Optimization of Cost Efficient Multilevel-ASK Modulation Formats under the Constraint of Chromatic Dispersion

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Abstract: Due to their narrow spectrum, multilevel modulation ASK-formats can increase the chromatic dispersion tolerance of optical systems. Since they suffer more from inter-symbol interference than binary signals, optimization of the amplitude levels is necessary.

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1. Introduction

To meet the demand of increased line rates and efficient use of bandwidth of modern communication systems advanced modulation formats such as multilevel amplitude and phase shift keying (M-ASK and M-PSK) or combinations of both attracted much attention [1-4]. Especially for metro networks, where the requirements concerning the available optical signal-to-noise-ratio (OSNR) are not as strict as for long-haul transmission, but where cost efficiency is a strict requirement, multilevel ASK formats are promising candidates because of their simple transmitter and receiver design [4]. Although chromatic dispersion within a metro network might be compensated, small deviations from the target dispersion could lead to high penalties concerning the required OSNR for a certain bit error rate (BER). Reduced bandwidth of optical signals leads to increased dispersion tolerance, but by increasing the number of signal levels the sensitivity towards inter-symbol interference (ISI) rises. This results mainly from the nonlinearities of the optical transmission system, namely the Mach-Zehnder modulator (MZM) and the photo diode, if the fiber input power lies within the linear range and all amplifiers are considered as ideal. The impact of ISI on the multilevel signal and thus to the OSNR requirements depends substantially on the signal's amplitude level spacing [1, 2]. [2] already shows an optimization approach for a bipolar 4-ASK format. In contrast to [2], we use different optimization methods, and include unipolar ASK formats and 8-ASK bipolar, which is a very promising candidate concerning receiver sensitivity. The bipolar formats are mixtures auf ASK and DPSK as described in [2] and [4]. Since the effect of dispersion on the signal scales with the square of the data rate, all simulation results are displayed normalized and are valid generally for every data rate.

2. System Setups for Unipolar and Bipolar ASK

Figure 1 shows thesetup for multilevel unipolar M-ASK. Direct detection is used to keep the effort low.

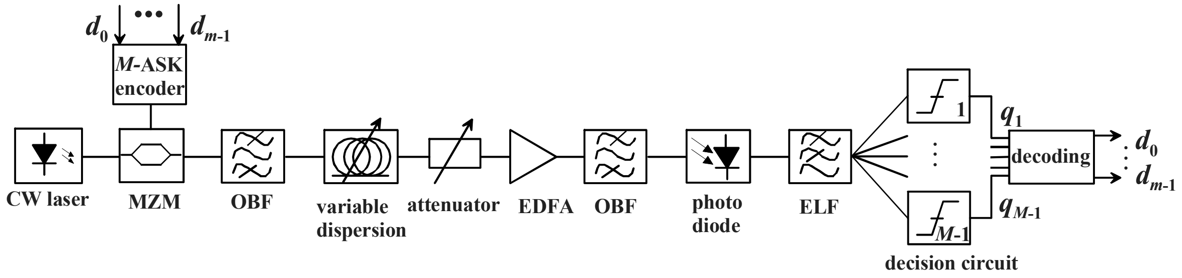


Fig. 1: Simulation setup for unipolar direct detection NRZ-M-ASK. Only one single MZM is needed. Optical bandpass filters (OBF) are Gaussian filters of 3rd order, electrical lowpass filters (ELF) are 5th order Bessel filters, both optimized for individual modulation formats.

A number of $m=\log_2(M)$ data streams is Gray-encoded into an M-level electrical driving signal with a maximum amplitude for the M^{th} level of voltage V_π of the ideal MZM. Non-return-to-zero (NRZ) pulse shape is considered for all formats. To further increase the cost efficiency the MZM and the continuous wave (CW) laser could be replaced by a directly modulated laser (DML). Our method would also work for this scenario. The fiber is considered as linear. The intention to use the modulation formats in WDM (wavelength division multiplexing) networks leads to the consideration of two optical filters, to model the WDM multiplexer and the demultiplexer. These filters are Gaussian filters of 3rd order with a bandwidth of 1.5 x data rate R for 2-ASK, 0.95R for 4-ASK and 0.63R 8-ASK.

An EDFA (erbium doped fiber amplifier) with attenuator is used to vary the OSNR. The photo diode is followed by a 5th order electrical Bessel filter with the 3dB-bandwidth of $0.74R$, $0.68R$ and $0.37R$ for 2-, 4-, and 8-ASK, respectively. These bandwidths are optimized for maximum back-to-back (b2b) receiver sensitivity. After the electrical filter the signal a logic decision circuit as described in [1] with three thresholds for 4-ASK and seven thresholds for 8-ASK is used to recover the original data sequences. The BER vs. OSNR is determined by Monte Carlo simulations. As quality criterion the required OSNR at a BER of $5\cdot 10^{-4}$ is calculated. Figure 2 shows the setup for bipolar NRZ-M-ASK. $m=\log_2(M)$ data streams are Gray-encoded into an (M-1)-level electrical driving signal with DC offset as driving signal for the MZM. A phase modulator (PM) which is driven by the m^{th} binary differentially precoded electrical data stream ensures negative polarity. This results in an M-level bipolar signal after the PM. The optical filters are $1.5R$, $0.95R$ and $1.43R$ for 2-, 4- and 8-ASK bipolar, respectively. The 8-ASK bipolar format turned out to be very sensitive towards ISI, therefore a broader optical bandwidth is required. At the receiver side the signal is split into a DBPSK (differential binary PSK) and a (M-1)-ASK branch. The (M-1)-ASK branch equals the unipolar ASK receiver. The DBPSK branch contains a Mach-Zehnder-Delay-Interferometer (MZDI) followed by a balanced receiver. After the electrical filters (same for ASK and DBPSK branch) with bandwidths $0.74R$, $0.37R$ and $0.25R$ a binary decision can be made.

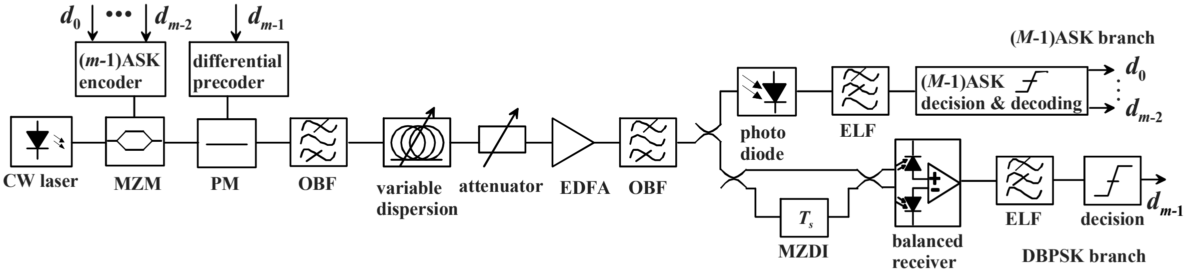


Fig. 2: Simulation setup for bipolar direct detection NRZ-M-ASK, a mixture of (M-1)-ASK and DBPSK. Optical bandpass filters (OBF) are Gaussian filters of 3rd order, electrical lowpass filters (ELF) are 5th order Bessel filters, both optimized for individual modulation formats.

3. Optimization Methods

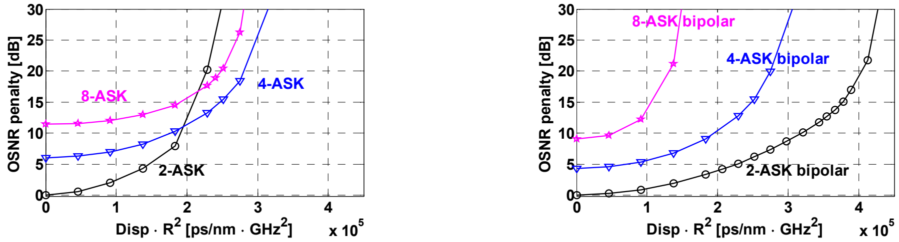
If the EDFA noise is the only transmission impairment, it can be found that the optimum level spacing is equal distances between the amplitude levels of the optical field, i.e. quadratic spacing after the photo diode or balanced receiver [1, 2]. Hence, within the multilevel eye, the lowest electrical eye opening is the smallest. Because of the nonlinearity of the MZM and the photo diode in interaction with the filters an analytical level optimization is difficult. Any minor approximations lead to severe differences in the calculated results. Therefore, the following empirical optimization approaches are chosen:

(1) Method 1 is the equal spacing in optical field, which is optimum without dispersion.
(2) Method 2 uses equally spaced levels in the electrical domain, which is square root spacing in the optical domain. This was also used in [1] for dispersion tolerance optimization.
(3) Method 3 evaluates the eye diagrams at the receiver with a high dispersion close to the maximum dispersion for which open eyes can be measured for each individual modulation format. The levels are adjusted to achieve a squared level spacing in the electrical domain, which would refer to an equal spacing in the optical domain. Due to the ISI, the expected BER is not directly related to the eye opening, but a BER based optimization would take much more time and effort. This method does not consider the filters within the optimization process.
(4) Method 4 essentially works like the third, but includes the filters during the optimization.

4. Results and Discussion

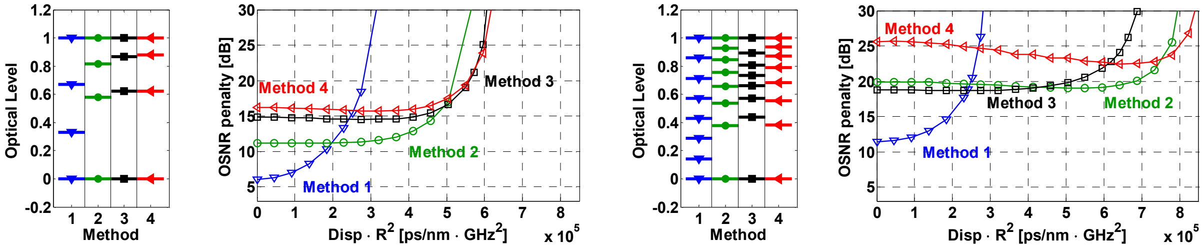
Figure 3 shows dispersion tolerance for unipolar and bipolar formats with amplitude levels according to method 1. Since the effect of dispersion increases quadratically with the data rate, the x-axis is normalized to R^2.The figures show the OSNR penalty of the multilevel formats compared to each binary b2b case. Indeed, the b2b OSNR of 2-ASK bipolar is about 3 dB less than for 2-ASK unipolar. Each increase of the level count (i.e. 2,4,8) leads to an increase of the b2b sensitivity of about 5 dB. For the unipolar case, higher order modulation formats give a small gain in dispersion tolerance, but for bipolar formats the dispersion tolerance decreases with the number of levels because of the high ISI sensitivity of the DC-offset-ASK part. Figures 4 and 5 show the dispersion tolerances for all formats with optimized levels and the level spacing in the optical domain. Increased dispersion tolerance always comes on the expense of reduced b2b sensitivity. Unipolar ASK formats show a high dispersion tolerance for method 2. Optimization by regarding the distorted eye diagrams (method 3 and 4) brings an additional improvement.

For bipolar formats method 2 reduce the dispersion tolerance and the b2b sensitivity. However, for 4-ASK bipolar the dispersion tolerance can be significantly increased by method 3 and 4. For 8-ASK bipolar it is difficult to increase the dispersion tolerance notably. This format is most sensitive to chromatic dispersion. Concerning the differences between method 3 and 4, for the 4-ASK formats the influence of filters on the optimization is negligible. Regarding the 8-ASK formats, the optimized levels with filters differ significantly from those without filters.



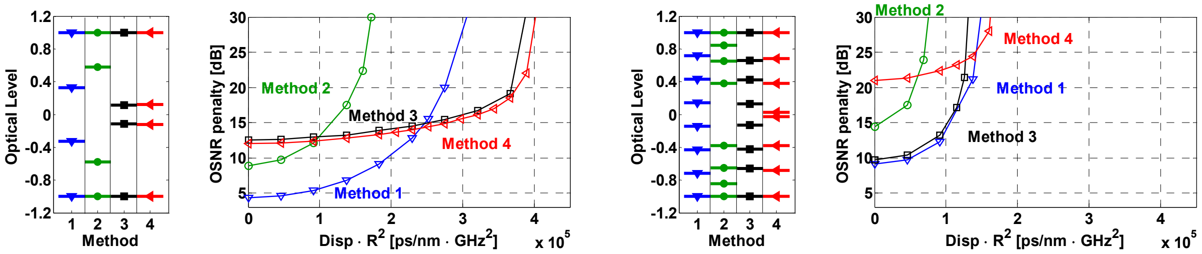
(a) (b)

Fig. 3: Method 1: Optimization for maximum receiver sensitivity. OSNR penalty (compared to binary case) vs. normalized dispersion: a) unipolar ASK formats, b) bipolar ASK formats, dispersion scales with the square of the data rate.



(a) (b) (c) (d)

Fig. 4: Amplitude levels and dispersion tolerance for each optimization method. Unipolar modulation formats: 4-ASK unipolar: (a), (b). 8-ASK unipolar: (c), (d). Dispersion plots: OSNR penalty compared to binary case vs. normalized dispersion.



(a) (b) (c) (d)

Fig. 5: Amplitude levels and dispersion tolerance for each optimization method. Bipolar modulation formats. 4-ASK bipolar: (a), (b). 8-ASK bipolar: (c), (d). Dispersion plots: OSNR penalty compared to binary case vs. normalized dispersion.

5. Conclusion

We optimized the amplitude levels of unipolar and bipolar multilevel ASK signals for the use in cost efficient optical metro networks to achieve maximum chromatic dispersion tolerance. Equally spaced levels in the electrical domain are a good choice for unipolar formats. However, our proposed eye diagram based optimization methods can further increase the tolerance. For bipolar formats, only the eye diagram based optimization methods bring a significant improvement. These methods can also be applied for direct modulated lasers and thus even more cost efficient system setups.

6. References

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