56 Gb/s, PAM-4 Transmission Over 25 km, Using IQ Modulator and Unequally Spaced Levels

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Abstract: We propose a PAM-4 modulation scheme with unequally spaced levels in order to mitigate chirp effects caused by IQ modulators. Experimental results of 56 Gb/s transmission over 25 km link demonstrate the robustness of this modulation concept.
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1. Introduction

For short range and metro-access optical transmissions, low cost solutions are an attractive alternative to coherent systems. In recent years, Intensity modulation and direct detection (IM-DD) systems have become very attractive due to their simplicity, power dissipation and cost [1]. Most of these systems employ non-return to zero on-off shift keying (NRZ-OOK) modulation, which is simple to implement and has very good optical to noise ratio (OSNR) tolerance. However, with the ever increasing demand for higher line rates, multilevel modulation becomes more attractive [2, 3]. Higher level IM formats such as pulse amplitude modulation 4 (PAM-4) provide the same bit rate as a NRZ-OOK format at lower baud rates, thus reducing the negative dispersive effects of the fiber and facilitating optical transmissions at bit rates of 56Gb/s or higher [3,4].

In this paper we investigate the performance of PAM-4 at 56 Gb/s data rate when using an IQ Mach-Zehnder modulator (MZM) to generate the optical signal. We believe that IQ modulators, while not the cheapest alternative, will become the main option in future flexible optical systems. We propose a PAM-4 scheme with unequally spaced levels which removes the effects of modulator chirp, thus enabling transmission distances of up to 25 km.

2. Mitigation of chirp effects

First, the generation of equally spaced levels PAM-4 using an IQ modulator is presented. Two pseudo random bit sequences (PRBS) are generated. The power level corresponding to bit '1' of the first PRBS is twice that of the second PRBS, while the power level corresponding to bit '0' should be zero for both PRBS. The first PRBS enters the I branch of the IQ modulator and the second one is connected to the Q branch, as can be seen in Fig. 1(a):

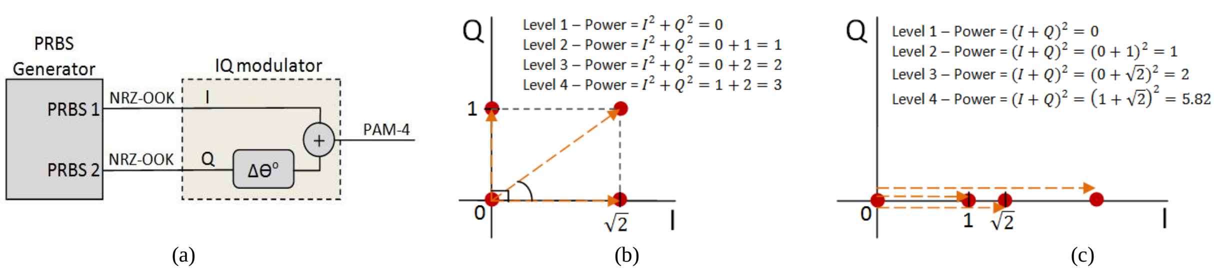


Fig. 1. (a) Diagram of PAM-4 generation, (b) constellation of equally spaced levels PAM-4 with π/2 phase bias, (c) constellation of unequally spaced PAM-4 with zero phase bias.

In order to obtain equidistant power levels at the output of the IQ modulator, the phase bias of the Q branch needs to be π/2. Fig. 1(b) shows the resulting constellation. It can be seen that the constellation points are not on the same axis, meaning that the signal is modulated in both intensity and phase domains. In an IM-DD system the phase modulation introduces chirp, which causes additional inter-symbol interference (ISI) when the signal is affected by chromatic dispersion (CD). To counter this phenomenon, the phase bias between the two branches of the modulator must be set to zero. By doing this, it becomes impossible to generate an optical PAM-4 signal with equally spaced levels and thus the unequally spaced levels are obtained. In a back-to-back (BTB) scenario this approach will provide worse bit-error rate (BER) than the equidistant levels PAM-4 for the same OSNR requirements. However, when propagating through standard single mode fiber (SSMF), the drop in performance is smaller in the case of unequally spaced levels PAM-4 and after a certain link distance it will provide better BER than its counterpart [5].

3. Experimental Setup and Results

Fig. 2 shows the experimental setup used for the investigation of the two different PAM-4 implementations:

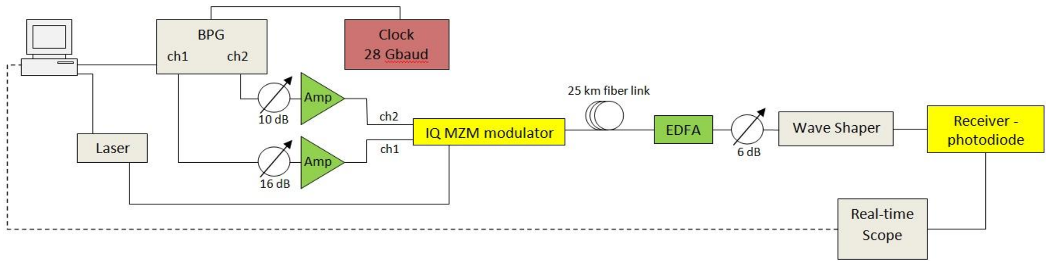
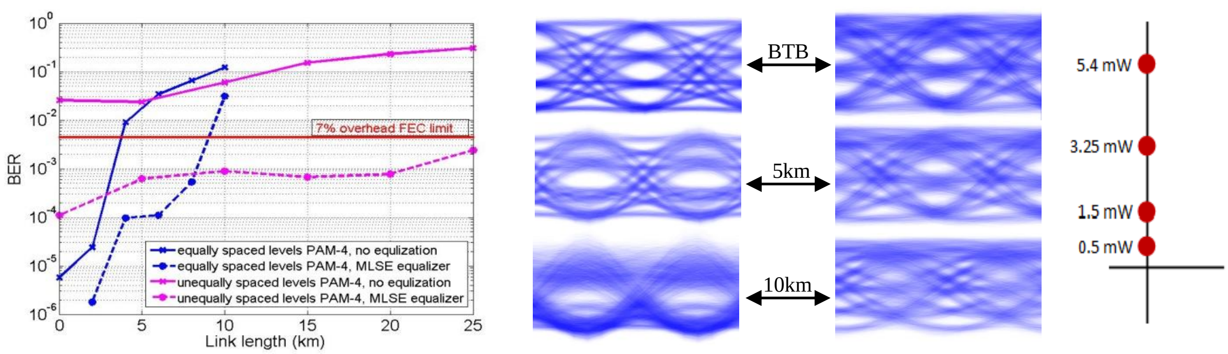


Fig. 2. Block diagram of experimental setup – 28 Gbaud, PAM-4, link up to 25 km.

A bit pattern generator (BPG) is used to generate two NRZ-OOK signals with the baud rate of 28 Gbaud. One channel is attenuated by 6 dB in respect to the other. After 24 dB amplification, the two signals will have the appropriate peak-to-peak voltage (2V and 1V) in order to operate the MZM in the linear region. The resulting constellation of the unequally spaced levels PAM-4 is shown in Fig. 3(c). After passing through the SSMF fiber, the PAM-4 signal is detected by an InGaAs photodiode and sampled by a real-time scope at 50 GSamples/s. The performance of the two PAM-4 modulation schemes evaluated at link lengths of up to 25 km is presented in Fig. 3(a), where maximum likelihood sequence estimator (MLSE) equalizer has been used:



(a) (b) (c)

Fig. 3. (a) Performance comparison between equally spaced levels (blue) and unequally spaced levels (magenta) PAM-4, (b) received eye diagrams for equally spaced levels (left column) and unequally spaced levels (right column) PAM-4 after 0, 5 and 10 km, (c) and the unequally spaced levels PAM-4 constellation with corresponding optical power levels (at the receiver the levels will be inversed).

It can be seen that for short transmission distances of up to 8 km the equidistant levels PAM-4 performs better. However, for links of 10 km or longer, this scheme cannot achieve BER below the forward error correction (FEC) threshold of 0.004 (7% Super-FEC). On the other hand, the unequally spaced levels modulation scheme is performing better after 8 km and can extend the transmission length to 25 km. The eye diagrams in Fig. 3b also show the difference between received signals affected by chirp (left side) and signals that are chirp free (right side).

4. Summary

We have indicated the chirp disruptive effects introduced by an IQ modulator used for generating PAM-4 after propagating through SSMF. A novel method based on unequally spaced levels that solves the chirp problem is proposed. We experimentally demonstrated the advantages and disadvantages of this solution and shown that transmission lengths of up to 25 km at 56 Gb/s are possible using this novel PAM-4 modulation scheme.

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