thus constant power in each detection period, simple direct detection at *m* b/s is equivalent to RZ-ASK signal detection with a degraded extinction ratio. On the other hand, if a delay interferometer (DI) is placed before the photodiode, the RZ-DPSK pulses would be demodulated and detected at *m* b/s. However, in addition to the demodulated RZ-DPSK pulses, the RZ-ASK pulse in the detection period would also lead to a residual pulse with power being 1/4 of the input pulse power if the ASK consecutive bits are not the same (that is, either "10" or "01") while no residual pulse would be present if the ASK consecutive bits are the same (that is, "11" or "00"). In this way, both tributaries could be detected without any optical time demultiplexing.

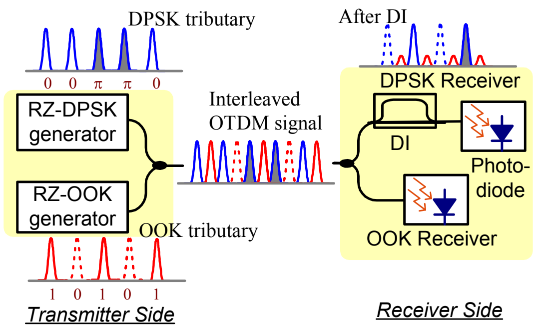

Fig. 1 ASK/DPSK hybrid OTDM signal format and its transmitter and receiver.

Experiment

We have experimentally investigated the generation and reception of such an ASK/DPSK hybrid OTDM signal. Transmission over a medium-range distance has also been demonstrated. A semiconductor mode-locked laser diode (MLLD) generated optical pulse train (wavelength 1554 nm, FWHM ~1.5 ps, repetition rate 10.61 GHz) were separated and modulated by decorrelated patterns via an optical phase modulator and an intensity modulator, respectively to generate the two individual RZ-DPSK and RZ-ASK tributaries. The choice of pulsewidth can be much broader as far as the pulses have no overlap after interleaving. A tunable optical delay line (ODL) was inserted to let the optical 10.61-Gb/s RZ-DPSK pulses properly time-interleave with the 10.61-Gb/s RZ-ASK signal pulses to form a 21.22-Gb/s hybrid OTDM signal. A polarization controller and a tunable optical attenuator were used, to assure the two tributaries having the same peak power and polarization. The hybrid OTDM signal was then amplified to around 0 dBm and was coupled into a piece of 40-km single mode fiber (SMF) with corresponding dispersion compensation. The ASK/DPSK interleaved signal is detected by the receiver unit as shown in Fig. 1. The delay interferometer (DI) used has a relative arm delay of 94.3 ps for DPSK demodulation.

Fig. 2(a) shows the back-to-back eye diagrams of the ASK/DPSK hybrid OTDM signal when a 50-GHz wideband p-i-n photodiode was employed. By direct detection using a 10-GHz p-i-n receiver, the RZ-ASK signal can be simply detected, as shown in Fig. 2(b). When the hybrid OTDM is passed through the DI, the RZ-DPSK signal is demodulated, as shown in Fig 2(c). However, the RZ-ASK tributary signal may or may not contribute a residual pulse in each detection period, depending on its bit pattern, as discussed. As the RZ-DPSK signal dominates, it can be detected by using a 10-GHz p-i-n receiver, as shown in Fig. 2(d).

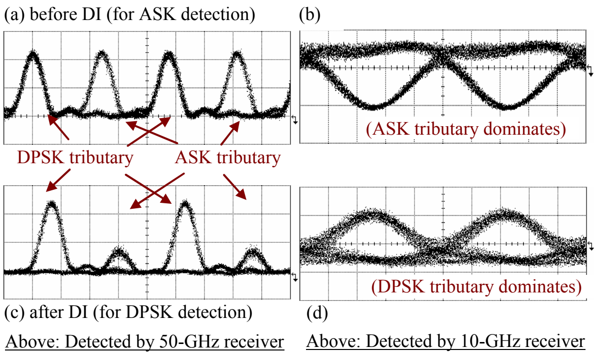

Fig. 2 Back-to-back eye diagrams of the ASK/DPSK hybrid OTDM signal detected by receivers with different electrical bandwidths. Time scale: 20 ps/div.

We have measured the bit error rate (BER) of the ASK/DPSK hybrid OTDM signal, as shown in Fig. 3. Both tributaries were modulated by $2^{23}-1$ pseudo random binary sequence, yet the two optical signals were decorrelated via ODL. The receiver unit shown in Fig. 1 was employed, and the received optical powers were measured before the p-i-n photodiodes. The back-to-back receiver sensitivities for the ASK and DPSK tributaries were measured to be around −16 and −19 dBm, respectively and error-free operation was achieved in both cases. There were about 4.5-dB or 1.5-dB power penalties compared with the measured conventional RZ-ASK or RZ-DPSK sensitivities, respectively. For the ASK tributary reception, the average power of the DPSK pulses, which was twice that of the ASK tributary, was counted into the received power of the ASK tributary signal. Therefore, two thirds of the received power was useless for ASK detection and led to degraded extinction ratio, which corresponded to ~4.5 dB of power penalty. Similarly, for DPSK reception, the power penalty could be attributed to the degraded eye due to the presence of the residual ASK pulse.

After 40-km transmission with corresponding dispersion compensation, both the received RZ-DPSK and RZ-ASK tributaries had a power penalty of about 0.5 dB, which might be caused by the wide spectrum of optical pulses and the residual fiber dispersion. In the above measurements, the two tributaries were evenly time-interleaved. It is expected that the detection performance depends on proper interleaving alignment of the two tributaries. Fig. 4 shows the measured power penalty of both tributaries under different interleaving misalignment. It is shown that the interleaving misalignment tolerances were around ±10 ps and ±20 ps for the RZ-ASK and the RZ-DPSK tributaries, respectively, at a 1.5-dB power penalty.

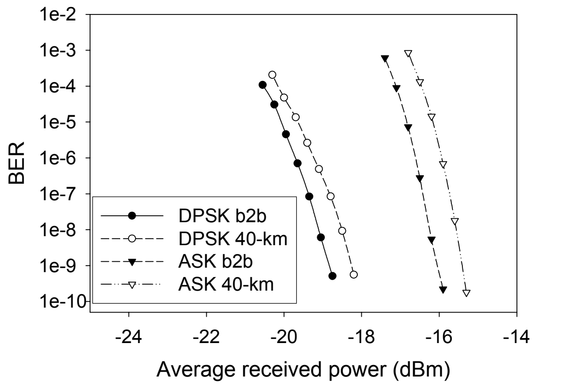

Fig. 3 BER measurements of the DPSK and ASK tributaries of a 21.22-Gb/s hybrid OTDM signal.

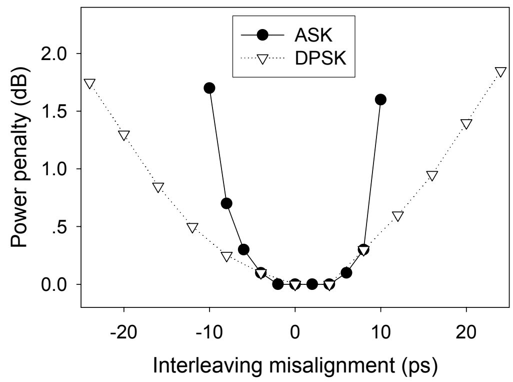

Fig. 4 Power penalty of the ASK and DPSK tributaries due to interleaving misalignment.

Conclusions

We propose to interleave an optical RZ-DPSK signal with an RZ-ASK signal to form a hybrid OTDM signal at a doubled aggregate bit rate. We have shown that signal reception does not require optical time demultiplexing to separate the two tributaries, thus the two OTDM tributaries can be detected with their conventional receivers. The 20-Gb/s aggregate bit rate can be fully realized by 10-Gb/s components. Experimental results showed effective reception and robust performance of such ASK/DPSK hybrid OTDM signals. The project was partially supported by a research grant from HKRGC (CUHK4240/04E).

References

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