Tolerance of Misalignment between ASK and DQPSK Modulation in ASK/DQPSK Orthogonal Modulation Systems

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Abstract

We investigate the tolerance of timing misalignment between ASK and DQPSK modulation in ASK/DQPSK orthogonal modulation systems, and show that such impairment strongly depends on ASK formats (NRZ, RZ, or inverse-RZ) and DQPSK modulation methods.

1 Introduction

Multilevel optical orthogonal modulations combining amplitude-shift keying and differential quadrature phase shift keying (ASK/DQPSK) have drawn much attention recently for their improved optical transmission properties such as greater spectral efficiency [1], [2]. The implementations of these modulation formats usually require concatenation of several modulator stages, whose time slot alignment should be carefully adjusted for proper operation. However, the relative time delay of those modulators may drift over time due to temperature variation and devices aging, leading to timing misalignment (TM) between ASK and DQPSK modulation.

The impairment from TM depends on ASK modulation formats, such as non-return-to-zero (NRZ), return-to-zero (RZ), and inverse return-to-zero (IRZ). In [2], it was qualitatively mentioned that IRZ-ASK/DQPSK had better tolerance to TM. However, systematic studies have not been performed yet. Furthermore, the robustness of ASK/DQPSK to TM also depends on many other effects such as DQPSK modulation methods, input data pulse shape, and the optical filter bandwidth. In this paper, we will investigate the TM tolerance of ASK/DQPSK orthogonal modulation systems for different ASK formats (NRZ, RZ, or IRZ) and DQPSK modulation methods. The impacts of input data pulse shape and optical filter bandwidth on TM are also discussed.

2 ASK/DQPSK transmitter

Fig. 1 shows the ASK/DQPSK transmitter configurations for different ASK formats and DQPSK modulation methods. NRZ-ASK signal is generated by feeding the continuous wave light into a data-driven Mach-Zehnder modulator (MZM). For RZ carving, another MZM driven by a sinusoidal voltage at half of the bit rate is employed. The generation of IRZ-ASK signal consists of an MZM driven by an RZ-shaped radio frequency (RF) signal [3], which is obtained through the logical AND operation between a RF clock signal and the

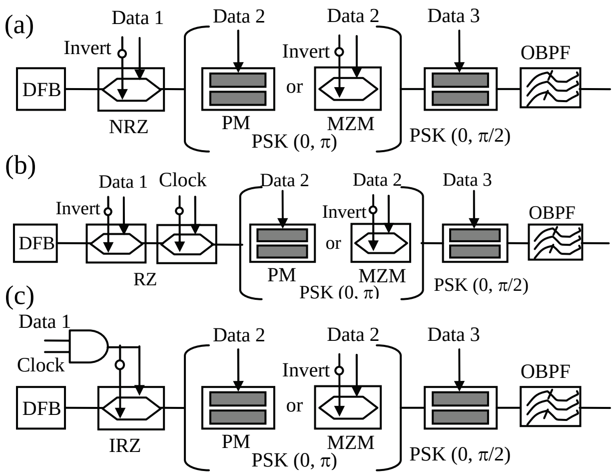

Fig. 1. ASK/DQPSK transmitter configuration for (a) NRZ-ASK/DQPSK; (b) RZ-ASK/DQPSK; (c) IRZ-ASK/DQPSK. DQPSK in (a)~(c) can be modulated by using either PM or MZM.

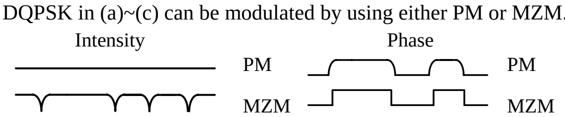

Fig. 2. Modulation characteristics of PM and MZM

NRZ data signal. For DQPSK modulation, two cascaded stages are usually required. The first stage modulates the phase of optical signal to 0 or π, while the second one adds 0 or π/2 phase shift. In terms of implementation, there are two methods to realize (0 π) phase change by using: i) phase modulator (PM); or ii) MZM, as shown in Fig. 1. The difference between the two modulator options is shown in Fig. 2. PM keeps the optical intensity constant and modulates the phase subject to its bandwidth limitations. However, it introduces imperfect phase modulation in data transition region, which would cause additional power penalty. In contrast, MZM produces instantaneous phase jumps but at the expense of some residual intensity modulation. Though such difference of the two methods is not critical when ASK modulation and DQPSK modulation are properly aligned, the impairment from TM strongly depends on this effect. That is because when timing is misaligned, the data transition region of DQPSK signal is located in the mid-point of data time slot of ASK signal. Therefore by using MZM, the DQPSK data-related dips inevitably lead to inter-symbol interference (ISI) to ASK signal. For PM, if the bandwidth of the optical bandpass filter (OBPF) is sufficiently large so that the signal can keep its constant intensity after filtering, such ISI can be effectively avoided. But, in strongly optical filtering systems or for sharp-edged input DQPSK data pulses, dips would also be introduced after filtering. Therefore, ISI between DQPSK and ASK signals should also be taken into consideration.

3 Results and discussion

Monte-Carlo simulations were performed to investigate the dependence of TM-induced distortion on ASK formats and DQPSK modulation methods. Three uncorrelated 10-GHz data sequences (data1~ data3), each consisting of 500,000 bits with 40 samples per bit, were modulated in each case depicted in Fig.1. The data pulse was assumed to be raised-cosine shaped with α controlling the edge sharpness for both ASK and DQPSK data pulses. Fiber transmission link was modeled as a single-input, two-output setup [4]. The signal was split into two orthogonal polarization modes. OBPF in the channels was Gaussian shaped with a filter bandwidth of 0.8 nm. At the receiver, ASK signal was square-law detected, while DQPSK signal was detected by using an MZ interferometer with a symbol period delay and ±π/4 phase shift. The electrical filter was a 4^{th}-order Butterworth filter with a filter bandwidth of 7-GHz for NRZ-ASK or DQPSK, and 13-GHz for RZ-ASK or IRZ-ASK. The system was assumed to be in thermal-noise-limited operation region and the performance was evaluated in terms of receiver power penalty with respect to the power for NRZ signal with no TM (t_0=0) at a bit error rate (BER) of 10^{-4}. Fig. 3 depicts received power penalty versus misaligned time t_0 for different ASK formats and DQPSK modulation methods. It is shown that by employing MZM, ASK signal is sensitive to t_0 due to ISI from DQPSK data. In contrast, when PM is used, ISI can be avoided. In terms of DQPSK, the figures show that the use of PM would introduce additional power penalty but does not influence TM sensitivity of DQPSK, which, however, is significantly impacted by ASK formats with IRZ more robust to TM. From the figures, it is also shown that the performance of NRZ-ASK/DQPSK and RZ-ASK/DQPSK is near optimal for t_0=0. For IRZ-DQPSK, however, it is possible to improve the performance by offsetting a certain t_0, whose value should depend on DQPSK modulation methods. Results in Fig. 3 assume that the sampling phase is optimized, whose sensitivity is found to be also dependent on DQPSK modulation method, as shown in Fig. 4.

4 Conclusions

We investigate TM tolerance of ASK/DQPSK under the effects of ASK formats (NRZ, RZ, or IRZ) and DQPSK modulation methods (PM and MZM). It is shown that DQPSK modulation methods influence ASK signal's TM sensitivity, but not DQPSK signal's. The method using PM is shown to be more insensitive to TM. In contrast, ASK formats influence DQPSK signal's TM sensitivity, but not ASK signal's, with IRZ more robust to TM. The results also show that the performance of IRZ-ASK/DQPSK can be improved by offsetting a certain t_0.

5 References

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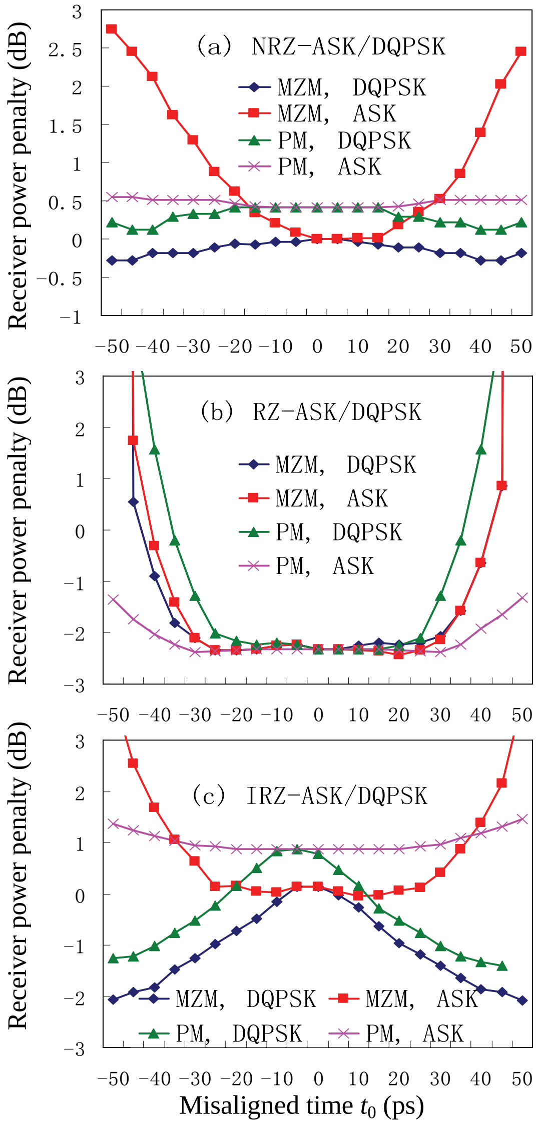

Fig. 3. Receiver power penalty versus t_0 for different ASK formats and DQPSK modulation methods. (a)~(c), sampling phases are optimized.

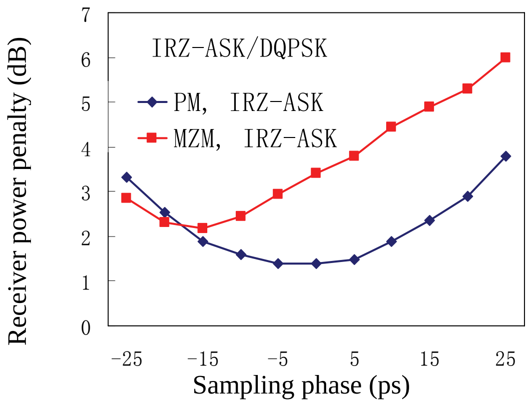

Fig. 4. Sampling phase sensitivity of IRZ signal for different DQPSK modulation methods and t_0=45 ps.